TECHNOLOGICAL FORECASTING IN PERSPECTIVE

A framework for technological forecasting,
its techniques and organisation;
a description of activities
and annotated bibliography by

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ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

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A Framework for Technological Forecasting, its Techniques and Organisation

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The Organisation for Economic Co-operation and Development was set up under a Convention signed in Paris on 14th December 1960 by the Member countries of the Organisation for European Economic Co-operation and by Canada and the United States. This Convention provides that the OECD shall promote policies designed:

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- *to contribute to sound economic expansion in Member as well as non-member countries in the process of economic development;*
- *to contribute to the expansion of world trade on a multilateral, non-discriminatory basis in accordance with international obligations.*

The legal personality possessed by the Organisation for European Economic Co-operation continues in the OECD, which came into being on 30th September 1961.

The members of OECD are: Austria, Belgium, Canada, Denmark, France, the Federal Republic of Germany, Greece, Iceland, Ireland, Italy, Japan, Luxembourg, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States.

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PREFACE

The influence of technological advance is becoming ever more important in many sectors of national activity. While it has until now been most striking in industry and defence, technology is gradually invading many other sectors, such as education, and its direction is becoming a major pre-occupation of governments as well as of private enterprise.

It is important to foresee as clearly as may be possible, the nature and probable impact of a rapidly growing technology. This is to some degree possible because of the still considerable time which must elapse between the discovery of new knowledge through fundamental research and its application in technology.

Technological forecasting which has developed gradually since the end of World War II, attempts to provide some indication of future trends. It is important for two main reasons. Firstly, the rapid growth of opportunity offered by the many advances in science and technology necessitates a high selectivity on the part of the decisionmaker both at the level of the individual firm and on a national scale. Choice between alternative paths may make all the difference in competitive performance. But there is a second and more important reason why technological forecasting is necessary. Science and technology are increasingly recognised as influences in the transformation of society and governments must therefore strive to foresee the impacts which technological developments are likely to have on future society and to guide the application of new knowledge in the attainment of national goals. Recognition of the possibility of planning for future options by guiding technological development along alternative paths in an economic, social and political context presents both a stimulus and a challenge to the policy-maker.

In view of these possibilities, only now gradually becoming visible, OECD decided to undertake a "state of the art" study of technological forecasting. Dr. E. Jantsch, who carried out this investigation, presents in this volume a survey of the techniques and trends of technological forecasting. In this task he has been greatly assisted by many executives and experts in the Member countries as well as specialists in the various fields of science policy. It is hoped that the compilation will be of value to a wide circle of industrialists and government policy-makers.

Thorkil KRISTENSEN.
Secretary-General
Organisation for Economic
Co-operation and Development.

FOREWORD

When the work on this report began, it was believed that technological forecasting was practised in a few places only and that a survey of techniques and organisational forms could be carried out on the basis of a limited amount of information to be gathered. This turned out to be a poor forecast indeed. Not only did the information expand in volume virtually to exploding point, but the scope of the enquiry broadened to take on new dimensions, including the social sciences. What had started out as a survey became a discussion of significant ideas and activities in the hope that somehow a consistent and representative view of the state of technological forecasting today might emerge.

From October 1965 to May 1966, twelve OECD Member countries were visited: Austria, Belgium, Canada, the Federal Republic of Germany, France, Italy, Luxembourg, the Netherlands, Sweden, Switzerland, the United Kingdom, and the United States of America. On the invitation of its government, one non-Member country—Israel—was included. Approximately 250 individual contacts were established during these visits with, ***inter alia***, international organisations, government agencies, universities, foundations, research institutes, industry, consulting firms and a number of distinguished individual personalities. Particular emphasis was placed on industry, military administrations, and research institutes. These visits, supplemented by the evaluation of approximately 400 literature references, form the basis for this report. The manuscript was completed in August, 1966.

The general response to OECD's investigation was overwhelming and confirmed the impression that technological forecasting has emerged into full view from the somewhat obscure position it had occupied until the end of the 1950's. Very few companies (and even military administrations) regard their procedures and techniques in this area as confidential. On the contrary, a vivid interest in an exchange of information is manifest at this stage in which the published account is still very incomplete. This interest may serve to justify the present report, in spite of its numerous shortcomings.

The report, whose objective is two-fold, is intended to:

- Serve the Committee for Science Policy and the Secretariat of the OECD as a background report for consideration in connection with possible future activities involving or bordering on technological forecasting.
- Provide a basis for comparison, a framework, and perhaps a useful synthesis, which may aid and stimulate thinking at the operational level; this is the reason for presenting such a voluminous text and, in particular, discussions of roughly 100 techniques or elements of techniques found during the investigation, and of the organisation of technological forecasting activities; it is also the reason for adding an annotated bibliography.

The purpose has not been to contribute to research in the field but rather to give an account of the state of the art and of practical applications. This has been attempted on as objective a basis as seemed possible: a conscientious endeavour has been made to place single-track thinking, often encountered in intellectual exploration, in a broad context and to straighten out inconsistent " languages " which blossom in this phase.

A fairly strong subjective component will make itself felt in three ways: 1. the presentation is set into a wider framework than is usually thought appropriate to the subject, while the structuring of the problem, based on the fundamental polarity between exploratory and normative technological forecasting, is strongly oriented towards the integration of forecasting throughout the entire technology transfer space; **2.** the description of the state of the art as encountered is supplemented by indications of trends for the near future; **3.** a strong personal bias has to be taken into account in discussions of desirable future developments and of tasks in general, as well as in value judgments applied to present ideas. This has been found the best way to avoid " amorphous " and meaningless statements on essential issues.

This subjective component obviously carries a considerable potential of controversy[1]. The author hopes it will be received in the same co-operative spirit that prompted so many explorers in this field to make available to him their own partial and tentative ideas which point far into the future.

As in so many areas of management, behavioural, and other social sciences, the United States has taken the lead in a thorough and systematic exploration of technological forecasting and in its development from fantasy to **a** technical art, and ultimately perhaps to a science. If so much is being said and written today about a " technological gap " between the United States and other countries, it should not be forgotten that the management technologies which play a crucial role in accelerating the pace of progress are available without cost: techniques can be learned, and attitudes can be developed. To facilitate technology transfer in a relatively narrow sector of management science is the principal aim of this report.

Any one making a thorough attempt to come; to grips with technological forecasting in its many dimensions will soon be led into regions of uncertain, even fantastic character. This report seeks to point out aspects of significance for the ultimate potential of technological forecasting in such (still unintelligible) regions, while averting the danger **of** being " carried away " by the temptations of limitless fantasy.

If the author's fascination for the subject, which has grown during the preparation of this report, is shared by some of his readers, this would **be** a source of deep satisfaction to him, and would constitute the most valuable achievement he could hope for.

1. The objective statements, too, seem to be controversial to some extent. A recent survey conducted for the U.S. Government (lit. ref. 183, 352) for example, arrived at the conclusion that technological forecasting is (*a*) " practiced very little," and (*b*) " of little interest to potential users inside or outside the Federal Government." The differences between such statements and the findings of this report can be explained mainly by differences in the information base used and also by personal bias (almost inevitable in a field which is only now assuming a clearly discernible shape).

THE BROAD MEANING OF A FEW BASIC TERMS FREQUENTLY USED IN THIS REPORT

The following terms have been adopted because ***(a)*** they are simple and comprehensive, (*b*) they correspond to the actual pattern existing today at the ***operational level*** and, therefore, ***(c)*** best serve the purposes of this report. They are not intended as rigorous definitions and no claim is made for their universal applicability. Sources of the original introduction or precise formulation of these terms are indicated in brackets, when known.

A ***forecast*** is a probabilistic statement[1], on a relatively high confidence level, about the future. A ***prediction*** is an apodictic (non-probabilistic) statement, on an absolute confidence level, about the future. An ***anticipation*** is a logically constructed model of a possible future, on a confidence level as yet undefined (adapted from Ozbekhan). " The future " referred to in these notions includes situations, events, attitudes, etc.

Technology denotes the broad area of purposeful application of the contents of the physical, life, and behavioural sciences. It comprises the entire notion of technics as well as the medical, agricultural, management and other fields with their total hardware and software contents.

Technological forecasting is the probabilistic assessment, on a relatively high confidence level, of future technology transfer. ***Exploratory technological forecasting*** starts from today's assured basis of knowledge and is oriented towards the future, while ***normative technological forecasting*** first assesses future goals, needs, desires, missions, etc. and works backward to the present (Gabor). The subject of both types is a dynamic picture of a technology transfer process. Technological forecasting may be aided by anticipation and may " harden " to prediction.

Technology transfer is a (usually complex) transfer process within a ***technology transfer space,*** which may be represented as outlined in Chapter 1.1. It takes place at different ***technology transfer levels,*** which can be roughly divided into development and impact levels, and is composed of ***vertical*** and ***horizontal technology transfer*** components (adapted from H. Brooks). Vertical technology transfer, moving through the development levels, is characterised by the four research and development phases (Stanford Research Institute)—discovery phase, create phase (leading to ***invention,*** a term not sharply definable for complex technological systems), substantiate phase and development phase (leading, for example, to a prototype)—followed by the engineering phase (leading to a functional technological system, which may be a hardware product, a process, or an intellectual concept, etc.). The extension of this vertical transfer by a considerable subsequent horizontal technology transfer (for example, application and service engineering, marketing, diffusion of knowledge) marks ***technological innovation.*** Any change in the technology transfer space effected by technology transfer is referred to as ***technological change.***

Technological planning is the development of an intellectual concept concerned with the active implementation of technology transfer (both vertical and horizontal).

The term ***social technology*** (Helmer) refers to technology with substantial implications for society, frequently being based on ***social invention*** (Gilfillan), which denotes an invention with considerable potential impact on the technology transfer levels of social systems and society, ***Social engineering*** (adapted from Helmer) is human activity to effectuate and direct social technology transfer.

Fundamental research is research on the fundamentals of science and technology*. ***Fundamental scientific research*** broadly pertains to the level of scientific resources (natural laws, principles, theories, etc.) and ***fundamental technological research*** to the level of technological resources (technological potentials, etc.) in the technology transfer space (see explanations and examples in Chapters 1.1. and 1.2.).

There is a wide and almost continuous spectrum from very ***pure*** to heavily ***oriented research*** (adapted from Weinberg).

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1. European readers, by association with " weather forecast," sometimes think of a forecast in the same sense as has been adopted here for a prediction. A weather forecast is usually given in the form of a prediction in Europe, but as a probabilistic forecast—" 80 per cent probability of rain "—in the United States and Canada.

2. It is essential to understand that this notion is devoid of any motivational content; in this, it differs from meanings frequently attributed to " fundamental research " in connection with problems of allocation of resources at an aggregate level, and usually signifying " pure research."

Functional research, in an industrial context, denotes research connected with present activities and the organic extension of such research—non-functional research is concerned with future new activities (Royal Dutch/Shell).

Function—(or mission—) oriented planning is opposed to product-oriented planning in industry (or service- and system-oriented planning in military environments and an instrumental approach in civilian government, respectively).

Information science means those fields of learning concerned with the content, meaning, communication, storage, retrieval, manipulation or use of information. This includes, but is not restricted to, advanced computer programme development, decision-making, artificial intelligence, gaming and simulation, operations research, linguistics, behavioural sciences and communication theory. Information technology is the application of information sciences to a decision-making problem, and an information system is the product of this process. (System Development Corporation, quoted from lit. ref. 406.)

Models are representations of processes describing in simplified form some aspects of the real world. A simulation is the operation of a model by manipulation of its elements with a computer, a human player, or both. (Abt Associates, quoted from lit. ref. 84.)

MAJOR FINDINGS AND RECOMMENDATIONS

The general situation encountered during this investigation can be summarised by the following three points:

1. Technological forecasting emerged as a recognised management discipline around 1960; its modern form has gradually taken shape since the first attempts were made in the mid-1940's to attain " informed judgment " through systematic and comprehensive evaluation; it has been adopted on an increasingly wide scale in industry, research institutes and military environments since the late 1950's;

2. The value of technological forecasting has been proved, not only in terms of the accuracy of specific forecasts (to which numerous positive indications and the general satisfaction of practitioners, though as yet few statistical evaluations, testify) but even more effectively in terms of its contribution to the definition of long-range strategies;

3. Technological forecasting is not yet a science but an art, and is characterised today by attitudes, not tools; human judgment is enhanced, not substituted by it. The development of auxiliary techniques, gradually attaining higher degrees of sophistication (and complexity) since 1960, is oriented towards ultimate integration with evolving information technology.

The report supplements the description of the present situation by pointing out trends and future tasks as well as linking technological forecasting to parallel developments.

Part I. If technological forecasting is to be related to the kinds of tasks which emerge in connection with medium- and long-range planning, especially in a modern industrial context, it must be seen in a proper (not too narrowly chosen) ***framework.*** In this report, technological forecasting is defined as the ***probabilistic assessment of future technology transfer,*** which here denotes the entire range of vertical and horizontal transfer processes that constitute the advancement of technology and the effectuation of impact in technological as well as non-technological (economic, social, military, political, etc.) terms. The intellectual concept of a " technology transfer space " is introduced to represent the modes of technology transfer and to illustrate the tasks of technological forecasting.

The full potential of technological forecasting is realised only where ***exploratory and normative components*** are joined in an iterative or, ultimately, in a feedback cycle. The basic conditions for meaningful normative technological forecasting—clearly defined constraints at the various impact levels (including goals at the level of broad social impact) and abundance of technological opportuniiies—have been generally fulfilled, for the first time in Western civilization, for approximately the past 25 years. The growing recognition of normative forecasting underlies the development of technological forecasting in a modern sense, i.e. as a management discipline conforming to the new modes of technological innovation and closely related to planning.

Whereas exploratory forecasting alone tries to assess passively the ***inertia*** of our social system and of individual technology transfer processes, normative technological forecasting—by applying spur and focus to research and development-can be expected to influence actively the speed of such processes and help the social system overcome the weight of its own inertia. Effects in this direction have already become visible in defence and space technology and may have contributed to the general reduction in the time required for a complete technology transfer process leading to industrial technological innovation. In this context, the correct assessment of ***future environments*** and of the corresponding goals, requirements, and human desires has emerged as one of the most difficult problems which can be properly solved only by the systematic evaluation of feasible alternatives in an iterative or feedback cycle. In the realm of social technology where the fatal danger of a mere extension of the present is of particular concern, this problem has given rise to the notion of " possible futures " (" alternative world futures," " futuribles," etc.).

The area of ***fundamental science and technology*** is still the battlefield of competing philosophical concepts with respect to the applicability of normative thinking. The widespread negative belief, which finds its principal exponent in Thomas S. Kuhn, is disproven by the growing importance of normative technological forecasting for the guidance of fundamental research in industries and research institutes with advanced management concepts. Probably one of the most far-reaching consequences of the systematic application of technological forecasting will be a change in nature and an expansion in volume of fundamental research, which will be directed increasingly to answering questions put to it in terms of basic relationships and alternatives and of ultimate potentials and limitations.

An important response to the demand for an ***integration of fundamental science and society,*** advocated by a school of thought which finds its expression in the concepts of R.G.H. Siu and Alvin M. Weinberg, can be seen in the COSPUP studies, sponsored by the US National Academy of Sciences. It is recommended that the scientific work contained in these studies be made the nucleus of analogous undertakings in other countries.

Technological innovation, in its present predominant modes, is primarily a result of normative thinking. Technological forecasting, with a strong normative component, is of great value for accomplishing the following main purposes: acceleration and guidance of technology transfer; filling of the " gap " created by the rapid changes in certain sectors of industry and the economy; optimisation of the pattern of vertical technology transfer and systematic exploitation of " communalities " (conceptual or hardware modules); exploration of opportunities and requirements for horizontal technology transfer (application and service engineering, marketing, etc.) and general support of the present marked trend in this direction; finally—and in future perhaps one of the foremost concerns of long-range technological forecasting—anticipation of structural changes in industry and inter-industry patterns caused by technological innovation. The useful application of technological forecasting to these and other problems of technological innovation is already being demonstrated on a fairly large scale by industries of an innovating type.

Technological forecasting and ***planning*** have a natural and inherent tendency towards fuller integration which, in the 1970's, may possibly result in the disappearance of forecasting as a distinguishable discipline. This is becoming visible especially where planning is tied explicitly to a decision tree scheme and forecasting to a normative relevance tree scheme: both tree concepts can be brought to congruence. A natural (but not absolutely necessary) consequence is a change from product-oriented towards function-oriented planning. Another implication is the adoption of high-level goals—ultimately the supreme social goals—for the top of the decision/relevance tree, thus linking private and military technological planning to the requirements of the society.

The quantification of planning (and forecasting) in the social, military, and economic areas is about to find a common measure in monetary value. Such quantification may become more homogeneous through a uniform cost/effectiveness approach in all three areas, which would greatly facilitate the integration of technological forecasts over a multitude of technology transfer levels and areas, The cost/effectiveness approach has been spreading in the military area since its introduction to American military planning in 1961, and initial attempts are being made today to apply it to the social area. In the economic sphere, the increasing tendency to supplement economic analysis (return on investment) by other criteria linked to corporate objectives seems to indicate that cost/effectiveness assessments on the basis of systems analysis could be used to advantage and may soon replace the current approaches.

Inter-disciplinary forecasting in the political, social, economic, military and technological areas is at present the major activity in ***social technology,*** which is gradually moving into the focus of general interest. Technological forecasting is a major input and—in view of the potential harmful effects of new technologies generated at the present fast pace and implying increasingly far-reaching consequences—is perhaps of foremost concern.

Almost everything still remains to be done concerning the support of technological forecasting by ***information science.*** It is recommended that attention be paid to this problem in the development of future management information systems and in the general advancement of information technology.

Part II. The development of special ***techniques related to technological forecasting*** has gained *a* great deal of momentum in the past few years. Part II of the report discusses more than 100 distinguishable versions of techniques, elements of techniques and formal attitudes[1]. These can be grouped under some 20 different approaches in four broad areas: intuitive thinking and exploratory, normative, and feedback techniques. Most of the hundred odd versions encountered are in use in industry and in military environments, but generally only in an auxiliary function. There is no discernible relationship between good forecasting and the use of techniques. Their most important contributions to pratical forecasting can be summarised by the following three points:

1. Chapter II. 1 on " Techniques in Perspective " reviews the types of such techniques, states of the art, and practical utilisation, and may be read to advantage by those readers interested in the more general aspects.

1. They elucidate the role of individual input factors, compel a comprehensive consideration of such factors, and assure some homogeneity of the results;

2. They tend to reduce prejudice and bias;

3. They permit the evaluation of complicated patterns on input information and facilitate the systematic evaluation of alternatives.

Apart from an increasing sophistication in the employment of long-known techniques, such as trend extrapolation—now supplemented by envelope curve extrapolation, etc.—the following new developments are of ***particular significance*** and fit in with important present and future tasks of technological forecasting:

a) The " Delphi " technique for the improvement of intuitive thinking with the aim of achieving expert consensus; this technique may become most important in the selection of high-level goals, including supreme social goals;

b) Morphological research[1] aimed at a systematic and unprejudiced screening of opportunities in connection with exploratory forecasting;

c) Relevance tree techniques (pioneered by the PATTERN scheme) for normative forecasting and the assessment of " communalities."

The adaptation of techniques developed in different contexts--e.g. systems analysis, network techniques, matrix thinking, input/output analysis, linear programming and other special techniques forming part of operations research, and, to some degree, scenario-writing—is also very fruitful in the area of technological forecasting. Such techniques as contextual mapping, not yet adequately exploited for forecasting, gaming, and model-building in general may be added. The application of operational models, of both exploratory and normative types, can be expected to converge so as to produce feedback models that will ultimately become part of comprehensive future-oriented decision-aiding information systems. Such systems are already receiving consideration in the area of information technology.

A particular feature of current developments in forecasting techniques is the attempt to adapt them to the processing of probabilistic input information, with probability distributions constituting the output, and to the systematic evaluation of alternatives.

Whereas earlier techniques aimed at forecasting over only a few levels of technology transfer, recent years have seen a tendency to develop techniques for integrated forecasting over many levels. At the same time—and partly as a consequence of this tendency—techniques have become more elaborate. However, they present no problem whatsoever to computer operation (with the exception of open gaming).

Part III. A discussion of the ***forms of organisation of technological forecasting*** is based on a study of more than a hundred continuous or periodic activities identified in the course of the investigation carried out for this report. More than 60 per cent of them (representing a 55:40:5 split between Europe, America and Israel) are undertaken in an industrial context, the remainder being accounted for by forecasting institutes and consulting firms, military environments, various efforts on a national level, and international organisations. Most of the non-industrial activities are outlined in some detail in Annex A.

Forecasting institutes and consulting firms offer technological forecasting mainly in connection with their corporate planning and management consulting services. Four ambitious " package " services, including technological forecasting report series—two in the overall technical area, two in special technical sectors—are subscribed to by approximately 500 industrial companies (some subscribing to more than one) which pay an annual total of $ 4 million for them. If *ad hoc* forecasts and other individual services with considerable technological forecasting content are included, it may be estimated that industry at present invests $ 15 million per year in technological forecasting acquired from special institutes and consulting firms—nine tenths of which accounts for the United States and Canada.

Forecasting services by institutes and consulting firms appear, at the present time, to be geared to the needs of medium- and large-sized industry. No solution has yet been sought for the growing needs of small business.

The industrial application of technological forecasting has advanced more rapidly in the United States than elsewhere. It may be estimated that about 500 to 600 medium- and large-sized American companies have established a technological forecasting function as part of their operations. It can be estimated that these companies, generally of the innovation-minded type, spend annually at the present time approximately $ 50 million for internal (in-housebin addition to the $ 10-15 million mentioned above for external—technological forecasting. This may represent a share of the order of one ***per cent of the total research and development expenditures*** by these companies. In leading companies, an efficient tech-

1. Morphological research was first formulated in 1942, but remained an " invention " not followed by " innovation " until recently; in that sense, it may be regarded as new.

nological forecasting function may account for profit gains through new products amounting to as much as **50** times the investment in the " catalytic " forecasting function which triggered research and development in the respective areas.

The most important development in both ***industrial and military environments*** which has been favoured—and partly caused—by the incorporation of technological forecasting is the change from organisation which is oriented to products or military services and weapon systems, towards a ***function-oriented organisation.*** The long-range future aspects can be properly dealt with only in terms of functions. This tendency is of a revolutionary character in industry— where another revolution in the direction of far-reaching verticalisation and product-orientation was completed not long ago in America and is still in progress in Europe —as well as in military planning environments, where it ends a long tradition. The Planning-Programming-Budgeting System (PPBS) of the US Department of Defense is the most comprehensive expression of this new thinking in military planning, which is also gaining ground in other countries. A natural consequence of the orientation towards functions, and one which can be observed equally in industrial and military environments, is **a** trend towards greater centralisation, or at least central co-ordination; a function-oriented approach depends on the definition of corporate objectives and broad missions at the top level.

In industry which remains product-oriented, i.e. in the bulk of industry today, medium-range forecasting (including costing and other detailed assessments) is in most cases performed in a decentralised manner while long-range forecasting is mainly carried out in horizontal committees or staff analysis groups. In military planning, medium-range assessments are usually strongly co-ordinated at the center, whereas long-range forecasting is sometimes left " hanging in the air " at decentralised points without clear definition of long-range goals and missions. Sweden perhaps offers the perfect example today of a fully-integrated, function-oriented approach to forecasting and planning, embracing both medium-range and long-range thinking.

The use of relevance tree schemes in normative technological forecasting, and of decision tree schemes in military planning, makes it appear feasible—and desirable—to " plant " uniform and ***centrally assessed and updated " free tops "*** down to the levels of military missions and tasks in all organisations working towards the same general objectives (for example, the total defense research and development effort of a nation), in so far as they use relevance tree techniques.

On a ***national level*** technological forecasting is only gradually being introduced into national planning. The two most striking attempts are being made in France and the United States. Whereas long-range forecasting, as a contribution to the Fifth French Plan, can be regarded as an initial experiment only, the preparations for the Sixth Plan indicate a much more ambitious effort, with the centre of gravity no longer residing in a government agency, but in a contracting economic institute.

In the United States, the gradual introduction, since 1965, of the Planning-Programming-Budgeting System in all departments and agencies of civilian government, constitutes a revolutionary approach with very far-reaching consequences. It involves the integration of forecasting and planning structures in a function-oriented framework for decision-making and quantitative five-year planning, tied in with long-range social goals and national objectives. This highly ambitious approach can be expected to assume great importance for social technology, which may become the area of the greatest concern to governments in the 1970's.

The need for technological forecasting in a context of national objectives and limitations is also being increasingly felt in several other European countries as well as in Canada and Israel. In certain sectors of industry, Italy has taken promising initiatives.

Professional societies, in general, have not yet undertaken the important tasks in technological forecasting at national level which should become one of their foremost responsibilities. Most societies, especially in Europe, are not even organised in such a way as to allow them to assume such tasks.

Tasks for ***international organisations*** related to technological forecasting have been grouped under ten types. Only half of these have as yet received any attention, and few organisations have become active in this area. During the visits made in preparation of this report only three organisations—CECA, Euratom, and ICAO—were found to be capable of performing valuable in-house technological forecasting.

" Look-out institutions " are called for by many distinguished scientists and other people concerned with social technology. The principal purpose of such institutions would be to conceive and systematically evaluate alternative feasible futures so as to permit the selection of optimum solutions towards the long-range goals of society and the alignment of planning accordingly. A number of " forerunner " activities are briefly discussed in the report.

Annexes to the report contain a descriptive account of continuous or periodic technological forecasting activities which have been identified in non-industrial environments, an annotated bibliography, and a name and subject index.

Part Z

A FRAMEWORK FOR TECHNOLOGICAL FORECASTING

The earth is not a resting place. Man has elected to fight, not necessarily for himself but for a process of emotional, intellectual, and ethical growth that goes on forever. To grow in the midst of dangers is the fate of the human race, because it is the law of the spirit.

Rend DUBOS.

Chapter I.1

THE FUNDAMENTAL CONCEPT OF A TECHNOLOGY TRANSFER SPACE

Technological forecasting is the probabilistic assessment of future technology transfer. **This** formula, deceptively simple on the surface, but **in** reality more complex than any other notion advanced so far[1], will underlie the entire structuring of the problem tackled in this report.

A useful framework for technology transfer, again deviating from older notions, was recently outlined by Harvey Brooks[2]. Somewhat extended and adapted to the purposes of this report, it can be expressed in the form of a flow scheme which will serve to illustrate the major points developed throughout the report.

The flow scheme can be represented within a three-dimensional technology transfer space. We consider first a ***two-dimensional scheme of technological progress,*** useful for the demonstration of simple processes, which will then be logically extended by the third dimension. For practical reasons, which will become obvious, we choose an upward direction of progress[3] and number the levels accordingly, starting at the bottom. We have to distinguish at least eight levels for the points to be made later; but while eight is the minimum number for our problem, a much finer subdivision could be conceived for future problems of technological forecasting. The eight ***levels*** of technology transfer, accompanied by an illustrative example, are as follows:

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1. Typical older definitions involve only the three lowest levels of the flow scheme presented in this chapter, and imply one-dimensional, or at best two-dimensional, technology transfer. Take for example Lenz's definition, given in 1961/62 *(lit.* ref. ***151):*** " Technological forecasting may be defined as the prediction of the invention, characteristics, dimensions, or performance of a machine serving some useful purpose for society. (It is not required that the invention be described)." " The considerable extension in levels and dimensions suggested in this report is not an arbitrary choice, but conforms with the tasks and modalities of technological forecasting as practised or envisaged in **1966;** Schon *(lit.* ref. 352) comes closer to this notion by defining technological forecasting as " the forecasting either of invention, innovation or diffusion of technology."

2. Harvey Brooks, " National Science Policy and Technology Transfer," Conference **on** Technology Transfer and Innovation, **16-17** May **1966,** in **Washington, D.C.** The scheme was explicitly presented for two dimensions (vertical and horizontal technology transfer) and up to the level of application only, but the full three-dimensional technology transfer space, **as** outlined in this chapter, was implicit in **Dean** Brooks' sweeping view of the general problem.

3. No value judgment is implied in the **use** of the term " progress " ; it is employed only as **an** indication of the direction of movement over time.

TECHNOLOGY TRANSFER LEVEL		EXAMPLE
Impact Levels	VJII. Society.	VIII. Implications of communications for society.
	VII. Social Systems.	VII. Defense and other national aspects of communications.
	VI. Environments.	VI. Communications sector of industry.
	V. Applications.	V. Market for communication systems.
....	....	....
Development Levels.	IV. Functional Technological systems.	IV. Solid-state communication systems and functional subsystems.
	111. Elementary Technology.	111. Solid-state technology, integrated circuit technology, etc.
	11. Technological Resources.	11. Diffusion techniques, planar techniques, etc.
	I. Scientific Resources.	I. Recognition of the natural phenomenon of semi-conduction; "majority" and "minority -- carrier concept, etc.
Direction of progress.		

The integration of development and impact levels, which may present some difficulties from the point of view of older notions of technology transfer, is logical for technological forecasting, which is concerned with vertical technology transfer across the boundary line and up to higher levels.

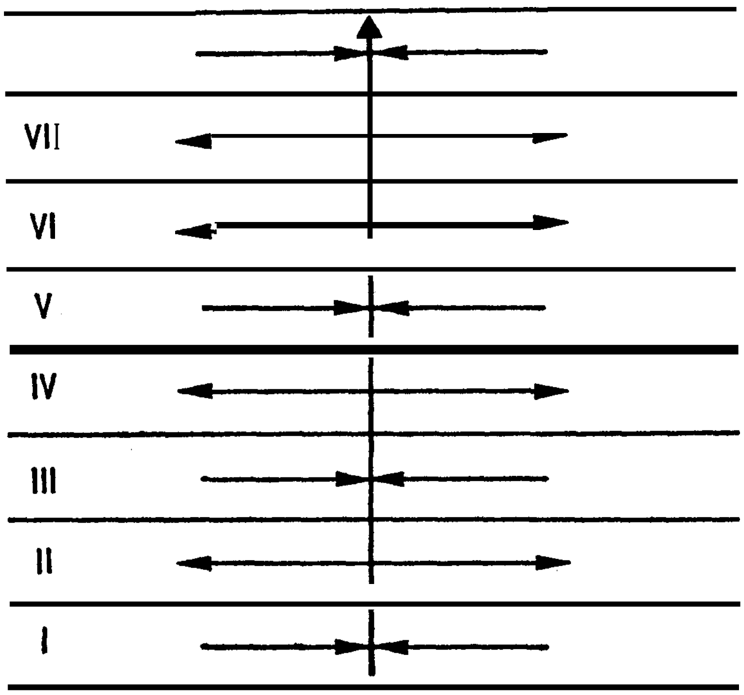
It will be noticed that these eight levels comprise important sub-levels; the examples given for levels **III** or **IV** clearly represent different sub-levels. However, for the sake **of** simplicity, we shall retain our minimum of eight levels.

Technology transfer can now be seen as taking place in a vertical as well as in a horizontal direction. Whereas a vertical transfer leads from fundamental science to technology, and further to systems (products, processes, etc.) and their impacts on different levels, horizontal transfer in this flow scheme, with the flow directions indicated in the diagram, represents for example: empirical postulation of a scientific theory (level **I),** fructification of other fundamental technological research (level II), merger of discrete technologies (level **III),** diffusion of existent technology (level **IV),** demand for auxiliary or support systems (level **V),** "invasion" of other industrial sectors (level **VI),** technical aid programme for developing countries (level **VII),** ethical constraints on social goals (level **VIII).**

This scheme holds equally for development and impact of products (hardware), processes, concepts (software, for example computer software), skills and techniques (e.g., medical techniques)—in short, for the whole spectrum denoted by "technology," in contrast to the narrower term "technics."

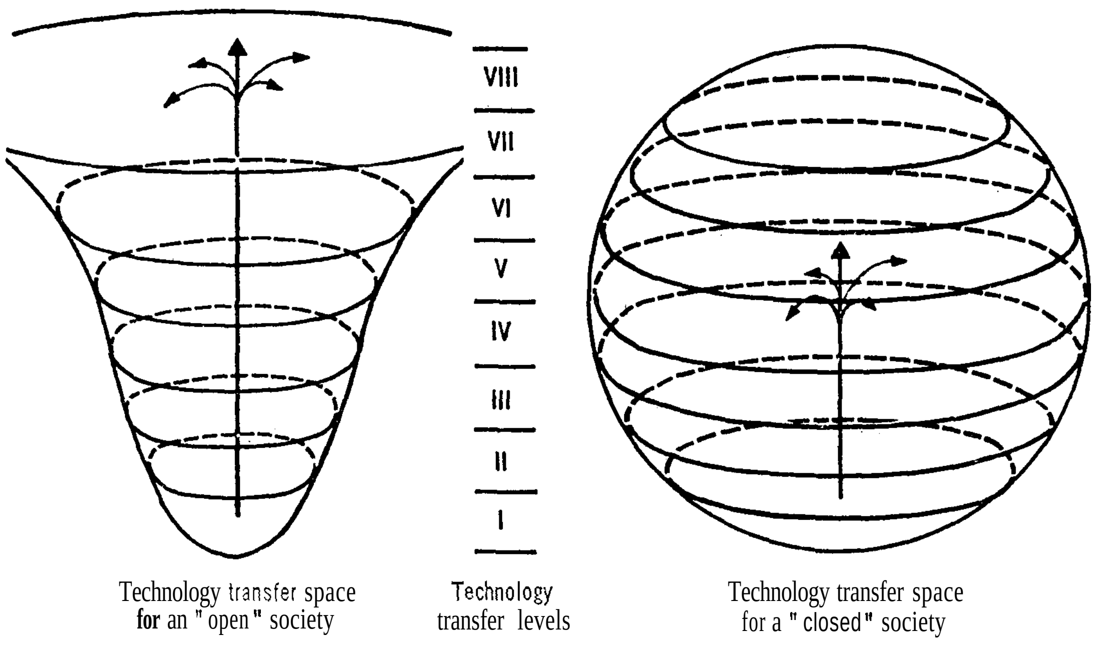
The flow of technology transfer in this two-dimensional scheme of technological progress can be represented by any combination of vertical flow in the upward direction and horizontal flow in both directions.

Simplified two-dimensional flow does not take into account the interaction **of** technological progress with non-technological surroundings. Selling a technical product to a market for non-technical applications already



constitutes such an important interaction of this type, of which there are **a** great number at every level. We have to extend the flow scheme to a three-dimensional space to accommodate the complete process.

The three-dimensional ***technology transfer space*** constitutes the framework for all types of technology transfer that have to be considered in the context of technological forecasting: technological development and impact as well as interactions with the non-technological world at all levels. The boundaries of the technology transfer space would be so defined that all such interactions take place inside. This space can be represented in two basic versions, for an " open " and for a " closed " society[1], assuming a tulip-shaped and a spherical form, respectively.



Technology transfer space for an " open " society

Technology transfer levels

Technology transfer space for a " closed " society

1. **A dictatorship would be cigar-shaped,** not **spherical,** in **this representation.**

The example inscribed in the tulip-shaped space represents a *"social invention"* (see Chapter I.7.) which is permitted to interact freely in an " open " society and to combine with other factors to produce any kind of uncontrolled impact. The example inscribed in the spherical space refers to the usually ill-defined ***technological innovation.***

The difference between the " open " and the " closed " society increases with higher levels. Infinite width may, in principle, already have been reached at the level of functional technological systems or of applications; this is normally prevented by factors inherent in the economy (only a relatively narrowly defined range of products and applications, from among all the possibilities, will be considered in a sound economy). However, at the higher levels of social systems and society, such an infinite dilution of the technological progress reaching them is becoming a matter of acute concern today (see also Chapter 1.2. below).

In the technology transfer space, the following entities appear, in the graphical form of representation indicated:

ENTITY	REPRESENTATION
A. Scientific and technological factors, systems, effects, objectives, goals; social effects, goals, etc.	0-dimensional (points)
B. Totality of scientific and technological factors, systems, effects, etc. on each level	1-dimensional (lines)
C. Totality of technological and non-technological factors, systems, effects, objectives, goals, etc., on each level	2-dimensional (horizontal cross-sections)
D. Integrated technological progress	2-dimensional (vertical cross-section)
E, Integrated technology transfer	3-dimensional (tulip-shape or sphere)

Each level (each horizontal cross-section), at a given time, can be represented by a rate-of-change profile. ***Time* is** an implicit factor in the flow scheme. For a given point on the level, the rate-of-change profile may contain vectors in different directions—vertical, horizontal, or at an angle—and could not be represented by a simple topological form.

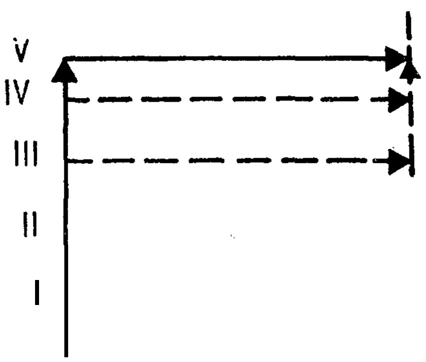
Today, the organisation of technology transfer usually favours integrated vertical transfer. **Brooks** points out that a tendency towards more horizontal integration is already becoming visible: the trend consisting of growing emphasis on service and on software will serve ***to*** slow down hardware progress (the same hardware will **be** put to **a** wider spectrum of uses). Some companies such as Eastman Kodak (Instamatic camera, representing a new approach to application, not technological progress) or the 3M Company (Minnesota Mining and Manufacturing Company), have adopted policies of horizontal integration. New services are springing up that are mostly science-based (and include a vertical technology transfer component) but depend strongly on horizontal integration at various levels.

The proposed new charter for the **US** National Science Foundation, providing for the inclusion of applied technology, would mean a shift from primarily vertical integration to a vertical/horizontal combination.

The vertical and horizontal vectors involved in the following mechanisms of technology transfer (from **Brooks'** list) will be clear: movement of people, entrepreneurial activity, literature, developer-user relationship, education, consulting aqd advising, meetings, marketing and application engineering, patents.

The concept of the technology transfer space and its graphical representation constitute only an auxiliary means of illustrating, in simple fashion, relationships and directions encountered in the actual problems of technological forecasting, and should not be regarded as an expression from which anything can be derived.

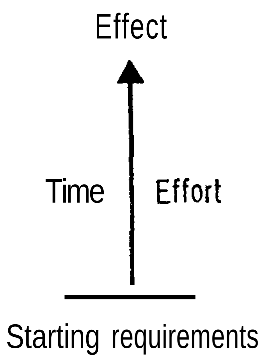
Technological forecasting is concerned with every form and direction of transfer as well as with the ratesd of change within the entire technology transfer space. One of the important potentials of technological forecasting becomes immediately evident from the graphic representation: the recognition of possibly preferable alternatives to attain the same end-point (the same



end-effect). Instead of producing a certain effect by the diffusion of existent technology through the sale of a product adapted to a given application, it might be preferable to sell a licence on the elementary technologies involved, or on an already developed product version, leaving to the end-user the task of adaptation to the requirements of his own application.

The basic questions which technological forecasting attempts to answer may be regarded as falling within four areas:

1. Time span required for technology transfer between any two points in the transfer space (in particular, development time);
2. Effort involved in the effectuation of any technology transfer between any two points in the transfer space (in particular, development costs);
3. Effect at end-point of any technology transfer between any two points in the transfer space (in particular, functional capabilities



of technologies, performance characteristics and production costs of functional systems, impact on higher levels, effects of merging technologies or diffusion of technology in the horizontal direction, etc);

4. Selection of a suitable starting point (determination of starting requirements) in the transfer space to effectuate technology transfer to a specified end-point (end-effect) on an equal or higher level.

The first three types of questions are characteristic of exploratory—and type 4 of normative—technological forecasting (terms that will be explained in Chapter 1.2. below).

This is a very simplified scheme which should not be taken too literally. Technology transfer usually cannot be described adequately by a simple line. It may be necessary for many scientific or technological resources and many elementary technologies to merge before a functional system can be built; the success (effect) of a commercial product will depend on a particular combination of technological functional capability and market factors (cost/effectiveness, also a decisive factor for the defence " market "); etc.

Although technological forecasting, as conceived here, also embraces the special case of purely horizontal technology transfer, such as the diffusion of existing technology, this is usually still made a separate subject of study, which can be considered a sub-discipline of technological forecasting. This is merely a matter of tradition. In a narrow sense, often encountered today, technological forecasting is characterised by a marked vertical component.

The technology transfer space is a useful tool to structure thinking around technological forecasting. Modifications which may appear necessary with advances in the art of technological forecasting should alter the tool, not limit the developing concepts of the art.

EXPLORATORY AND NORMATIVE TECHNOLOGICAL FORECASTING

You got to give God a chance.
Isidor I. RABI.

Inventing the Future.
Dennis GABOR.

Before World War II, most attempts at technological forecasting belonged to the realm of fantasy. By exploring the paths of possible technological progress into the future, and paying relatively little attention to constraints, needs and desires, not only was the boundary between attainable progress and fantasy obscured, but—more important—the mere pointing out of recognised opportunities did not in itself provide a strong incentive to exploit them.

As late as 1952, Gilfillan (*lit. ref. 40*), in an authoritative review of the state of technological forecasting, emphasised the principle of opportunity (or suitability) and listed only exploratory steps for the investigation of the " levels of future causality."

Technological forecasting began to emerge as a serious art—not yet a science—when objectives, needs, and desires were introduced as normative elements in forecasting, and constraints were recognised and taken into account.

Typical basic attitudes that lead to normative forecasting include the following:

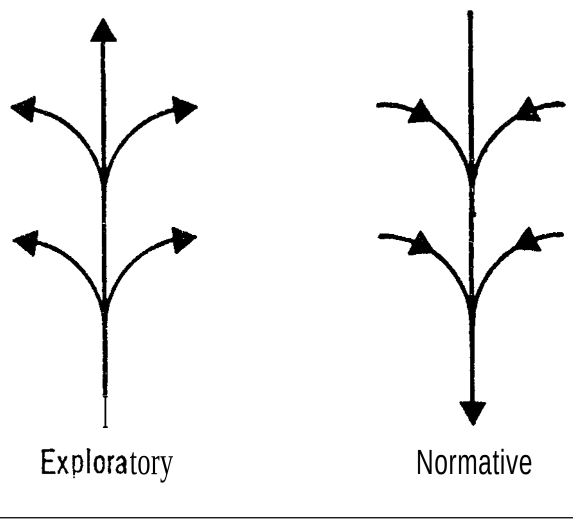
— Recognition of responsibility towards society or nation;
— Recognition of economic potentials;
— Recognition of an ultimate technological potential;
— Awareness of constraints, for example in natural resources, company resources, etc.;
— Hedging against threats.

How little was known about needs and desires 30 years ago is documented in the very remarkable collection of technological forecasts published in **1936** by **C.C.** Furnas (*lit. ref. 266*), **a** renowned American metallurgist and engineer. Although he was well ahead of his time in recognising some of the important goals and requirements, he did not venture to express himself in normative terms because he lacked understanding of the potentially powerful driving force of such goals and requirements. He tried, instead, to explore the chances a self-acting development process would have of attaining these goals. His view on the subject of television—Zworykin had demonstrated his " iconoscope " (a modern cathode ray receiver) not long before—reflects this over-cautious thinking: " I am waiting for my television but **I** cannot live forever. When I think that the first radio impulse transmission was accomplished by Joseph Henry in **1840** and the first radio broadcast was not until **1920** I feel a little discouraged about the arrival of this television business while my eyes still function. No one has dared even to think **of** television in natural colours as yet."

At this same time **(1936-37),** Gilfillan ***(lit. ref. 243)*** pointed out potential implications, but left the question open: " Will the public accept TV and pay for it? "

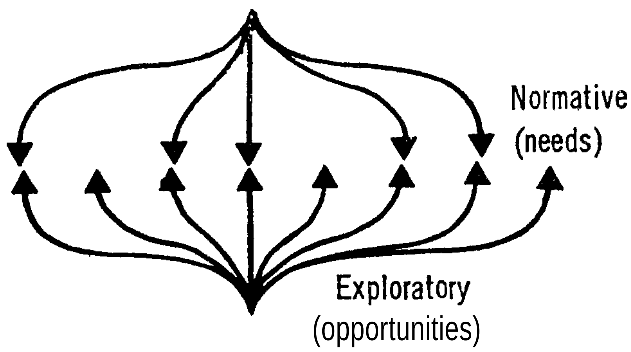
In the following year regular television broadcasting started in the United Kingdom, and the first invention essential to colour television, which was to be achieved by Goldmark, was only half a decade away[1]. It is interesting to note, in the continuation of the above quotation from Furnas, how even an unprejudiced forecaster in that period is content to accept the assumed absence of ever-renewed incentives and requirements to go further : " **As** soon as television becomes a reality for the average American the last frontier of communication will have been closed, but an immense amount of improvement will still be possible in all departments." Today, we feel that we are standing only at the threshold of an Age of Communication, which already has definitely put an end to the isolated consideration of technological progress. McLuhan ***(lit. ref. 374)*** expresses this change in a graphic vision: " Western man acquired from the technology of literacy the power to act without reacting. The advantages of fragmenting himself in this way are seen in the case of the surgeon who would be quite helpless if he were to become humanly involved in his operation. We acquired the art of carrying out the most dangerous social operations with complete detachment. But our detachment was a posture of non-involvement. In the electric age, when our central nervous system is technologically extended to involve us in the whole of mankind and to incorporate the whole of mankind in us, we necessarily participate, in depth, in the consequences of our every action. It is no longer possible to adopt the aloof and dissociated role of the literate Westerner."

This brings us back to the ***fundamental polarity of exploratory and normative technological forecasting*** which is related to the polarity between



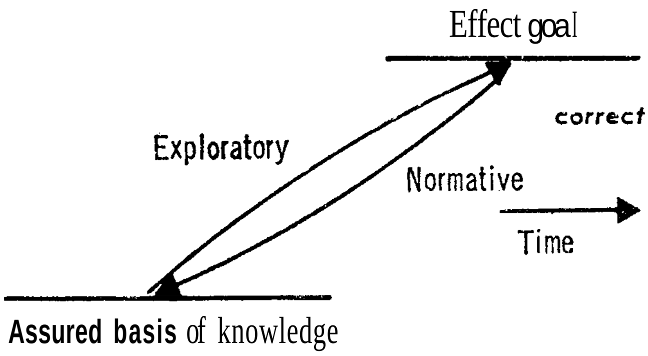
1. The relatively long " incubation time " to large-scale application in this case was affected by the war and other " irregular " factors.

action and reaction. In our technology transfer space the corresponding directions would be opposed to each other. It is important that the interaction of exploratory, or opportunity-oriented, and normative, or mission-oriented, forecasting be stated correctly: Every technology transfer level implicitly has a profile for the present, and profiles for various futures. The forecast of a particular technology transfer, as represented by the vectors of exploratory forecasting in the technology transfer space, has to be made within an additional ***time-frame.*** In the same way, a normative forecast (what should be developed in order to attain a given goal), as represented merely by the vectors opposing the direction of technology transfer, does

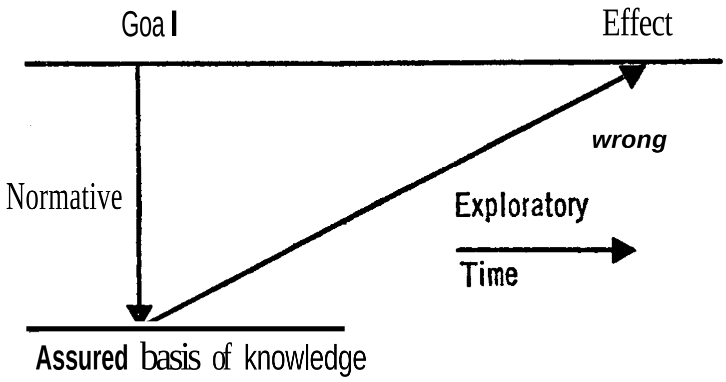


not as yet include an explicit time factor, and this must then be introduced. The basic form of ***interaction*** between the two forms is " matching " by iteration or in a feedback **loop.** Methodologically, this is the most difficult aspect of technological forecasting.

A correct forecast, including a correct interaction between the two elements, would have to be placed within **a** time-space continuum which cannot be represented graphically for the full technology transfer space (because it **has** four dimensions).



The most difficult problem in technological forecasting today is the placing of normative forecasting in the correct time-frame. Whereas exploratory forecasting encounters less (but enough) difficulty in conceiving an end-effect as a future effect on the basis of a time-span estimate, normative forecasting only too often envisages a set of objectives and requirements —and, most often of all social goals—on the tacit assumption that goals for the present are also representative of the future. Not only does this lead to a mismatch, but it also creates the danger of a serious distortion of



the historical process. Normative forecasting, in Gabor's words, " can start beyond the term to which the social system is carried by its own inertia." Insufficiently future-oriented forecasting, by the same token, can be conceived of as reducing the inertia artificially and slowing down the historical process.

The typical tasks for opportunity-oriented or ***exploratory technological forecasting*** can be illustrated with an example from electronics:

LEVEL OF TECHNOLOGY TRANSFER	TO BE FORECAST	EXAMPLE
VIII. Society	Impact on Society.	World-wide instant communication, artificial organs for man, etc.
VII. Social Systems	Impact on national economy, defence, health programme, etc.	" Technological gap " between countries, extension of defence and space strategies, support for development of artificial organs, etc.
VI. Environments	Consequences for structure of industry, leadership of innovating companies.	Changing relationship between systems and components manufacturer (growing together), diversification into medical electronics, city-building, hospital management, etc.
V. Applications	Technological, economic and social acceptance, measure of " success."	Applications to new tasks, incentives for mass production, market strategy, " business cycles " for rate of successive and related innovation.
IV. Functional Technological Systems	Description of system and detailed performance characteristics, development time and effort, production costs.	Low-cost high-reliability electronic systems, increase in capacity per volume and mass unit, etc.
111. Elementary Technology	Functional capabilities, technological parameters.	Integrated circuits: number of component functions accommodated, frequency, power dissipation, feasible reject level for mass production.

LEVEL OF TECHNOLOGY TRANSFER	TO BE FORECAST	EXAMPLE
II. Technological Resources	Basic technological potential.	Level of microminiaturisation feasible with current and future techniques, limits of " molecular engineering, " high-frequency potential, etc.
I. Scientific Resources.	Trends in scientific principles and theories, unapplied knowledge, applicability to technological progress.	Quantum electrodynamics, " quasi-particles, " etc.

Mission-oriented or *normative technological forecasting* tackles the following characteristic tasks, illustrated by an example from space technology:

LEVEL OF TECHNOLOGY TRANSFER	TO BE FORECAST	EXAMPLE
VIII. Society	Social goals.	Space as an environment to benefit man, space as challenge, etc.
VII. Social Systems	National objectives.	National space programme.
VI. Environments	Missions.	Planetary missions.
V. Applications	Tasks.	Nuclear rocket propulsion.
IV. Functional Technological Systems	Relevance of systems to tasks, technological feasibility, cost/effectiveness.	Nuclear-thermal propulsion unit, nuclear-electric (for example ionic) propulsion system.
III. Elementary Technology	Relevance and feasibility, development gaps, etc.	NERVA-type or SNAP-type nuclear reactor technology, gaseous nuclear fuel technology, thermionic technology, metal vapour turbine cycles, etc.
II. Technological Resources	Technological potentials and limitations, required fundamental technological research.	Three-fold specific impulse by use of hydrogen as propellant in connection with nuclear external heating, continuous low-thrust acceleration by electric propulsion, etc.
I. Scientific Resources	Absolute (natural) potentials and limitations, required fundamental scientific research.	Conditions for and energy yield of nuclear fission, thermodynamic superiority of low-molecular-weight gases, ionisation potentials, zero gravity in orbit (for low-thrust " spiralling out "), thermionic principle, etc.

Normative technological forecasting very closely approaches the " self-fulfilling prophecies " against which older publications used to warn. The pendulum is now swinging to the other extreme: the driving force, and the "propaganda value," behind a prophecy are used consciously to allow it to come to " self-fulfilment." The involvement of the forecaster in the forecast, constituting a powerful source of energy, is put to use in its implementation.

It should be clearly understood that normative technological forecasting is meaningful only if two conditions obtain:

If the levels to which it is applied are characterised by constraints; normative forecasting can be applied to the impact levels (goals, objectives, missions) only if these levels are sufficiently " closed " by natural or artificial forces, or by consensus (for example, an agreed set of values or ethical directives, etc.) ; fully-integrated normative forecasting is applicable only to a " closed " society;

If more opportunities exist and are recognised on these levels than can be exploited under the given constraints; normative forecasting is essentially an attempt to optimise, which implies selection.

For the first time in the history of Western civilisation these two basic conditions are becoming a reality. Normative forecasting today is both possible and necessary. Only 25 years ago the second condition could not generally have been said to obtain.

This second condition will be assimilated by traditional thinking more readily than the first. It is illustrated by the result of a recent study by the National Planning Association in Washington: if the United States undertook to achieve by 1975 all its present national goals, it would cost 50 per cent more than the total Gross National Product in this period—not to speak of goals that were newly formulated during this time.

In a recent McGraw-Hill survey of research and development in US industry (*lit.* ref. *54*), only 24 per cent of all industry indicated " lack of profitable projects " as the major obstacle to the performance of more research and development in 1965 and 1966. The non-ferrous metals and aerospace sectors had the lowest figures in this respect—7 and 10 per cent respectively while the paper and pulp sector headed the list with 32 per cent. (The figures refer to a complete cross-section of industry, not to the leaders or to the big companies only). The shortage of scientists and engineers was singled out as the major obstacle by 29 per cent of industry and the remainder cited mainly financial reasons.

In American companies with well-organised research and development, the abundance of opportunities is emphasised almost unanimously. This important point—as well as confidence in normative forecasting, based on experience—are expressed in the formula " You can invent to order," coined by the top executive responsible for long-range planning in one of the innovating companies characterised by the most thorough and sober planning in the United States; this attitude has become the key to a most spectacular company success.

During the OECD investigation made for this report and on former extended tours of European and North American research-intensive industry, the author has acquired the personal conviction that both the basic attitude referred to above and the normative approach in leading US Companies—and also their absence in many more traditionally-minded European companies—are at the bottom of the much-discussed problem of the US-European « technological gap » in electronics, nuclear energy, and other areas. **An** important " breakthrough " in normative forecasting techniques has been accomplished in the United States by the integrated application of relevance tree schemes such as PATTERN (see Section **11.4.5.).**

In military technological planning, a strong normative component has always been present and has been greatly enhanced by the comprehensive cost/effectiveness studies applied in the United States, the United Kingdom, France, Sweden, and other countries.

The decision of the United States government, taken in October 1965, to introduce the Planning-Programming-Budgeting System (PPBS) of the Department of Defense (*lit. ref. 241*) to the executive branches and other government agencies, marks a most important step towards a future integrated cost/effectiveness basis for government action. The basic idea is that the agencies are supposed to develop their " businesses " independently, in a manner analogous to that of a big decentralised company, and to try to win " corporate " support for the implementation of their plans on the basis of cost/effectiveness.

The first of the two conditions for normative forecasting mentioned above—a " closed " society or at least " closed " levels—will be accepted less readily. The reason for this is a widespread lack of understanding **of** the different spiritual dimensions of planning. Very often the one-dimensional polarity between free enterprise and dirigism (interventionism) is believed to constitute the only degree of freedom available in choosing one's own position—a simplification which has caused considerable confusion recently in a number of European countries.

This report is not the place to discuss the implications of planning. Instead, a few sentences will be quoted here from one of the most venerated leaders of liberalism, a man who has contributed significantly to the spirit of freedom in Europe, Salvador de Madariaga[1]: "**A** human society cannot exist without a certain degree of compulsion. This is a force which, among human beings living together, acts in a manner similar to that **of** gravity in the Universe. Each object which is not supported falls to earth**...** The two driving forces behind human society are ambition and necessity: the decline of Western civilization commenced at the moment when politically influenced legislation started to paralyse these two forces."

The two countries which have led in the recognition of the need to formulate social goals and to promote normative technological thinking in relation to social impact, namely the United States and France, have governmental forms which favour the free enterprise principle.

What is denoted as " compulsion " in the quotation from de Madariaga may be illustrated by a striking example: Almost all genetic mutations (99 per cent) are deleterious, but the few positive mutations dominate under natural conditions, while the harmful ones die out. This natural equilibrium —or even, when viewed over the time span of man's evolution, this beneficent principle— has been drastically upset by advances in medical, food, and other technologies. We must assume that the artificial conditions created by modern technology will give rise to human degeneration if no control is exerted. This control can be conceived in two ways: repairing genes on the

1. **Neue Zürcher Zeitung (Zurich, Switzerland), foreign edition of 31 July 1966. (Original German.)**

molecular level, or preventing reproduction by couples either member of which is affected on the genetic level. The first way will not be feasible for some time to come, even with reasonable advances in molecular biology. There are approximately one billion " letters " of information stored in one spermatozoon—one thousand "letters" in each gene—and there is no means of checking all of them. On the other hand, molecular biology will, in the near future, offer for the first time the possibility of detecting, by simple chemical methods, the existence of deleterious recessive genes. The elimination of hereditary diseases will be possible through the prevention of reproductive mating between parents carrying the deleterious genes. For example, slightly more than **30** per cent of the world's population carry a gene responsible for sickle-cell anemia. With random marriage approximately one-tenth of the total number of marriages would be between potential parents both of whom carry the gene; one-fourth of their children would be sick. Thus, in the near future, the world will be faced by the necessity of deciding between " compulsion " to stop the spreading of hereditary diseases—the technology for detection on the genetic level would then be available—or of letting mankind degenerate because of some of the consequences of technological progress[1]. The question of good and evil in technology cannot be posed more dramatically, nor the problem of selection more urgently in order to permit enjoyment of its benefits without their being simultaneously cancelled out.

The assessment of *cost/effectiveness for social goals,* rejected as utopian of blasphemous until recently, is now receiving serious attention in the United States. Resources for the Future, in Washington, D.C., added to its activities in 1966 a programme for exploring the feasibility of a useful approach. The introduction of the Planning-Programming-Budgeting System in US government agencies will necessarily lead to " pioneering work " in this direction in areas such as health, urbanisation, and crime prevention where research expenditures are already expected to increase considerably within the next ten years. In the **US** Department of Health, the high position of Assistant Secretary for Systems Analysis has been created, and systems analysis functions are planned for the newly established US Department of Urbanization and the future **US** Department of Transportation.

The basic difficulty with a " closed " society within a democratic system is the problem of *consensus.* Harvey Brooks pointed to the necessity for widespread consensus in areas where individual interests are involved, such as urban transportation and pollution control, in contrast, for example, to the space programme where few people have to be convinced in spite of the large public expenditure involved.

The recent report to the US President on " Technology and American Economy "—chiefly an investigation of the future impact of automation on employment—constituted one of the first attempts to seek consensus from widely different groups, for example industrialists and union leaders. The result, although somewhat amusing to the reader not personally concerned, is justifiably regarded as encouraging.

The participation of scientists and engineers in the selection of social goals is a much-disputed subject (see also ***lit. ref. 11***). A number of renowned scientists, active in many fields (see also Chapters **1.7.** and III.6.), sponta-

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1. **Dr. Max Perutz, Nobel laureate who is engaged in research in this broad field, advocates a comprehensive " warning scheme," leaving the decision to the individuals affected. One may expect no more than a marginal effect from such a scheme.**

neously took the lead in urging the creation of " look-out institutions " and have adopted a normative attitude as soon as they have recognised the full problem. Other scientists, although deeply concerned, reject the idea of normative forecasting: " Planning for social goals is sheer nonsense " and " **A** social strategy saying ' I shall find a way ' is bad," are two characteristic statements by Nobel Prize winners. The principle that scientists should point out consequences of planned actions and, if necessary, sound warnings is more generally accepted.

The ' Delphi ' technique (see section 11.2.3.) has been developed to improve the consensus between scientists and other experts. It may become an important tool for the selection of social goals, national objectives and broad missions.

The problem of future high-level goals will be considerably complicated by the logical extension of the simple matching of exploratory and normative technological forecasting to feedback systems (see, for a more detailed discussion, section 11.5.1.). The future goals will then not only be forecast along the lines of highest probability, but ***anticipations*** (known also as " possible futures," " alternative futures," and " futuribles ") of less probable, but possible, consistent future goals and situations will be systematically explored and will, in an iterative feedback loop, be permitted to influence current decisions as well as the orientation of exploratory forecasting. " Scenario-writing" is a technique developed as the exploratory component in efforts to attain these ends—the use of feedback techniques will make it possible to integrate this technique with normative forecasting.

The selection of the ultimate criterion, finally, promises to become difficult. Too little is known of the desires of man to formulate a universal synthesis. " Happiness " is still the trivial formula which is often encountered even among serious students of " futures-creative thinking." In the absence of a better formulation, one might choose from among some of the more deeply rooted criteria, such as " Survival of human spirit " (Polykarp Kusch), or " The creation of conditions to ensure that a maximum variety of individual incentives may be followed " (René Dubos). The delicate balance of Dubos' criterion represents perhaps the best expression of the nature of the " compulsion " which planning for social goals will require: it is not at all an excuse for a minimum of control as it might superficially appear to be (one may imagine what its rigorous application to the problems of urban life, pollution, noise control, etc., could imply), but nevertheless assures a maximum of freedom.

Planning in these regions—and normative technological forecasting in particular—tends to become a task of almost superhuman proportions. Is it possible to obtain the powerful and disciplined co-ordination of human energy that would be required? **US** Secretary of Defense Robert S. McNamara[1], who, in his department, has accomplished some of the most remarkable tasks of normative thinking, pointed out the alternatives, and one may detect a shade of resignation in his words: " Who is man? Is he a rational animal? If he is, then the goals—mutual interest, mutual trust, mutual effort—can ultimately be achieved. If he is not, then there is little point in making the effort. All the evidence of history suggests that man is indeed a rational animal—but with a near infinite capacity for folly. **His** history seems largely a halting, but persistent, effort to raise his reason above his animality. He draws

1. **In a speech before the American Society of Newspaper Editors, 18 May 1966, in Montreal (Canada).**

blueprints for Utopia. But never quite gets it built. In the end, he plugs away obstinately with the only building material really ever at hand: his own part-comic, part-tragic, part-cussed, but part-glorious nature." Will this picture of man, realistic today, be changed in the future—or will the upsurge of ambitions, in response to the urgent challenge, collapse or produce nothing but a " sizzle "?

It appears, however, unlikely that mankind will be able to turn back from that historic development which can be identified with the rise of technology and which will tend to make society increasingly less " open-ended " —whether we like it or not. Irving H. Siegel's forecast on the future of forecasting, tinged with a note of sadness, is grounded in this recognition: The skill in forecasting will improve because the type of freedom will be different. A broadening of the organisation and supply side and a limitation in variety on the demand side will make forecasting easier because there will be fewer alternatives. A qualitative change of society will make it more sensitive to the " propaganda element " of forecasting. The involvement of the forecaster in forecasting will increase—another reason for an improvement in forecasting. The overall direction of historical movements will still be difficult to forecast due to the power concentrated in individuals such as heads of governments.

What is needed most in the present situation is the wisdom to master the problems connected with a new dimension of collective ambition. There can be no doubt that, with full integration of exploratory and normative technological forecasting in a feedback scheme, man is developing a powerful means of directing and concentrating human energy and of interfering with the movement of history; he will have to guard against consequences of the sort Goethe's " sorcerer's apprentice " experienced.

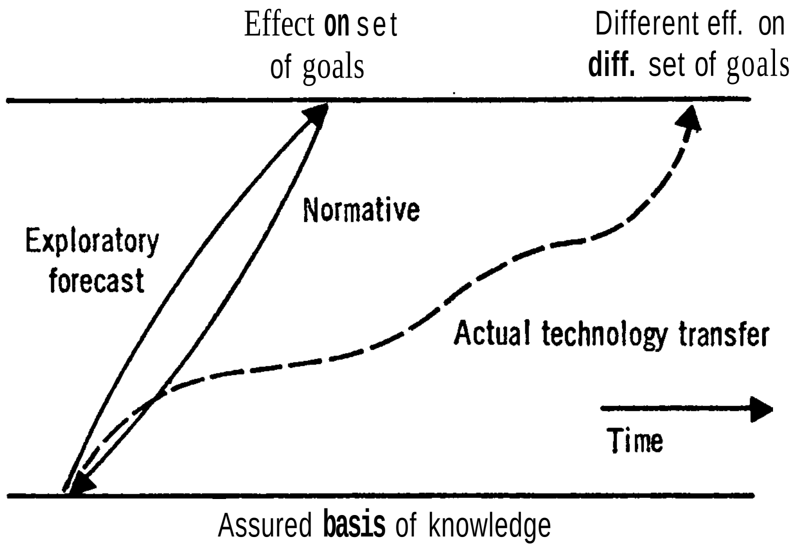
Chapter 1.3

THE TIME FACTOR IN TECHNOLOGICAL FORECASTING

History is a very poor guide; we have improved.

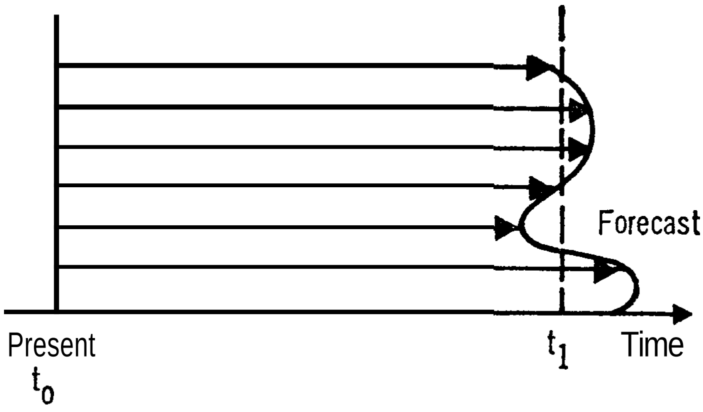
Harvey Brooks.

For the correct assessment of a time-frame in technological forecasting, many requisites are called for beyond, and even more important than the mere information concerning the accomplishment of a specific technology transfer. The graphic example, which might be typical of a development



that is delayed because a contributing sub-technology is lagging behind, illustrates one of the dangers. Not only does the mismatch of the end-effect with a set of goals for which it was not intended constitute a danger, but so does a deviation from the assessed time-frame in any of the intermediate development (technology transfer) steps.

In an actual time-frame, where vertical cuts represent the cross-section of the technology transfer space at a given moment, a pattern of individual forecasts will generally lead to a projected future cut that is more or less distorted.



A forecast, giving a time-frame, implicitly assesses the inertia of a certain technology transfer. Extrapolation of time-series (see section 11.3.3.) is a simple technique to that end, and envelope curve extrapolation tries to do the same for **a** succession of developments in the same functional capability area.

The assessment of the inertia of a given technological system will become more difficult in the future because the interactions both inside and outside the system will increase. A major factor will be the growing interaction of technological systems with the social system. General Electric's TEMPO Center believes that trend extrapolation over time will become " unproductive" due to these more complex interactions.

On the whole, it is not well understood on what grounds the decisions on the financing of research and development are taken " by a not very clear introduction of expert opinion and of pressure groups " (Gabor) and perhaps of other factors. A rationale for such decisions exists only where a well-organised medium- and long-range technological planning function—or, to be more precise, technological forecasting fully integrated with technological planning—provides a firm basis for decision-making. **A** representative company in this connection might be exemplified by the Xerox Corporation, or Bell Telephone Laboratories (A.T. & **T.).** Some pertinent and highly interesting case studies have been undertaken by a number of economists in the United States, and the results have been published in the volume, " The Rate and Direction of Inventive Activity " *(lit. ref. 65).*

It has already been implied in Chapter 1.2. that normative forecasting, and the ultimate extension of exploratory and normative technological forecasting to integrated feedback schemes have the potential of concentrating and directing human energy in such a way as to influence the inertia which is present in the flow of history. The effect may become visible in two ways:

- Acceleration of technology transfer ; a sophisticated forecast has to include this effect—and often does, especially in the type of forecast effecting « self-fulfilling prophecy » ;
- Possible deceleration of technology transfer, after a period of pressure against technological frontiers ; this phenomenon is emphasised by both the **RAND** Corporation ***(lit. ref.*** 29) and General Electric's TEMPO Center.

The RAND Corporation goes even much further in suggesting that pressure against technological frontiers may also give rise to the decelerating factor of unnecessary complexity: "The possibility we are speculating about is this: the burdensome complexity of current systems may not be an unavoidable consequence of the demand for higher performance, but rather, the consequence of an emergency need to squeeze out the last possible ounce of capability from a temporarily overtaxed state of the arts... The hope, in short, is that a slight relaxation in our extreme pressure against the technological frontier might greatly reduce the troublesome complexities of weapon systems."

The same RAND report mentions another potential decelerating factor: the improvement of goal selection by normative forecasting may reduce the efficiency of development and production and slow down technology transfer. In the absence of a strong normative forecasting component, easier (more "efficient") ways of development might be chosen. However, the conclusion of the RAND report, which was drawn up in the context of US Air Force developments, may also be stressed for civilian developments, "social technology," and other areas amenable to technological forecasting: "Both efficiency and proper aim are important; but if we must compromise them, it is probably best that efficiency suffers."

The following time spans, introduced as broad categories, determine the time-frame of technology transfer up to the application level (for the first four levels we use the Stanford Research Institute's classification of research and development phases):

1. Time span until discovery (discovery phase);
2. Time span between discovery and technological applicability or invention (create phase);
3. Time span between invention or availability of a suitable technological configuration and commencement of full-scale development (substantiate phase);
4. Development time (development phase);
5. Cycles of major technological innovations in a specific area;
6. Acceptance (business) cycles.

The two cycles mentioned under 5 and 6 are, of course, strongly related to each other, but are not identical. Acceptance cycles are becoming the factor "leading" development in technological areas that are characterised by strong normative thinking, such as aerospace and computers.

Phases 1 to 4 do not necessarily follow each other without pause. Every phase depends on a configuration of feasibilities, which may have to await maturity of other fields. There are many discoveries which have not yet led to an invention or development. It is one of the major tasks of technological forecasting to determine the proper timing of the phases.

An investigation by Gilfillan (*lit. ref. 40)* of 19 inventions "voted most useful," and introduced between 1888 and 1913, shows the ofllowing time-frame:

Time from first thought of invention to first working model or patent	176 years
Time from latter to practical use	24 years
Time from latter to commercial success	14 years
Time from latter to important use..	12 years

The 176 years are not always representative of the first three time spans we envisage[1]; the 24 years plus a varying number of years sliced off the 176 would probably provide an indication of the time span from discovery to the end of the development phase (our first four time spans).

The 50 years from working model or patent to important use compare unfavourably with the corresponding intervals in an evaluation made by Gilfillan *(Zit. ref. 40)* of *200* out of the 500 " most important " non-military inventions introduced between 1787 and 1935 (the average interval is 37 years) and of the 75 " most important " inventions introduced between 1900 and 1930 (here the average is 33 years).

An evaluation of 35 major innovations between 1711 and 1950 *(lit. ref. 39)* shows an arithmetic mean time-lag of 13.6 years between invention and commercial success (with a high standard deviation of 16.3 years), and a correlation, in the same reference, of nine cracking processes introduced in the petroleum industry between 1913 and 1950 indicates an arithmetic mean interval between invention and commercial operation of 12.8 years, with individual processes ranging from 3 to 24 years.

We have improved since then. The total time span from discovery to innovation (large-scale acceptance) is today generally assumed to be 15 years for efficient technology transfer processes. An analysis of past projects carried out by Lockheed (US) showed an average time span of 4.2 years from invention to innovation. Nylon took about 3 years from discovery to invention and 10 years from there to innovation. Technological forecasting is capable of reducing unnecessary pauses between the different phases almost to zero. The effect on the individual research and development phases themselves is perhaps more subtle, but has been noticeable in a number of prominent developments, almost all of which were preceded by technological forecasting including a strong normative component.

The ***time span until discovery*** can be estimated intuitively only if predominantly normative thinking is able to stipulate feasible dffects or to " read " certain evolving patterns of fundamental science. For example, it is possible today to venture a forecast on the time span leading up to the formulation of new ordering principles on the subatomic level, and of a new theory of elementary particles, by the signs of " pregnancy " which no student of the field may overlook.

The ***time span between discovery and technological applicability or invention*** can be influenced considerably by technological forecasting by reducing practically to zero the time-lag between discovery and the start of the create phase. This is the case especially where normative forecasting has prompted research in a well-defined area without being able to forecast the precise invention.

The " show window " example of this is the transistor (see, for example, ***lit. ref. 57)***. When the Bell Telephone Laboratories, formulating new goals for peace-time research, decided in 1945 to strengthen solid-state work, with particular attention to possible contributions to communication technology,

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1. We are more aware today of the need to distinguish between a " poetic " first thought and work leading to a discovery. The voice-operated type-writer was predicted by the German engineer Plessner in 1892, but has still not been invented. Only today are we able to see the prerequisites for its invention and to work towards meeting them. Gilfillan is obviously fascinated by tracing " first thoughts "—television, according to him *(lit. ref. 40)*, was first thought of in 1847 by Souvestre who predicted it in a satirical manner.

for which available technology became insufficient, the most probable outcome expected by Shockley (who was given responsibility for this research) was a solid-state field effect amplifier. After one year it was clear that only two alternative avenues for the future remained promising: semi-conduction and electroluminescence. The experiments carried out in **1947** and **1948** by Bardeen and Brattain, in Shockley's group, led to the discovery of the point contact transistor, an amplifier working on different principles. The importance of the discovery was grasped at once, and the direction of the work changed accordingly. The junction transistor, then forecast correctly by Shockley on theoretical grounds, was invented in **1951,** and large-scale application development started practically without delay.

Similarly, nuclear reactor development started in **1939** with little delay after the discovery (or demonstration) of nuclear fission in **1938.** This is a particularly interesting example, because it shows how instrumental normative thinking became in reducing the time-lag. A number of European scientists, who had had to flee from Hitler, recognised potential danger if this discovery were taken up and developed by Germany. Their approach to President Roosevelt, through Einstein's famous letter, initiated the formulation of a strong national objective, which in turn led to a concentrated effort. The first goal, a nuclear reactor, was achieved three and a half years later, and the war-time objective of a nuclear bomb after another two and a half years.

The counter-example of one of the truly accidental discoveries of importance—penicillin—shows a time-lag of ten years, which was obviously due to the lack of a clearly defined goal and **a** normative direction. Sir Alexander Fleming had accidentally come upon penicillin in **1928** (by the unexpected contamination of a culture plate of staphylococcus by spores of Penicillium notatum) and described and named it in **1929.** However, penicillin **in** the form then available was too weak and impure to demonstrate its full curative properties, and was used in laboratories only. It was not until René **Dubos** described another antibiotic (gramicidin) in **1939** and drew attention to the potential implications of the field, that general interest in antibiotics led to a systematic investigation with clearly defined aims.

The time span—only one week—from the discovery of the maser principle to the first working device (at Bell Telephone Laboratories) will probably hold the record for some time to come.

The ***time span between invention and commencement of full-scale development (substantiate phase)*** can obviously be considerably reduced by technological forecasting, especially with respect to the merging of sub-technologies. At Lockheed **(US)** the time-lag between invention (recognition of potential) and the beginning of the actual substantiate phase is usually cut down to a few weeks as a result of flexible (informal) technological forecasting.

In certain areas of research and development, where strong objectives are provided and technological forecasting with **a** pronounced normative component is systematically applied, the time-lag between invention and full-scale development can therefore be expected to be very short.

The fourth time span—***development time—is*** also, though to a lesser degree, sensitive to technological forecasting, which can effect a noticeable reduction simply through more appropriate guidance and concentration of effort.

Development is also dependent, in a manner not clearly understood, **on** the magnitude of the steps taken and the complexity of the systems aimed at. The "giant steps," or "leaps," that have become characteristic of defence developments, are—according to General Electric's **TEMPO** Center —a direct consequence of technological forecasting which sets the goals farther and farther into the future. It is reported that the comprehensive 15-year forecast of the **US** Air Force "Project Forecast," carried out in 1963, became fruitful only after two "idle" years because it provided no ideas that could be tackled right away.

On the other hand, the RAND Corporation's "Delphi" panel on future weapon systems (***lit. ref.*** 269) believed that a drastic reduction of development time could be effected by crash programmes. The majority of the panel thought that, with two exceptions, weapon systems which were not expected to become available until the end of the century could be made available in the 1970's on the assumption of crash programmes. (There were a few systems, however, for which development work was apparently assumed to start later under normal conditions).

Technological forecasting, according to preliminary experience in the United States, has already reduced the development time for a type of small innovations which constitute improvements on known basic technologies. For functional technological systems that are esentially new, the effect is not yet very pronounced—although for many developments in firms with fully integrated technological forecasting and planning functions such an effect can probably be demonstrated. For integrated circuits, Fairchild achieved commercial success in less than three years. In general, the "magic number" of seven years still seems, as in the past two decades, to be a good average for the development time of systems of reasonable complexity. Four to five years is often given for smaller systems and sub-systems. Chemical processes may take three to four years in typical cases. Lead times in the pharmaceutical sector (5-10 years) are increasing in the United States because of more thorough testing. Complex weapon systems take approximately ten years. (The American F-111 multi-purpose aircraft and the B-70 Mach-3 bomber up to prototype; the planned development time of the Swedish "System 37 Viggen" multi-purpose aircraft.)

Cycles of major technological innovations can be clearly distinguished in certain areas characterised by strongly normative thinking. Five-year cycles are mentioned for the aerospace and the electronics sector, ten-year or somewhat longer cycles for nuclear energy. The cycles in the semi-conductor field, for example, may be said to be marked by the following developments:

1st half of the 1950's: Alloy technique.
2nd half of the 1950's: Diffusion technique.
1st half of the 1960's: Integrated circuits.
2nd half of the 1960's: Large-scale integration (1,000 to 10,000 entries).

An average 13-year cycle has been found for telephone exchange technology and is consciously used for planning purposes at A.T. & T. (American Telephone and Telegraph); the semi-electronic switching system of 1965 is expected to be followed about 1975 by integrated circuit technology. This is an interesting example of "lead" times by the "precursive" basic components and circuits technology.

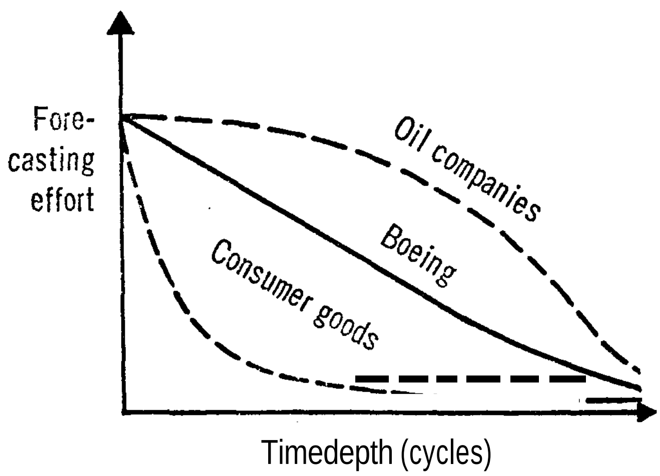
Thinking in development cycles greatly facilitates the tasks of technological forecasting. It provides a time-frame which can be used at a relatively high confidence level, and it "smooths" development. Envelope curves (see section 11.3.3.) represent a systematic application of such thinking.

Development cycles are also a natural basis for structuring technological forecasting. The Boeing Company estimates that it divides up forecasting between development cycles approximately in accordance with the following relationship:

4 cycles	ahead:	**0.5**	per cent	of forecasting	effort
3 »	» :	**3.5**	»	»	»
2 »	» :	**36**	»	»	»
1 »	» :	**60**	»	»	»
		100	per cent		

The Boeing-707 commercial jet aircraft materialised from forecasting that became substantial **2** cycles ahead: its prototype, the Dash-80, was developed in the early 1950's (at a cost of $ 80 million in company risk money), and flew in **1955.**

Boeing's distribution of forecasting effort decreases almost linearly with increase in time-depth. The big oil companies (for example, Esso Research and Engineering in the United States) believe in a more gradual decrease, whereas the bulk of the companies, especially in the consumer-oriented areas, let forecasting drop rapidly with increasing time-depth.



Technological and business acceptance cycles[1] should be in line with development cycles, if forecasting is applied properly to both the technical and the business side. However, they not always are; it has been said that the failure of the European independent computer and aircraft industry to win a larger fraction of the world market is mainly due to a lack of understanding of business cycles in this area. Computer marketing, led by **IBM,** follows a five-year cycle. (Although this could also be interpreted as a development cycle, the normative factors seem to be anchored more to the applications side. IBM's policy calls for the marketing of a new computer generation only when an incentive is created on the market—a subtle modification of strongly normative technological thinking by an exploratory component in marketing.)

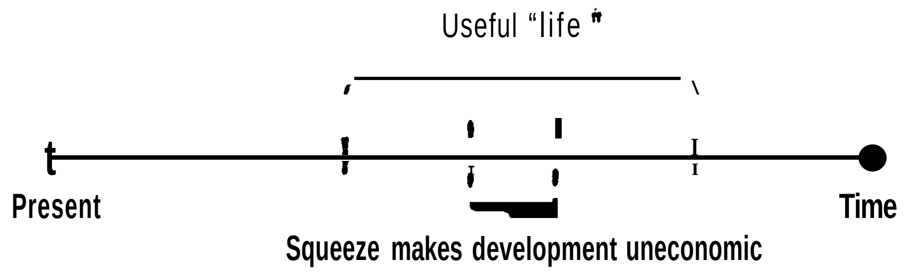
1. Acceptance cycles should not be confused with " business cycles" in the sense in which they are introduced into general economic theory.

Business acceptance cycles in the computer field may be said to be marked by the successive introduction of computer " generations " as follows:

1st half of the **1950's:** Vacuum tube technology.
2nd half of the **1950's:** Semiconductor (printed circuit) technology.
1st half of the **1960's:** Solid logic module technology.
2nd half of the 1960's: Integrated circuit technology.

A business acceptance cycle of more than 10 years is generally assumed for major innovations in the automotive secotor.

Certain technologies may have to be fitted into acceptance cycles of other technological main-streams. The MHD- (magnetohydrodynamic) generator is an example of that: its first application will be limited by the advances of



nuclear energy, which has the potentiality of becoming still more economic over the coming decades. MHD may ultimately be coupled with very-high-temperature gas-cooled reactors, but the present developments will be useful only in connection with fossil fuel power plants and will thus compete with nuclear energy. The British Central Electricity Generating Board **(CEGB)** which, at the beginning of **1966,** still saw the possibility of an ample return on investment for the assessed period of economic MHD application, will conduct technological forecasting in this field over short periods so as to be alerted when the remaining " life time " is further squeezed out by delays in MHD or by unexpected advances in nuclear energy development.

The ***required time-depth*** of technological forecasts depends greatly on the areas and objectives to which they are applied. In general, forecasting is practised to that time-depth which still influences today's decisions. **On** the basis of this criterion, the great differences in the following typical list will be understandable; the indications in brackets refer to more formal forecasts:

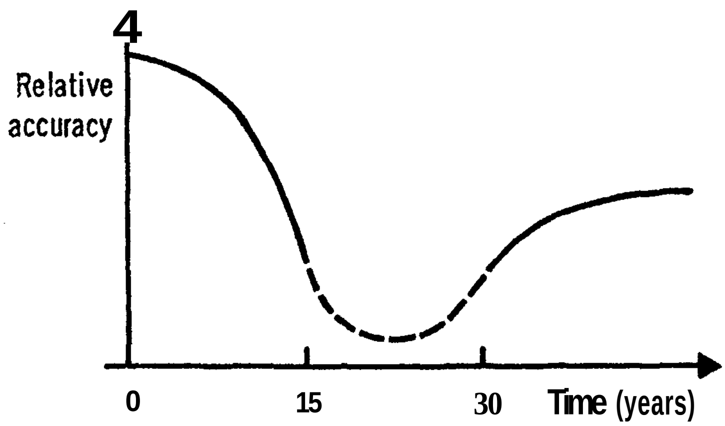
" Social technology," natural resources	up to ***50*** years and beyond
Companies in " social invention " areas (big oil companies, A.T. & T., Xerox, and communication in general)	**30-50** years **(5-10 years)**
Companies active in nuclear energy	**25** years (10 years)
Space Programme (NASA)	**20-30** years and beyond
Defence..	**20-25** years **(7-10** years)
National economy (French Plan).	**20** years **(5** years)

Technical companies of an innovating type (electronics, aerospace, chemistry, etc.) with corporate long-range planning	10-20 years (5 years)
Consumer-type product companies.................	5-10 years (3-5 years)

Some actual forecasting tasks become difficult for the time-frame required. The forecast for the Swedish "System 37 Viggen" aircraft, made in 1953, after the completion of basic studies and before the beginning of early technological studies, had to cover 38 years up to the expected final year of operation, 1991. Technological and tactical developments for this period also had to be forecast for a supposed enemy.

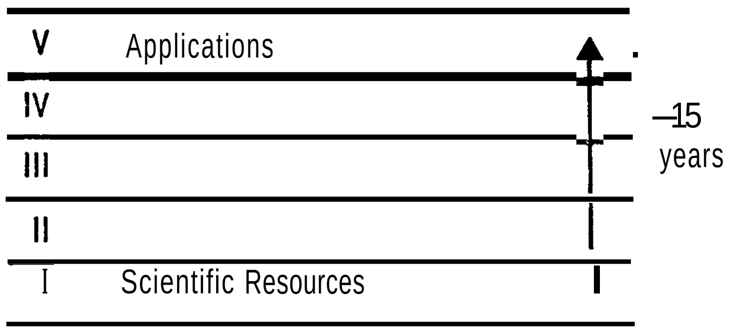
Forecasts for considerable time-depths will, of course, be increasingly vague the farther one penetrates into the future, This is not only natural and inevitable, but it also conforms with the requirements of technological planning. A typical long-range corporate plan covers five years, which is also a typical span for business acceptance cycles. For these five years technological forecasting has to be explicit on many factors: nature, cost, development time, performance, production cost, etc. The six-year span specified for Shell's explicit forecasting ties in with the three years required to build a new plant. Imperial Chemical Limited's (ICI-UK) "turning point" of 10 years is similarly determined. As a forecast penetrates farther into the future, its objectives change increasingly from functional capability to more general technological and economic potentials and limitations, to assessment of resources, to structural changes to be expected, and to general implications in future political, economic and social environments.

The required accuracy of a forecast, in technological terms, is therefore a function of time-depth—perhaps, for the immediate future, not a continuous function, but a step function in accordance with technological and business acceptance cycles. One may therefore attempt to define a "relative accuracy"—the degree of accuracy required for a given time-depth. The experience of the



big oil companies, which try to forecast up to 2,000 A.D. and beyond, can then be reprensented graphically. The "difficult years" are not so much in the distant future (where ultimate potentials and alternatives can be assessed without too much trouble), but those which fall within the 15- to 30-year time-depth range. Methodologically, too, they are the most difficult to explore. Normative forecasting will probably make progress possible in this area.

Generally, efficient technological forecasting of the traditional (mainly exploratory) type is assumed as feasible up to a ***15-year*** time-depth. This is the already mentioned "incubation time" which is assumed by many forecasters and technical managements for scientific discoveries to find large-scale technological application. **A** technological forecast which ideally grasped the potential of all the discoveries yet made would, then, yield a more or less correct description of the applications level of technology transfer



15 years hence. Whatever scientific discoveries were made in this period would still not have been carried beyond the development levels by technology transfer. **A** "sliding" 15-year forecast, annually revised for example, would guarantee a company with this comprehensive insight against being confronted by any surprises.

It should, however, be pointed out here that normative forecasting does not seem to be restricted to any definite time-frame and has the potentiality of stimulating scientific discovery and speeding up its transfer to higher levels. Contextual mapping and morphological research (see sections 11.3.5. and II.3.6. respectively) would be the exploratory techniques that could be rendered most fruitful by providing the elements for such long-range normative forecasting.

Time-independent contextual mapping is quite generally a valuable technique for exploring relationships and sets of conditions required for a given advance outside a time-frame. It is frequently applied by innovating companies.

In the area of "social engineering" concerned with very deep time-frames, and at the same time confronted with great uncertainties, contextual mapping will become a most valuable tool for assessing future situations and anticipations ("possible futures").

Much more understanding will be necessary before technological forecasting is able to introduce factors representing the inertia of a complex technology transfer process, or of our social system in general, and representing the feedback effect of acceleration or deceleration caused by technological forecasting itself.

Chapter 1.4

FUNDAMENTAL RESEARCH AND TECHNOLOGICAL FORECASTING

When the solid outweighs the ornamental, we have boorishness; when the ornamental outweighs the solid, we have superficial smartness. Only from a proper blending of the two will we have a higher type of man.

CONFUCIUS.

The fact that a scientific advance is useful does not make it unscientific.

Glenn T. SEABORG.

1.4.1. SCIENTIFIC TRADITION AND THE PROBLEM OF VALUES

The discussion of values in science is obscured today by a widespread reaction to the utilitarianism which governs a good deal of the relationship between science and technology in the economic area. This reaction is particularly pronounced in part of the Anglo-American scientific community in protest against the psychological theory of value which has found wide diffusion in these countries and postulates the negotiability of values. It has been satirically depicted by W.H. Auden in " Under Which Lyre: A Reactionary Tract for the Times ":

Thou shalt not answer questionnaires
Or quizzes upon world affairs,
Nor with compliance
Take any test. Thou shalt not sit
With statisticians nor commit
A social science.

Paradoxically, the events which contributed most to the " backtracking " of science which can be observed today were those which proved more than anything else that scientific and social concepts can enter into a dialogue: the first dramatic clashes between science and social systems, exemplified in the East by dictatorial intervention in the field of genetic theory and by the rejection of the theory of relativity, and in the West by the schism following the Oppenheimer hearings.[1] The battle for science is now fought between two sharply contrasting strategies which might be characterised as " encapsulation " and " integration," respectively. We shall briefly outline their main features by discussing points advanced by two equally brilliant

1. The preceding banishment, in Hitler Germany, of scientific results achieved by Jewish scientists does not represent a clash between concepts and systems, but a consequence of extreme racial discrimination.

protagonists: Thomas S. Kuhn for " encapsulation," and **R.G.H.** Siu for " integration."[1]

Kuhn (Zit. ref. 10) builds up an ingenious scheme for the ***" encapsulation " ofscience*** by claiming that any more intimate contact with the outside world can only serve to render it sterile. He backs up this view by heavily relying on examples from past Western science. It may be feared that the extension to the future of his conclusions, drawn from the past, will introduce a prejudice, or at least a bias, which will tend to obscure the problems of the future. Kuhn distinguishes two basic forms of scientific advance:

Normal science, which keeps inside the boundaries of established paradigms (conceptual schemes). Paradigms also provide the only (and self-sufficient) criterion for choosing problems: " The scientific enterprise as a whole does from time to time prove useful, open up new territory, display order, and test long-accepted belief. Nevertheless, the individual engaged on a normal research problem is almost never doing any one of these things." Verification, and its reversal, falsification (K.R. Popper), are not used to stimulate the extension or modification of a paradigm, but are applied **only** after anomalies have occurred. This mode of normal science, according to Kuhn, makes scientific activity singularly efficient due to its " unparalleled insulation... from the demands of the laity and everyday life."

Crisis, i.e. the accumulation of anomaly, leads to a scientific revolution by way of competition between alternative paradigms. Kuhn offers no hope that anomalies and the advent of paradigms, or the nature of possible alternative paradigms, can be forecast in any way. **In** fact, he retreats to a " purist " position: " We are all deeply accustomed to seeing science as the one enterprise that draws constantly nearer to some goal set by nature in advance. But need there be any such goal? Can we not account for both science's existence and its success in terms of evolution from the community's state of knowledge at any given time? Does it really help to imagine that there is some one full, objective, true account of nature and that the proper measure of scientific achievement is the extent to which it brings us closer to that ultimate goal? **If** we can learn to substitute evolution-from-what-we-do-knowfor evolution-toward-what-we-wish-to-know, a number of vexing problems may vanish in the process."

Weighing, ***sine ira et studio,*** the consequences of such a thorough " encapsulation " one may arrive at the conclusion that other " vexing problems " could easily vanish at the same time—for example the needs and desires of society, and ultimately, perhaps, the humanistic ideals which Kuhn believes he is defending.

Siu (lit. ref. 16), in developing a scheme for an ***" integration " of science and society,*** proposes to add some elements of Eastern wisdom—the Tao of science—to Western knowledge. He distinguishes between three forms of knowledge[2]:

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1. Alvin M. Weinberg's more rational line of thought has been mostly responsible for the implementation of the " integration " concept; Siu has given the deeper philosophical justification.

2. Siu points out that his three categories have been essentially anticipated by P. Sorokin with his triad: Sensate Truth—Rational Truth—Ideational Truth.

Rational knowledge, comparable to Kuhn's " normal science ";
Intuitive knowledge, roughly equivalent to Kuhn's introduction of alternative paradigms in a state of crisis;
No-knowledge, essentially an Eastern ingredient and the source of " ultimate enlightenment." In concrete scientific research, no-knowledge gives rise to negative strategies which are complementary to positive strategies. Sir George Thomson's notion that the truly basic laws of physical science are principles of impotence (see the following section 1.4.2.) belongs here.

Whereas creativity in research is normally regarded as the extension of rationality, it is, according to Siu, in reality " the fluorescence of no-knowledge."

The introduction of no-knowledge, in Siu's system, is essential for preparing a basis to deal with problems of value in science. He distinguishes between ***intrinsic*** and ***instrumental values.*** Intrinsic values', according to Siu's not quite exhaustive definition, are those desired for themselves; they are, by tradition: goodness, truth, and beauty. Instrumental values lie in the means to something else (money as a means to power, fame, happiness, etc.).

Supplementing Siu's line of thought, one may insert here different views on the general amenability of scientific knowledge to forecasting in a context of intrinsic and instrumental values. Whereas positivism maintains that the real world is a priori unknowable, the Austrian ***Victor Kraft*** (a member of the " Viennese school " of neo-positivism) points out that normative concepts usually also possess descriptive contents (" morally good " implies conformity to moral law, etc.).

The physicist ***P.W. Bridgman*** (***lit. ref. 2,*** quoted by Siu) advances the idea of a pragmatic operational analysis of physical concepts. According to Bridgman, **an** idea can be substantiated only when the conditions of use have been made clear. Terms that cannot be reduced to operations are considered meaningless. This is in line with the general attitude of critical realism which has become an immensely fruitful philosophical concept since World War 11.

Turning back to Siu, the " median way of leadership "—a " shadow of Tao " introduced by the recognition of no-knowledge—may aspire to render science useful to society. The following quotations from Siu, which include some of the incisive argument presented at the beginning of his book, outline his vision of a feasible integration of science and society:

> " Many scientists are on the threshold of emulating theologians of the sixteenth century. Some are beginning to develop a pugnacity that bespeaks a deep uncertainty of brittle pride. Others are transgressing beyond their limited compass of competence. Still others seem not to care a doit that the unitary purpose of culture is being blunted and that the wholeness of meaning and the very tradition of a co-operative society are being disintegrated. If encouraged along the current trends, science may soon reach the point of diminishing usefulness to humanity. To retain her contributing relevance is an important problem of the twentieth century...

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1. Siu's " intrinsic values " are on a more general level than Weinberg's *(lit. ref. 24)* " internal criteria " for scientific choice (ripeness of a field for discovery, availability of good research people). External criteria include scientific merit (impact on other fields of science), technological merit, and social merit.

What modern science is unwittingly doing is alienating intuitive knowledge and no-knowledge, with their attendant negative ways of enlightenment, from man's sensibilities by the imposition of rational knowledge, with its positive tactics, as the final test of reality. Paradoxically, it is precisely in the use of the negative method in this instance—an approach not recognised by science—that the fragmentation of man is engendered by science... Relinquishing the intellectual throne for the life of a commoner is a hard chore for science after three hundred years of free ranging and a hundred years of lordship...

Accordingly (the scientist) tries to contribute to what he considers the maximum of his own capacity by intensive concentration on his own speciality in the natural sciences, leaving it to the social sciences and humanities to effect the humane integration of the laboratory findings into social beneficence. As he observes the use to which his creations have been applied, however, he begins to note how far 'behind' are the social sciences and humanities. He yearns for a 'balance' between the social and the natural sciences. He hopes that the humanities in their progress will discover the answers to the dilemmas engendered by the output of his laboratory. So far his hopes have not been fulfilled. There is little reason to expect that the wide gulf between the independently progressing segments of human knowledge will be lessened by a continuation of this divided outlook on life."

Siu concludes by stating his own view that "the good life for the scientist (is) a stream of overlapping instants of totality in which the advancing infinitesimals of science are assimilated in the human-heartedness of life at all instants of time, in lieu of the current haphazard progression of scientific advances perhaps to be followed by stretches of human-heartedness. In this way, the portentous dilemmas are 'de-existed' before the crises, and faith in the future is restored at all instants of the present."

The situation has already changed somewhat since Siu wrote his flaming appeal less than ten years ago. A new "schism" is developing between scientists around the world, which corresponds precisely to the two concepts of science outlined above, "encapsulation" and "integration."

The majority of the scientists of the Weizmann Institute in Israel—which seems to owe its existence chiefly to the misconception of its founder, the first President of Israel (and a chemist by profession) that one can "sell" pure science—still cling to "encapsulation" in spite of the urgent and evident needs of their country still struggling to survive. Only a handful of scientists, out of a total of 400 at the Institute, have contributed to its income by taking the trouble to apply for patents which could earn licence fees. More than half of the total research effort in Israel is pure, undirected research with little spin-off other than the prestige gained for the young nation (which, of course, has to be valued very highly). C.P. Snow's statement (*lit. ref. 17)* that intellectuals are "natural Luddites[1]" still holds for the bulk of the scientific community, particularly in small countries.

1. The expression "Luddites" refers to organised bands of English rioters demanding the destruction of machinery who made their first appearance in Nottingham in 1811.

An élite among the scientists, however, is gradually adopting an attitude of "integration." If their number is still relatively small, their impact is already felt in many ways (see section 1.4.3. below, especially regarding the COSPUP effort in the United States). In a few outstanding instances natural scientists are even assuming a role of leadership in bringing about an "integration" between the natural and the social sciences by investigating the intrinsic values of their science and by relating them to the broad goals of society—which they usually have to ascertain through their own efforts[1].

For the following sections of this chapter, we retain the notions that:

— it is feasible to apply value judgments to all forms of scientific advance; there are intrinsic and instrumental values connected with fundamental science;

— normative concepts and operational (use-oriented) analysis can be applied to rational knowledge and, in a more intricate form, perhaps also to intuitive knowledge and no-knowledge.

1.4.2. FORECASTING IN THE AREA OF RATIONAL KNOWLEDGE

"Der Herrgott ist raffiniert, aber boshaft ist Er nicht" (The Lord is subtle, but he isn't simply mean)—the truth of Einstein's statement is of basic importance for the performance of fundamental research. It means, as Wiener (*lit. ref. 82)* has emphasised with much weight, that the level of fundamental research is favoured by one condition which holds for no other level traversed in the course of a technology transfer process: The environment of fundamental science and technology does not "react" to man's research, an objective can be pursued by a strategy which does not have to take counter-strategies by Nature into account. Here, and only here, the time factor is not implicit but is introduced by man alone. Forecasting is reduced to the recognition of invariable patterns of objectives, criteria and relationships, and to the assessment of man's capacity to approach them, and of the pace at which this can be done.

In spite of this state of affairs favourable to the inclusion of the fundamental level in technological forecasting, much less attention has thus far been devoted to this area than it deserves. There is no doubt that the "purist" attitude of scientists has acted as an inhibition to treading on their territory.

The incentive to forecasting at the fundamental levels is also enormous from another point of view: any error committed at these levels is reflected in large and expensive failures. Recognition of this incentive has inspired the US Navy to adopt a policy stressing technological forecasting at the fundamental levels. "Scientific opportunities" and "technological capabilities" are two different inputs to the US Navy forecasting system, which are combined at a later stage.

1. Taton *(lit. ref. 18)* points out that this attitude was also characteristic of some of the great French mathematicians of the 19th century: Fourier's belief—that the chief aim of mathematics is its public usefulness and its explanation of natural phenomena—led to a controversy among mathematicians at that time. Poincaré did not pursue a subject because of his mental resourcefulness but because of the needs of science. In giving a triple aim for mathematics—physical, mathematical and esthetic—he insisted that the physical and esthetic aims "are inseparable and (that) the best means of obtaining the one is to look at the other or at least never to lose sight of it."

The absence of normative thinking has been found to render fundamental research quite useless for the purpose of American defense developments (" Project Hindsight," see also section **1.5.4.** below).

Nuclear energy is a most striking example of a step-wise development of fundamental knowledge whose consequences were not seen by most people involved until a strong normative factor became effective. The main prerequisites for a nuclear fission chain reaction, and the forecasts parallel to their attainment, can be compared as follows:

PREREQUISITE	FORECAST
1. **Mass** defect, exogenous for fission of heavy nuclei.	
1905 - Mass/energy equivalence (Einstein).	
1911 - composite structure of nucleus (Rutherford).	**911/12 -** Soddy, **1912 -** Gustave Le **Bon** : " interatomic energy -- forecast in general terms.
Mid - 1920's — correct mass defect curve by F. W. Aston.	**920's -** various general forecasts grasping the potentials of both fission and fusion (for example, Andrade in 1927).
2. Electrically neutral particle (neutron) to penetrate through Coulomb barrier at low velocity.	
1924 - neutron predicted by Rutherford and Chadwick on scientific grounds.	
	930 - fusion forecast at correct energy level by Eddington by analogy with astrophysics; required temperature indicated almost correctly **(20** instead of **100** million °**K**).
	930 - Earl of Birkenhead assesses great potential for the " world of **2030 A.D.**"
	larly **1930's -** correct assessment of fission and fusion with mass defect calculation **by** S. Dushman.
1932 - neutron found by Chadwick.	**932/33 -** numerous informal forecasts by scientists recognising the potential role of the neutron in a chain reaction.
	933 - Rutherford ridicules the idea of harnessing nuclear energy.
	935 - Joliot-Curie, in his Nobel Prize lecture, gives serious attention to nuclear fission and the potentially great impact.
	935 - Szilard takes a patent on the fission of lithium (a light element, which can undergo fission only in an endogenous reaction).
	935 - Joliot-Curie and others take a patent on the moderator principle.
	936 - Furnas cautions on expectations regarding application.
3. Demonstration of nuclear fission.	
Dec. 1938 - Hahn/Strassmann experiment	
Jan. 1939 - announcement of results of Hahn/Strassmann experiment, shortly afterwards correct interpretation by Meitner/Frisch with correct prediction of energy release.	**939 -** after Meitner/Frisch interpretation, quick recognition of war potential by scientists exiled from Germany. Szilard, within a week, urges withholding of publication.
	939 - Nuclear reactor patent by Fermi and Szilard.

PREREQUISITE	FORECAST
4. Sufficient neutron yield to maintain chain reaction.	Strongly normative forecasts by Szilard and Joliot-Curie indicate crucial importance of this step.
March 1939-Szilard and Zinn find 2.3 neutron yield from U-235 fission (only 10 per cent wrong); Joliot-Curie, Halban, Kowarski make independent experiment	Beginning of 1939 - clear recognition of war potential by Szilard, Teller, and others, pointed out in letter by Einstein to President Roosevelt. Immediate start of exploratory development.
5. Delayed neutron fraction for reactor control; material factors (nuclear grade graphite, etc.).	Large-scale work since 1940, selection of alternative ways to achieve fission explosion (U-235 by gaseous diffusion and by mass spectrography, Pu-239 by reactor development) because chain reaction can be forecast only in a probabilistic way. Early 1940's - Scientists dream of simple, cheap reactor concepts—"a pot, a pipe and a pump."
May 1942 - Fermi obtains proof that controllable chain reaction is feasible. Dec. 1942 - Chain reaction achieved.	

In this parallel development of forecasts and accomplishments three factors can be held responsible for the absence of a clear forecast before the third step had been achieved:

The pattern of assured scientific knowledge was not systematically evaluated. The early calculation of a correct mass defect curve was ignored by most of the forecasts, which used to indicate an energy yield of approximately 0.01 mass equivalent (characteristic for fusion) instead of 0.001 for fission, and believed in the fission of light elements (hydrogen, lithium, etc.)—even Szilard made this mistake in **1935.** The early recognition of the potential role of the neutron in a chain reaction was also soon forgotten.

The sharply negative attitude of Rutherford, the "pope" of nuclear physics at that time, influenced many scientists; Rutherford apparently was preoccupied by the idea of an external neutron source which was (and is) not available for economic application and "repressed" the idea of a chain reaction.

The absence of normative thinking was reflected in the lack of focus on research up to the proven feasibility of step **3.** Fermi, for example, never went further, in some exploratory forecasting thoughts, than to foresee minor applications of the transformation of elements in producing radioactive tracers for medical purposes, etc[1]. **It** was only the demonstration of fission that produced a very rapid inception of normative forecasting, which, in turn, almost instantly "triggered" the decisive experiments to prove the feasilibity of step **4.** Normative forecasting then became powerful enough to justify an enormous research effort for three years until a probabilistic forecast finally hardened to prediction.

1. Mrs. Laura Fermi confirms this.

Among the scientists who were subsequently to become associated with the breakthrough and the early developments in nuclear energy, the only one who distrusted the authority of Rutherford, and risked his reputation by contradicting him on the occasion of his Nobel Prize lecture, was Joliot-Curie, an ambitious and worldly man who was always fascinated by the prospect of big impact.

The state of fundamental science and technology in certain areas amounts to an ***enforced absence of normative forecasting.*** The foremost example here is the pharmaceutical sector. Its usual mode of advance is highly empirical in the first phases. For example, a company may get a " lead " by making drugs empirically from animal organs and finding that all hormones so produced are steroids. The next step would then be to attempt the synthetic or semi-synthetic production of **a** similar spectrum of steroids. Eventually, effects will be empirically related to chemical structure. Only at this stage can technological forecasting become meaningful, and lead to " tailor-made " and perhaps specific products. Knowledge of how drugs act is still limited to very few. This highly empirical process is reflected in the useful yield of research and development: only one or two out of 3,000 chemical compounds developed and tested lead to a marketed drug.

There is a strong tendency today among scientists to seek to improve this situation and to apply the results of molecular biology to the foundation of a rational pharmacology. The derivation of objectives for such an undertaking is obviously a matter of normative technological forecasting. **A** similar effort was suggested in **1963** by the President of the **US** National Academy of Sciences, F. Seitz, with a view to turning ceramics from a hopelessly empirical into a more rational field of fundamental technology; the important advances of solid state theory have almost exclusively benefited metals and semi-conductors, leaving ceramics and other fields far behind.

Union Carbide has adopted a policy of re-examining traditional " horribly empirical " production processes and of trying to derive the objectives and the potentialities for a more scientific approach. Nuclear-grade graphite, for example, has long been made by a process that takes **9** months —and nobody changed it, because "everybody did it."

The **US** National Academy of Sciences - National Research Council established in **1958** a Materials Advisory Board which assessed " communalities " and research objectives on the basis of a mission/materials matrix —a typical normative forecasting approach—in order to define and focus research on materials, mainly for defense purposes. This survey is periodically updated by the Board, the second such updating having taken place in **1965.**

In the United States today, the attitude of industry in advanced research fields can often be expressed as " Get an idea and find the guy to invent it." United Aircraft, for example, tries to generate new programmes in exploratory research by normative technological forecasting. The pharmaceutical industry, hampered by the empirical state of its fundamental technology, nevertheless tries to apply normative forecasting on the applications side, by asking whether the end-point is clear or not; if, for example, the end-point is very foggy in asthma, the pharmaceutical industry decides to become active in asthma research.

One **of** the most advanced approaches to fundamental technology is represented by Honeywell's application of its elaborate normative forecasting technique PATTERN (see section II.4.5.)—developed for aerospace products—to the medical area in order to define and focus fundamental research and applied development in medical electronics. This has revolutionised Honeywell's programme in that field.

A basic and most fruitful task of technological forecasting is the ***assessment of fundamental potentials and limitations.*** **A** detailed discussion of this aspect, and practical examples of very far-reaching consequences, will be given in section 11.3.3. in connection with techniques aiming at the extrapolation of time-series of technological parameters or functional capabilities. The assessment of basic potentials by comparison with nature—outdoing nature or imitating nature—is an important version of this task, and may become particularly so in connection with molecular biology and its possible impact. Although the ways of technics have often widely deviated from the ways of nature—the wheel, the propeller, power engineering, etc.—there seem to be important areas where lessons can be learned from nature, for example in information technology (coding, cybernetics, recognition mechanisms, etc.) and also in thermodynamics (optimised natural processes) and other areas.

In companies that are advanced in their thinking, normative technological forecasting is being applied more and more systematically to the fundamental science and technology level in an effort to define the requirements and to assess alternative ways of meeting then. How such a forecast proceeds may be illustrated by an example from Lockheed **(US):** Organic superconductors could be feasible at room temperature. The theoretical requirement for this is clear—the minimum number of electron levels. Research is now under way to investigate the possibility of making organic superconductors biologically by finding the right enzyme for satisfying the theoretical requirement.

Few ultimate potentials can be assessed in an absolute way. The British physicist, and Nobel Prize winner, Sir George Thomson ***(lit. ref. 283)*** tried to assess ultimate potentials by deriving them from principles of impotence, i.e. laws which are statements of the principles of nature that cannot be violated (for example, the laws of conservation of mass and energy say that any interchange between the two follows a strict mathematical relationship). He advances the thesis that the truly basic laws of physical science are such principles of impotence—a Western version of Siu's no-knowledge mentioned in the preceding section, 1.4.1.

Ultimate potentials, not rigorously assessed, often prove to be too conservative—an experience confirmed by many companies, for example IBM. It can be expected that much fundamental research will be devoted in the future to improving the recognition of limitations and ultimate potentials. One may even venture to predict that technological forecasting will be largely instrumental in determining fundamental research in the near future, and that the requirement of more and better fundamental knowledge as input to technological forecasting will give rise to a considerable increase in the share of total effort devoted to fundamental research. Both the nature and the volume of fundamental research will be revolutionised by the systematic use of refined technological forecasting.

This trend is already becoming visible in companies with sophisticated management attitudes. It is expressly confirmed by the Xerox Corporation. This company has committed half of its coming five-year research budget, amounting to a total of $ 500 million, to advanced new products which will not come out until five years after the inception of research; a substantial fraction of this sum is devoted to research in fundamental science and technology in an attempt to provide the answers to the basic questions systematically derived from normative technological forecasting.

1.4.3. THE INTRINSIC VALUES OF SCIENCE AND SOCIAL GOALS

The attitude of " pure " scientists has already been discussed in section 1.4.1. and criticised in Siu's pointed remarks. One may add here that a significant change is already reflected in the response of scientists to attempts to use their expert judgment to assess national programmes. The French scientists, after refusing for five years to name their " options " for government-supported fundamental research, finally complied with the government requests two or three years ago and are now happy with this procedure. In the United States, one was even able to observe an attempt by a former field of fundamental science—oceanography—to cater for " social recognition" by assessing a future dollar value of investments in research (*lit. ref.* ***348).***

A most important start in the direction of **a** future "integration" of fundamental physical research and the broad social environment has been made by the *Committee on Science and* ***Public*** *Policy* ***(COSPUP)*** of the **US** National Academy of Sciences - National Research Council, initiated in 1964 by Kistiakowsky and now chaired by Harvey Brooks. Similar ideas in this direction, contained in the final report **of** the British Advisory Council on Science Policy in **1964,** chaired by Lord Todd *(Zit.* ***ref. 240)*** do not yet show any signs of materialising.

The **COSPUP** effort aims at a thorough review of the sectors of fundamental science in order to give a picture of the state of the art and of trends into the future with emphasis on intrinsic values. The committees for the individual sectors arc composed of renowned scientists who often give up research for two years to devote much of their time to COSPUP, which thoroughly screens their reports. The input reports, prepared by individual scientist panels, contain more explicit technological forecasting.

The " Reports on the Subfields of Physics " (*lit.* ***ref.*** 22) representing the input to the Physics Survey may serve as an illustrative example of the systematic and ambitious approach taken. Individual panels on eight sub-fields, with many world-famous scientists participating (sometimes sitting on more than one panel), compiled precise background material and undertook to establish consensus among themselves on such issues as the following (arbitrarily chosen from headings in the individual chapters):

Manpower;
Financial support;
Distribution of activity;
Present and future status of the field;
The future programme: assignment of priorities, recommendations, etc.;
Substantive questions and unanswered questions;
Modes of attack and levels of understanding;
New tools;
Opportunities presented;

Influence on concepts in other scientific areas;
Influence on techniques in other scientific areas;
Impact on technology, applications, etc.;
Intrinsic scientific interest;
Educational problems;
Relation to the industrial economy and to defence; opportunities and problems for industry and physics;
Manpower requirements for the next five years;
Manpower forecasts for five- and ten- years time-depth.

These headings reflect the conscious application of both types of Weinberg's (*lit. ref. 24*) criteria for scientific choice—" internal " and " external " criteria—and comprehensively circumscribe the areas of fundamental science in which exploratory and normative technological forecasting—one will notice the careful blending in the above headings—can be usefully applied. The high quality of the answers presented renders invalid any statement that fundamental science ought to be kept outside forecasting efforts and that scientific results should be gratefully received without asking questions which look to the future. However, the material presented in this first " round " of reports is generally not, at this point, treated in sufficient detail to become a guideline for other than science policy problems.

The COSPUP reports which had become available by spring 1966 concern the following fields (the name in brackets is that of the chairman of the sectoral committee, frequently used as an abbreviated designation of the report): Astronomy facilities (Whitford), Chemistry (Westheimer - *lit. ref. 21*), Computers in Universities (Rasser), Physics (Pake), Plant Sciences (Thimann); in preparation are the reports on Mathematics, Pure and Applied (Bers), Life Sciences (Handler), and Behavioral Sciences (Pfaffmann). The first two input reports (*lit. ref. 22, 23*), published in spring 1966, were in the fields of Physics and Theoretical Chemistry (one of the input reports to the Westheimer report); the rest will follow at short intervals.

Other reports originating from National Academy of Sciences committees and having a bearing on the " integration " of fundamental science and social goals dealt with the following fields: Oceanography (1958, 1966 and the much-criticised report on economic benefits from oceanographic research —*lit. ref. 348*—in 1964), Solid Earth Geophysics, Water, Pollution.

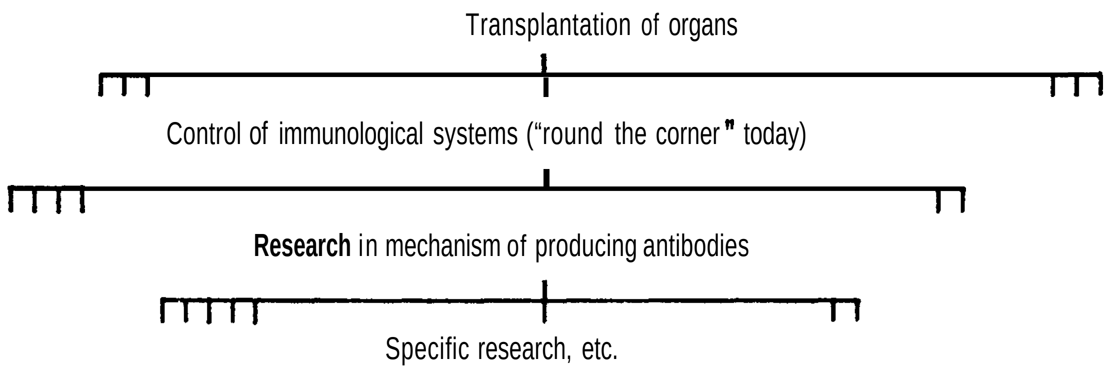
In connection with COSPUP and its high aims, the National Academy of Sciences is also planning to make a serious effort for the assessment of criteria for fundamental research in a social context. The collection of articles on basic research and social goals (*lit. ref. 20*), published in 1965, constitutes an initial exploration of this difficult area. The revolutionary undertaking of COSPUP, and the leadership assumed by a body of the highest scientific competence and ethical standing may well be regarded as the most significant development in fundamental science since its " emancipation " in the first half of our century. COSPUP could also become the nucleus for serious studies of the problem in other countries; the painstaking scientific work represented by the COSPUP reports could serve as universal background for the assessment of problems of a national or regional order.

Criteria for fundamental science, often mentioned today by people concerned with this issue, are derived from such considerations as the achievement of an equal degree of sophistication in all fundamental sciences—believed to be important for the continuous growth of science and technology—and, perhaps above all, the support of fields where the devoted people are. The latter consideration today points strongly to high energy physics, which is also the field where the unknown enters most dramatically in the form of " signals" and effects (such as the Lamb shift) reaching us from the void. " Quantum electrodynamics is today more fantastic than any vision by religious prophets," remarks **J.** Ackeret.

Normative technological forecasting starting from social requirements is capable of applying spur and guidance to fundamental research in areas of social relevance in the same way as they are applied by industry in the economic area (see the preceding section, **1.4.2.).**

One of the most burning of social questions, the cure of cancer, has never been investigated as systematically or thoroughly as it deserves. Gabor suggests that " a thorough scrutiny be made of all physical methods which have not been applied to cancer research (examples: microspectrography of cells by Fourier spectrograph and by holography methods)." Perutz suggests that cancer might be due to the loss of an inhibitive mechanism regarding the division of cells; the fundamental problem would then concern recognition devices between cells, an area which is now gradually becoming better known.

The relevance tree technique (see section II.4.5.), recently introduced with striking success to normative technological forecasting in the technical area (and also to the field of medical electronics) can become a most powerful tool in the systematic assessment of possible solutions to important social problems. An example for a relevance assessment is suggested by Bronowski:



In terms of a general undertaking, Bronowski proposed that the biological future should be translated into structural terms. He also suggests the formation of a committee of top scientists which could meet periodically and guide the construction **of** relevance trees for various goals and perhaps arrive at a consensus for the weight numbers and significance numbers which are to be estimated (for a detailed description of relevance tree techniques, especially Honeywell's PATTERN, see section **11.4.5.).**

As for the technical fields, normative forecasting by relevance tree techniques could be matched by morphological research (see section **11.3.6.)** which attempts to enumerate all possible combinations of functional parameters, i.e. all possible ways of providing a technological solution to a given problem. Morphological research could be adapted to non-technical areas and to all levels of technology transfer, including the impact and goal levels, although this might involve considerable modification in each specific case.

As normative forecasting techniques are beginning to revolutionise technical development, a tremendous impact could also be expected from their application to social issues. The techniques for facilitating the " integration " of fundamental science and technology with the real world of social needs and desires are becoming available now—all that is needed to apply them **is** a change in the attitude which negates ***a priori*** the possibility of such **an** integration.

I.4.4. CONCLUSIONS

Three most important general conclusions have been drawn in this chapter:

- Technological forecasting including a strong normative component will increasingly determine the nature and the growth in volume of fundamental research; the latter, in turn, will supply the answers to the questions concerning ultimate potentials and limitations that technological forecasting will put to fundamental research;
- The attitudes and techniques **of** technological forecasting, especially the relevance tree techniques for normative forecasting, are applicable to the stimulation and guidance of fundamental research contributing to social goals;
- The COSPUP effort in the United States could become the nucleus of related efforts in other countries or regions to assess the potential of fundamental science in relation to broad social goals and to focus fundamental research accordingly.

Chapter 1.5

TECHNOLOGICAL INNOVATION AND TECHNOLOGICAL FORECASTING

The history of scientific and technical discovery teaches us that the human race is poor in independent thinking and creative imagination, Even when the external and scientific requirements for the birth of an idea have long been there, it generally needs an external stimulus to make it actually happen; man has, so to speak, to stumble right up against the thing before the idea comes.

Albert EINSTEIN.

1.5.1. GENERAL CONDITIONS FOR TECHNOLOGICAL INNOVATION

The intricate mechanisms by which technological innovation is effected are only now becoming better understood in terms of vertical and horizontal technology transfer. Still less is known about the factors which set these mechanisms in motion. The approach that has been made to the study of these problems in the United States for the past twenty years—through case studies and the attempt to proceed from the specific to the more general, from micro-economic to macro-economic factors—is the most painstaking, and also the only valid one. A few important statements are now possible which do not conform with more traditional, ill-founded beliefs. They reveal where the essential functions of technological forecasting in stimulating and guiding innovation have to be looked for.[1]

Since the end of World War 11, a continuous research programme—summed **up** for every decade—has served, in an informal way, to inspire American economists in this field of study to concentrate their efforts. Three " rounds " may be distinguished, although not officially connected with each other:

1. Research in the **1940's,** summed up at the " Conference on Quantitative Description **of** Technological Change," sponsored by the Social Service Research Council Committees on Economic Growth and on Social Implications of Atomic Energy and Technological Change, **6-8** April **1951,** Princeton, New Jersey. The proceedings of this conference have been published.
2. Research in the **1950's,** mainly around **1956,** summed up at the conference on "The Rate and Direction of Inventive Activity - Economic and Social Factors," sponsored by the Universities-National Bureau Committee for Economic Research, in **1960,** Minneapolis, Minnesota. Papers and discussions are published in the **book:** " The Rate and Direction of Inventive Activity " (*lit. ref. 65).*

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1. **Unfortunately, a typology of technological innovation apparently has not been attempted so far.**

3. Research in the 1960's, carried out within the framework of the "Inter-University Research Program on the Micro-economics of Technological Change and Economic Growth," financed by the Ford Foundation. The "steering committee" of the Program is composed of the following economists: J. Markham (Princeton University, in 1966 temporarily at Harvard University, informal chairman), Z. Griliches (University of Chicago), E. Mansfield (University of Pennsylvania), R. Nelson (RAND Corporation), F. Scherer (Princeton University). Present emphasis is on the diffusion of new technology (an interim meeting in March 1966 included papers on the diffusion of the Austrian LD process—the most widely used basic oxygen steel process—and of computer technology).

A number of recent surveys attempted to derive, through statistical procedures, the basic conditions which favour technological innovation. At least two of these surveys found a strikingly uniform pattern:

1. General Electric's TEMPO Center for Advanced Studies, on the basis of 75 important technological innovations in the 20th century, discerned the following factors:
   - Purposeful nature of the innovator (most important);
   - Availability of a financial source;
   - Existence of an information base (sometimes causing multiple invention);
   - Learning, a factor which seems to favour outsiders who learn about the field;
   - Accidental factors, which contributed in a marginal way only in most cases.
2. Arthur D. Little, in a study (*lit. ref. 44)* of six weapon systems involving 87 "research and exploratory development events," found the following factors to have been most important:
   - A clearly formulated need;
   - Availability of resources to be committed ***at once*** (a delay of even one to two months has been found to have a discouraging effect—people stop producing ideas—and a six-month delay proves to be a terrible burden);
   - An experienced body of people.

A study by the National Planning Association, Washington, aimed at evaluating ideas, motivation, and sources for 80 recent innovations in six US companies, is in progress in 1966-67. The preliminary results indicate a complex pattern.

A study of the 19th century industrial revolution has recently shown[1] that the inherent basic laws governing innovation have not changed over time. The revolution did not take place in France, where the science was, but in Great Britain where the favourable conditions existed:

Entrepreneurial spirit;
Mobile labour supply;
A good communication system;
A liberal political system;
A market.

1. At the conference held on the occasion of the Hanover Technical Fair (Fed. Republic of Germany) in April 1966; the precise reference is not known by the author.

The socio-economic context of technological innovation has expanded ever since. This is now becoming apparent in the " second industrial revolution " (automation) in which the United States is leading (not Europe, where the science was).

The first place in each of these evaluations is occupied by a factor which implies strong normative thinking[1]. There is a common misunderstanding in Europe about this, sometimes reflected in the laconic phrase: " America has finders, not seekers. "

The relevance to innovation of the normative component in technological forecasting, which puts greater emphasis on the human qualities and on self-motivation, will be discussed in greater detail in section 1.5.3. below.

The problem of resources has come to the foreground during the past 25 years, a period in which the opportunities for innovation overtook the financial and manpower resources and the necessity of choice became a problem of the first order. According to the McGraw-Hill survey on American industrial research and development in 1965 and 1966 (*lit. ref. 54*), mentioned in Chapter I.2., two-thirds of industry as a whole considered financial and manpower constraints as the major obstacle to more research and development.

The increasing complexity of new technological systems is reflected in the size of the financial resources required:

More than $ 1 billion for complex weapon systems ($ 1.2 billion for the development of the two B-70 Mach-3 bomber prototypes, etc.), for space developments, and for some publicly supported civilian developments ($ 2 billion are globally committed, as of 1966, to the development of fast reactors);

An upper limit close to $ 1 billion for major developments by one company, with private risk money (Boeing-707 commercial jet aircraft reportedly $ 700 million, IBM-360 computer family with solid logic technology indicated to lie between $ 400 and $ 700 million, etc.);

A lower limit of approximately $ 1 million for the initial phase of most technological innovations today;

An " initiation fee " to be invested in creating conditions of highly specialised technological development (dust- and vibration-free laboratory rooms, etc.—estimated to amount to at least $ 2 million for integrated circuits).

The specific research and development expenditures per quantifiable innovation output, also tend to increase. In the pharmaceutical sector in the US, mainly as a result of legislation, research and development expenditures have increased linearly in the past, whereas new drug approvals have shown a continuous decrease, and the number of drugs marketed fell sharply between 1960 and 1965. Another important factor here is increasing competition.

The rise in both the upper and the lower limit of resources required for innovation in civilian technological areas today is creating new approaches:

Developments near the upper limit of the capacity of companies and private risk investment (variable according to country and technological field) are supported by public funds (supersonic transport

1. Normative thinking, as shown by Russia, can also be successful when derived from dictatorial incentives.

in the **US** and in France/UK, national nuclear energy programmes in a number of countries, etc.); soon public support on a large scale may also be generally extended to civilian developments in key technological areas, either by civilian development contracts or **in** a manner similar to the functioning of the British NRDC;

Developments surpassing the capacity of small companies or originating in universities, etc., acquired by holding companies—usually together with the originating company (in the United States, Litton Industries, Textron, Standard Oil of Ohio, and, in a modified form, American Research and Development Corporation; in Sweden, Incentive A.B.);

Developments surpassing the capacity of individual inventors are taken over, either by acquisition or by profit-sharing agreement, by companies with a corresponding growth and diversification policy (Union Carbide **in** the United States, expected to be followed soon by Ford Motor Co.); this approach partly replaces the traditional scheme represented by the Small Business Investment Companies, which are not in a position to deal with initial-phase expenditures which may now amount to about $ 1 million (out of the 900 SBIC's in the United States, only three have a capital of $10 million or more).

The general constraints on resources have already proven to be instrumental in the development of a function of technological forecasting which is usually referred to as "ranking of research and development projetcs," and for which a number of simple techniques have been developed (see Part II **of** this report, especially sections II.3.10, II.4.3., and 11.4.4.).

I.5.2. THE RATE OF INNOVATION IN INDUSTRIAL SECTORS

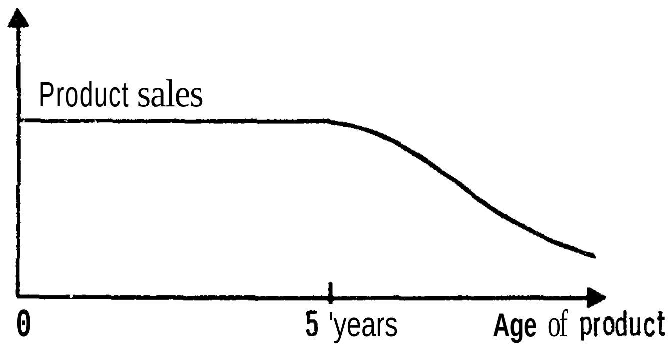
Adapting McGraw-Hill surveys ***(lit. ref. 54)***, the average ***annual rate*** of innovation in sectors of US industry may be indicated on the basis **of** the sales value of products which are new in nature and new on the market:

Per cent.

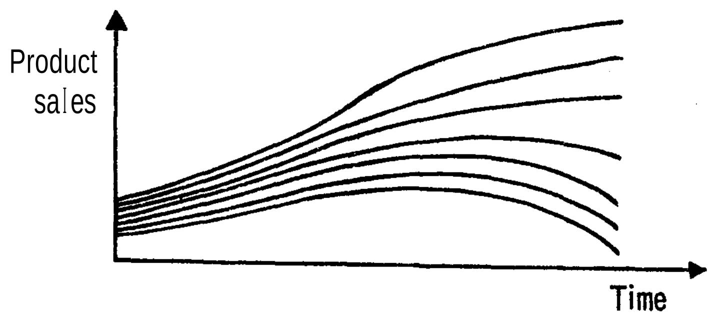
	1961-1965	1966-1969 (planned)
Autos, Trucks, and Parts	2.5	5.5
Aerospace		10.0
Other Transport Equipment (ships, railroad equipment)		5.8
Electrical Machinery		6.0
Other Machinery		5.8
Chemicals		4.5
Stone, Clay, and Glass	3.3	4.3
Fabricated Metals and Instruments	4.5	4.3
Textiles	3.3	3.3
Food and Beverages	3.0	2.8
Paper and Pulp	2.5	1.8
Nonferrous Metals	2.3	2.3
Petroleum and Coal Products	1.5	1.3
Rubber	1.5	1.0
All Other Industries	2.3	1.5
Total U.S. Industry	3.5	3.75

These are average figures for the whole US economy. Companies **of** an innovating type can surpass these figures considerably. There are examples of electronics and instrument companies whose average annual rate of innovation is close to **20** per cent.

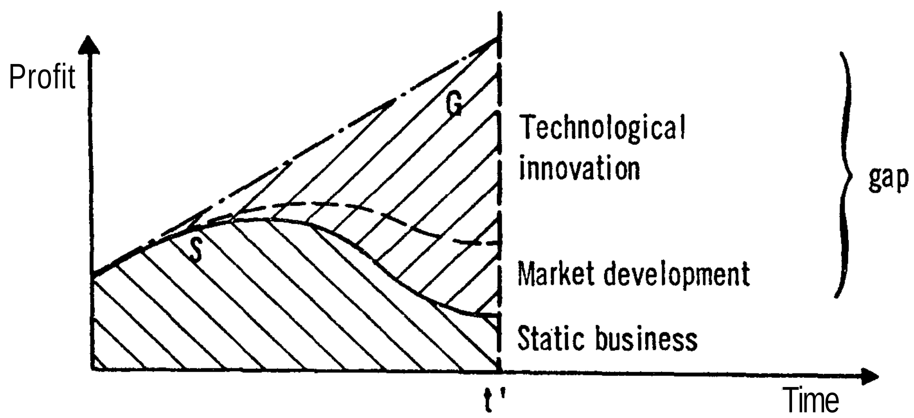
Today one often finds a more or less equal distribution function for products up to approximately five to eight years of age. Where marked technological or business acceptance cycles dominate the products of a company, they will strongly influence the distribution over age.



At individual company level, the incentive to rapid innovation is also felt in the form of a feed-back effect from the overall dynamic process. The market lives of typical technological products show sales maxima at different



time spans after introduction. The resulting total profit curve, without innovation, will decline after a short rise, whereas the specific company potential, including technological innovation, and market development, may lead



to a linear increase in profit. The Stanford Research Institute, in an evaluation of client companies (of which 10 per cent have applied "gap analysis" since 1963, as recommended by the Stanford Research Institute), found as an empirical relationship that the area S for the accumulated profit from static business equals the "gap" area G at approximately $t' = 7$ to 10 years for typical sophisticated companies in somewhat less sophisticated environments.

The rapid rate of innovation has created a climate of confidence, perhaps enhanced by technological forecasting, which is reflected in the answer given in the spring of 1966 to the McGraw-Hill survey *(cit. ref. 54)* question, "Do you anticipate a technological or basic research breakthrough in or for your major field by 1969?":

	AFFIRMATIVE *(Per cent)*	PERCENTAGE EXPECTED TO OCCUR IN: BASIC RESEARCH	NEW PRODUCTS	PROCESSING
Petroleum and Coal Products	69	—	14	86
Rubber	50	34	33	33
Instruments	50	—	100	—
Chemicals	48	8	67	25
Aerospace	40	20	40	40
Stone, Clay, and Glass	38	10	50	40
Electrical Machinery	31	20	60	20
Iron and Steel	30	—	—	100
Textiles and Apparel	29	12	13	75
Autos and Other Transport Equipment	24	—	29	71
Paper and Pulp	24	20	—	80
Food and Beverages	23	10	30	60
Fabricated Metals	20	—	—	100
Nonferrous Metals	19	—	33	67
Non-electric Machinery	18	12	65	23
All Other Industries	24	—	41	59
Total U.S. Industry	28	8	41	51

This list is an impressive testimony of confidence in the substantial contribution of vertical technology transfer towards filling the "gap."

The influence of national programmes, especially defence and space, in accelerating the rate of innovation in such sectors as aerospace, instruments, etc., is obvious. Less explicit, but—in spite of all statements to the contrary—very important, is the effect of "spin-off" from national programmes; it becomes visible not only as hardware "spin-off" but—most important—as a general "pace-setting" effect.

It is evident that technological forecasting can contribute significantly to filling the "gaps" continuously created in industrial sectors with a high rate of innovation.

A big electronics company, setting a \$ 1 billion growth goal for 10 years time-depth, recognised a \$ 300 million "gap" for which no programmes were yet identified. Consequently, formal technological forecasting was established and resulted in enough programmes being underway after three years for the goal to be exceeded by \$ 300 million.

Similarly, the Xerox Corporation in Rochester, New York, expects integrated technological forecasting and planning to fill a $ 1 billion gap in its $ 2 billion goal for 1975.

More important than a " gap " in sales growth is the " gap " to be filled in net income (profit). In general, new technologies have been found to be more effective in this direction than the marginal improvement of existing technology in markets already characterised by tight competition.

1.5.3. NORMATIVE FACTORS IN TECHNOLOGICAL INNOVATION

The predominant importance of normative thinking in effecting technological innovation has already been pointed out in section 1.5.1. An attempt is made to group in the matrix below a number of important normative factors which contribute to this end:

AREA	HEDGE AGAINST THREAT	MAINTENANCE OF POSITION	CHALLENGE
Military	**Enemy technology**	**Effectiveness**	**Leadership**
Economic.....	**Competition**	**Independence, average growth**	**Entrepreneurship, competence**
Social	**Disequilibrium**	**Conservation**	**Worthwhile adventure**

If it were not for the exploration of space (considered in its aspect of worthwhile adventure) one could say that today the stimulus provided by the normative factors generally decreases from the upper left to the lower right corner of the matrix. This may be interpreted as an indication of how small is the extent to which we are as yet capable of mastering our fate and of how large that to which it masters us.

Under the powerful effect of ***threats,*** for example, may be mentioned the investigations which led to the general conclusion that oligopoly is more conducive to innovation than monopoly (see, for example, the investigation of the postwar American aluminium industry in ***lit. ref. 59).*** The reasons are self-evident. The competition which exists between technologies and entire industrial sectors and which dominates the energy field today may also be included.

Threats in the area of military technology have always proved a most effective means of bringing about technological innovation with immeasurable consequences also for the civilian sector. The well-known case **of** nuclear energy has already been mentioned in Chapter 1.2. Radar is another striking example which will serve to illustrate this point.

Radar literally had to be invented twice (see, for example, ***lit. ref. 58)*** because the normative factor which could have spurred development following the first invention was lacking. The first demonstration of the reflection of radio waves by metallic objects was made by H. Hertz in 1887, and a speech by Marconi in 1922 suggested the use of beamed very high frequency radio waves to detect ships in darkness and fog. The chain of events that ultimately led to radar started in **1922** when Taylor and Young in the United States discovered the possibility of detecting moving ships by radio and suggested to superiors of the **US** Navy that high frequency transmitters and receivers be put on ships so that any two vessels could be alerted if a third passed between them. Radar in a useful form was invented for the first time in **1930,** by Hyland and (the same) Young of the **US** Navy, after they discovered the detection **of** aircraft by radio, and the idea of pulse-radar was conceived almost instantly. The idea died, due to the lack of an incentive[1] powerful enough to pursue it. This incentive was present four lears later, in **1934,** when pulse-radar was reinvented in the United States by Taylor and Young (again the discoverers of **1922),** and in the United Kingdom by Watson-Watt who proposed it to the Committee for the Scientific Survey of Air Defense at the beginning of **1935.** The incentive was the growing threat of a war with Germany. It is interesting to note that the objective set for a technological forecast by the British committee was the investigation of the possibility of death-rays; the task of directing energy was not found feasible for this mission, but led to the recognition of the radar potential. It is equally significant that Gôring in Germany rejected the idea of radar when it was brought to his attention in **1934,** reportedly on the grounds that it was purely a home defence device.

Disequilibria threatening the social area include over-population, crime, unemployment, increasing leisure and tension in general.

Food technology is another example of a field of innovation which has **long** been dominated by the thought of ***maintaining a position*** in the military area. **As** far back as the Second Empire, a prize was offered by Napoleon III for food conservation by sterilisation with a view to improving the army's food supply. (The solution, although found in France, was then industrialised in Great Britain.) Food technology, in the broad sense of the term, sprang from inadequate food logistics in World War I. **An** example of developments in this area prompted by World War II is instant coffee: Liebig had already attempted it in **1866-67** (in the form of a syrup), Japanese developments in **1905** were based on carbohydrates as carrier, and the Nestlé patents **for** instant coffee, in the contemporary sense, were taken out in **1935.** However, it was not until these patents had been placed at the disposal of the US Government **in** World War II that instant coffee became an economic proposition and, after the war, a world-wide technological innovation.

The maintenance of a company's position was at the roots of the invention **of** nylon, which was less accidental than is often believed. The management of Du Pont recognised the deficiencies **of** rayon and considered research in large molecules as fertile ground for possible innovations. Carothers was engaged because he had done prominent university research in this field. Whereas many of the potentialities of nylon were quickly recognised after the general normative goal had been attained, it took a relatively long time to recognise opportunities for which no strong incentives had existed before: nylon was not promptly applied as tyre cord, and recognition of the potential of nylon adhesives was very slow in coming. Orlon was at first envisaged **not** for wearing apparel, but only for industrial applications such as filter cloth.

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1. Electronic devices, for example cathode ray receivers, were not sufficiently developed in 1930 to make pulse—radar possible, but this was a secondary factor only—they were quickly developed once mission-oriented work on radar had started.

Another aspect of the "maintenance" attitude can be illustrated by IBM's engagement in computer development, which was instrumental in transforming the invention of the computer into the innovation which has had such far-reaching consequences. IBM's business was data processing, and a sizeable fraction of its market was in scientific calculators. In 1949, or early 1950, the management of IBM decided to engage the company in computer development in order to stay in business. Few people recognised a big potential before the first machine came out early in 1953—but by the end of 1953 everybody knew that the computer was IBM's future[1].

Imitation—not of existing technology, but of research and development—obviously acts as a powerful normative factor for companies that are not among the "born" leaders. Mansfield *(lit. ref.* **50)** who confirms this attitude on the basis of case studies, calls it the "bandwagon" or "contagion" effect. Six months after the demonstration of the laser, **70** companies had already taken on laser development work and in the spring of 1966 no fewer than 462 **US** companies were engaged in this field, which by then represented **a 75** to 100 million dollar business[2]. The technical director **of** a European aircraft manufacturer recently admitted a "fixation" on American industry which leads to the initiation of research and development in fields where, for example, Boeing is discovered to be active. The principal reason given sheds light on an attitude which can develop in the absence of clear normative thinking and forecasting in one's own house: the high risk involved in advanced research and development in the absence of a recognised imminent application is reduced if **a** company that practises long-range planning is known to be active in the field in question.

In the social area, the "maintenance" position would correspond to normative factors such as nature conservation, counter-measures against the harmful effects of new technologies (noise, pollution, etc.), or the balance between beneficial and deleterious human genes which is upset by artificial conditions (see Chapter 1.2.).

In the "noblest" column, ***challenge,*** are found quite a number of the most revolutionary technological innovations, for example the innovations represented by the transistor (see Chapter **I.2.—although** a clear incentive existed from the "maintenance" point of view, entrepreneurship was the determining factor), Xerography, the Polaroid camera, commercial jet aircraft, and missiles (large-scale development in the United States was started by North American Aviation in 1952 with the establishment of the Rocketdyne Division at a time when no one was interested in, or ready to pay for such development).

A most interesting example of an invention in the military area due to a normative incentive in a socio-economic context is reported by Lockheed: the rotary wing concept, which revolutionised helicopter technology, was evolved by a design man who was seeking to make a helicopter for the mass market.

A general attitude of wishing to "develop competence" is characteristic of many **US** companies in the aerospace field, such as Hughes Aircraft and

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1. Yet a 1955 forecast by IBM estimated that only 4,000 computers would be installed by 1965—the actual figure turned out to be approximately 20,000 in the US.
2. According to a census by Union Carbide, New York.

North American Aviation (both of which maintain privately funded basic research centres), TRW Systems, and Douglas Aircraft (which recently built a $ 20 million Space Simulation Laboratory). However, the original incentive of challenge is now somewhat obscured by the fact that such entrepreneurial anticipations are gradually becoming a prerequisite for normal business under government contract in very advanced areas.

In the social area, as mentioned above, the challenge of space constitutes a powerful factor and the magnitude of this undertaking cannot be minimised because of the military and political considerations which may have played a role in it. The discrepancy between the huge effort to meet this challenge and the totally insufficient efforts made in response to incentives stemming from " maintenance " and " threats " is all the more striking.

Today, technological innovation is more than ever due primarily to clear normative thinking—and to technological forecasting including a strong normative component. This is also true of technologies that were " dormant " for some time in the absence of a clear incentive. Superconductor technology, for which all the essential elements, including the helium liquefier and big magnet technology, were ready by about **1935,** was taken up seriously only in 1960 when a number of applications became apparent. Other examples include the maser, which for some time was an invention in search of applications, partly because its inventor, **C.** Towne, took an extreme " pure " research position and refused to become involved in industrial research (whereas its present companion, the laser, rapidly found applications, and its inventor, T. Mayman, is in industrial research today); town gas from oil, an invention by Esso Research **(US)** which had been in existence for some time and was not taken up by Esso **(UK)** (there was no incentive in the US due to the abundance of natural gas, in contrast to the situation in the **UK** at that time) before **ICI,** looking for a cheap hydrogen source for fertilizer production, developed steam reformation and also applied it to the town gas problem.

It is said that the absence of clearly defined systems requirements for sophisticated application, to some extent hampers the development of information technology today, so that computer and software development to this end is proceeding on too general a basis.

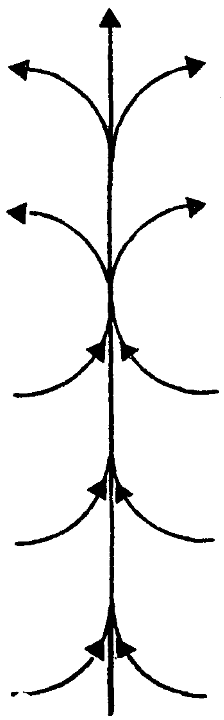
Opportunities and accidents sometimes lead to invention (penicillin), but very seldom to innovation. One example of such **a** rare event seems to be the 113-day steel strike in the United States in **1959,** believed to mark the real beginning of aluminium and plastics competition with steel.

There are fields for innovation where normative thinking does not help very much because of the empirical nature of the sector. The foremost example **is** the pharmaceutical sector discussed in Chapter **1.4.** above. Normative thinking in this field would have to be applied first of all to the recognition of the necessary improvements in fundamental knowledge. This state of affairs is reflected in the " inefficiency " of pharmaceutical research and development. The probability that a developed and tested chemical entity will result in a marketed product is said to lie between 0.0003 (United States) and 0.0007 (Switzerland)—i.e., a big company has to develop and test approximately 3,000 entities every year in order to introduce one or **two** new drugs on the market. **In** a still highly empirical sector such as synthetic fibres, the probability of success is reported to be in the order of 0.01.

Frequent changes in the normative directions set for a project have proved to be fatal. The most famous example is that **of** nuclear aircraft reactor development in the United States, which had to be abandoned, after expenditures amounting to $ 1.5 billion, because the changes in requirements (especially broad mission) had led to complete stagnation and to a demoralisation of the people engaged in the project.

I.5.4. THE TREND TO HIGHER COMPLEXITY IN VERTICAL TECHNOLOGY TRANSFER

Higher complexity here means, above all, a higher degree of interaction between vertical and horizontal technology transfer components: the merger of many separate scientific and technological developments, " communalities " in the applicability of individual developments to various functional systems and tasks, the multitude of applications and services which springs from a functional system.



The ***merger of scientific and technological developments*** is growing even more complex today with inter-disciplinary concepts gradually attaining highest importance. However, in 1945, Conant ***(lit. ref. 4)*** already stressed the " conceptual scheme " as the most essential prerequisite for invention and innovation at all times. The difficulty of thinking in complex inter-disciplinary systems is frequently mentioned in European industry as the biggest obstacle to innovation in advanced areas. The challenge of complexity appears to be welcomed in a positive spirit—and to be met by " total systems analysis "—only in the most dynamic part of American industry and defence and space environments today.

Two brief examples may illustrate what an open mind towards the problem **of** inter-disciplinary research can mean: Lockheed, since 1963, **has** had its own research in molecular biology—with the first applications to aircraft technology **(!)** becoming possible now—and **IBM** pursues fundamental research in biology and astronomy in its Watson Scientific Laboratory (established at Columbia University).

The intricate pattern of interaction between big and small discoveries and between old and new technology is emerging from two statistical evaluations of case studies in the innovation **of** complex American weapon systems:

Arthur D. Little, Inc. ***(lit. ref. 44)***, in a study for the Director of Defense Research and Engineering (DDRE), investigated six representative weapon systems (Polaris and Minuteman missiles, etc.). Out of 87 contributing "research and exploratory development events," only two constituted fairly recent technological breakthroughs —the transistor and the high-temperature shock tube (Kantrowitz), in addition to a group of discoveries related to nuclear fission **(not** evaluated)—whereas the remainder could be identified as small discoveries and improvements to older technologies.

"Project Hindsight" of the Office of the Director of Defense Research and Engineering (ODDRE) is a continouous project aimed at investigating, by working backwards: the relationship between new and old technology, the impact of management environments, and the cost index for investment in research. **A** first summary, based on 17 weapon systems with 600 "events" (generation of knowledge), was published in **1966** ***(lit. ref. 43a)***. Preliminary conclusions indicate that 95 per cent of the basic technology used (and developed and adapted to use) was 40 or 50 years old. Exploratory fundamental research, supported by **ODDRE** in universities, generally did not show up in the final result. **On** the other hand, mission-oriented research for well-defined systems prompted the acquisition of useful knowledge; the air-breathing subsonic Navaho missile, which in 1954/55 came too late as an effective weapon system, generated more technology than any other system. The conclusion is drawn that such functional systems should be consciously favoured which are capable of applying spur and focus to the general research effort!

The powerful effect of normative thinking—and normative technological forecasting—on invention and innovation could not be more dramatically expressed. Complex systems not only do not slow **down** the technology transfer process, but can obviously act to accelerate and focus it.

A "trigger effect" is apparently often prbduced by a specific invention or an advance in a sub-technology that sets in motion the chain **of** events which leads to innovation. It seems that a predominantly exploratory attitude can lead to large time spans between, **for** example, a first and a second invention both of which are essential for a given technological innovation. The chemical industry mentions up to 18 years for such time spans. Mansfield ***(lit. ref. 50)*** found that, in most industries, there is only a weak tendency **for** the same same **firm** to be consistently the earliest to introduce different advances; the leaders for one advance are often the followers for another, especially if a large time lag separated the two steps.

Such a "trigger" effect cannot, of course, be counted **upon to occur** automatically. Any strategy including it will have to be based on rigorous screening and critical forecasting to assess the prerequisites for the crucial advances. Examples such as rockets (known and applied since the time of the ancient Greeks—requirements for space missions known for many decades), direct conversion techniques (thermoelectric and MHD principles already known and demonstrated in the 19th century, etc.), or supercritical steam turbines (thermodynamic advantages known since steam turbines were first envisaged) represent different aspects of the same phenomenon: that the recognition of a potential in concrete terms may long precede its feasibility.

Some technologies depend more closely than others, and in a way which is clearly recognisable, on ***"precursive" technologies.*** One need mention here only semiconductor technology and its "lead" on telecommunication or information processing technologies which, in turn, are largely instrumental in determining aerospace and weapons technology, etc. Phases between different countries can also be distinguished.

Many plastics were already known in the 1920's, but became an innovation only after the rise of petrochemistry. Polyethylen and polyester chemistry on the basis of isocyanates, etc. (the German Baier development), invented in 1937, became an innovation only in 1962 with the development of machinery for the processes.

It would be possible today to modify, by recognition of intricate input/output relationships, the concept of a "***clustering***" around innovations—i.e. a succession of minor innovations and imitations related to a major innovation—which plays a central role in Schumpeter's theory of economic development.

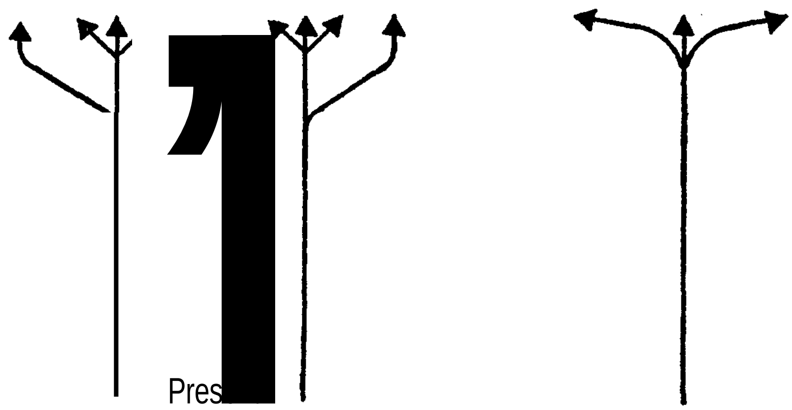
The ***marriage of complex systems*** leading to integrated, more complex systems, sometimes takes strange ways in the absence of clear requirements: whereas a conventional submarine hull was first chosen in connection with nuclear propulsion (Nautilus class), and an advanced hull was evaluated in combination with conventional propulsion (no forceful mission provided), the Polaris missile, which had been assessed before nuclear submarines, entered into a more mature planning stage. The potential of the total nuclear Polaris submarine system with the advanced hull was recognised only at a late stage.

The problem of "***communalities***" between developments towards different goals has only recently been receiving increased attention. It may be expected to assume the very greatest importance when the potential of possible "modulised" developments becomes fully recognised and when the constraints on availability of resources for developments towards an ever increasing number of goals are much more severely felt.

It can be safely forecast that the application of technological forecasting will have important consequences not only for the efficiency, but also for the pattern, of vertical technology transfer. Techniques are becoming available which can be applied to complex technology transfer: morphological research (see section II.3.6.), relevance tree schemes (section II.4.5.), network techniques (section II.4.6.), and total systems analysis (section 11.4.8.). One of the most important factors in innovation—normative thinking—can obviously be greatly enhanced by normative technological forecasting, and ultimately by feedback systems. The improvements to be expected will perhaps be most important for the recognition and optimal employment of "communalities," the highest-ranking issue of the future, and for the development of complex technological systems.

1.5.5. THE GROWING ROLE OF HORIZONTAL TECHNOLOGY TRANSFER IN INNOVATION

Application and service engineering tend to become increasingly important for technological innovation today. This means that the strong accent on vertical technology transfer is gradually shifting to horizontal technology transfer—although vertical transfer is still highly favoured.



The growing share falling to the service sectors can be observed in all countries with a high standard of living.

At the same time, real " breakthroughs " are already being achieved on the applications level. The striking success of the Kodak " Instamatic " and " Super-8 " cameras bears testimony to the untapped potentials of innovation at this level: whereas previously camera development had been geared to the exigencies of amateur photographers who represent at most 10 per cent of the population in advanced countries, Eastman-Kodak—by using known technology alone—developed a " fool-proof " concept which successfully caters for such groups as young mothers, etc., representative of the remaining **90** per cent.

Application engineering has already acquired primary importance in the field of industrial automation. The failure to recognise this—and the belief that computers and control systems could be sold " off the shelf" —were held responsible a few years ago for early disappointments in this field and have been severely criticised, for example in the United Kingdom.

What service engineering may mean in the future becomes clear from the interest developed, and steps taken, by some of the leading American companies in the communication field (including information processing):

General Electric is preparing for city building (the city seen as a communication network—see ***lit. ref. 377);***

IBM is deeply involved in the development of techniques for education (in connection with sophisticated teaching machines);

RCA has bought the Random House Publishing Company;

The Xerox Corporation has acquired University Microfilm, Inc., and runs a youth periodical read by 15 million schoolchildren in the United States and is establishing a behavioural research programme —all activities in preparation for an expected role in education 10 years hence.

Needless to say, technological forecasting played an important part in these long-range decisions which are focusing on future environments considerably different from ours.

New forms of marketing assume an instrumental role in technological innovation. The most striking example is again provided by the Xerox Corporation: a Thermofax copying machine cost $ **99,** and produced copies at an operating cost of 8 cents per page; the Xerox **916** machine cost somewhere between **$20,000** and $ **30,000** and produced copies at ***5*** cents per page. In spite of the lower operating costs, the situation was very unfavourable for marketing the machines. The basically new approach taken by the Xerox Corporation—not to sell but to hire out the machines for a basic fee of **$ 90** per month, offering a few hundred free copies and selling additional copies —was based on the expectation that demand would increase rapidly once **a** cheap start had been made by a user. In the six years since its introduction, xerography business has accumulated to $ **2** billion.

Marketing is known to have become one of the crucial factors in computer, aircraft, and nuclear energy innovation. By many " insiders," marketing is considered to be a more decisive factor in the present US lead in these fields than is any new technology of a type involving vertical technology transfer. In Europe, one may readily observe a fatal lack of recognition of business acceptance cycles and of correct assessment of economic requirements.

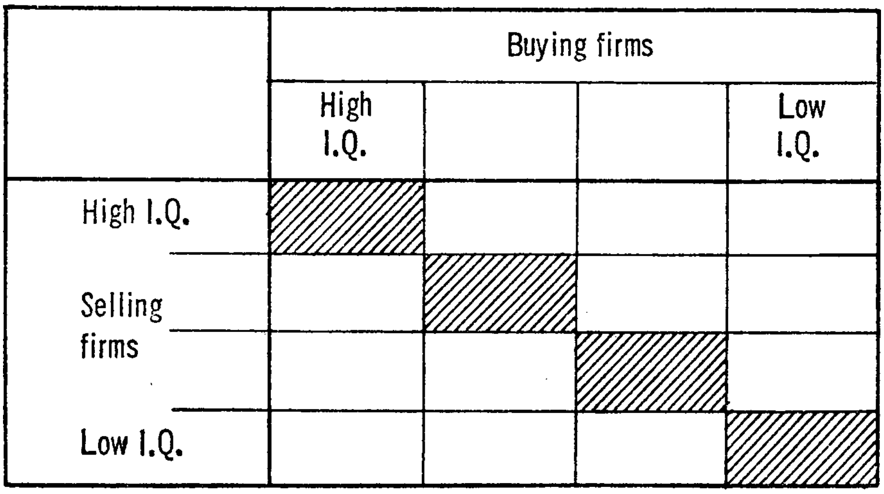
Olivetti may be cited as an example of imaginative marketing in Europe: a combined typewriter/calculator machine would cost considerably more than both machines separately. Market research with Italian banks—which invariably have to occupy a position on the " Piazza Duomo " of small towns **in** order to stay in business and, as a consequence, are often terribly short of office space—showed that the banks would be prepared to pay up to three times as much for the combined machine as for the two separate machines.

The question of whether the ***market*** is ***imaginative or unimaginative*** could not be resolved unambiguously during the investigations for this report. **On** the one hand, the majority of companies **of** an innovating type seem to agree that very few ideas are generated by the market. Companies developing fundamental technologies, such as semi-conductor technology, invariably have to rely on their own imaginations—and on their own technological forecasting. On the other hand, applications of complex systems may meet with the imaginative co-operation of the market in certain fields. IBM always prefers to work with customers, and cites those in the aerospace and nuclear energy fields and certain banks as " creative " customers. The development of the first real-time airline reservation system was started as a joint venture by IBM and American Airlines in **1955,** and the system delivered in **1962.** None of the other airlines came through until later. In connection with such " pioneering " customers, it is also necessary to recall the role of Pacific Gas & Electric in the development of **the** boiling water reactor system by General Electric.

Gellman[1] has proposed a general relationship between selling and buying firms with different " innovation quotients " (IQ—the implication in the

1. At the Conference on Technology Transfer and Innovation, 16-17 May 1966 in Washington, D.C.

abbreviation is doubtless intentional). Optimal selling, according to Gell-man, holds for matrix fields of equal IQ on the selling and buying side—there is little chance of selling by a high IQ firm to a low IQ firm. The reality is probably more complicated than this matrix representation.



National attitudes, finally, seem to play an important role in innovation of the horizontal type. The small consumer industry in the United States generally seems much less afraid of advanced technology than in other countries. Bronowski calls this difference in attitude a " patriotic problem," because advanced technology has become the source of patriotic feelings.

The most important implications of horizontal technology *transfer to* developing countries—which is capable of producing real innovation by application to drastically different sets of economic, environmental, and social factors—will be mentioned only briefly here. An example is the application of solar energy conversion, as developed in Israel and found uneconomic there, to other countries in Africa and Asia. Historically, work on solar energy conversion started in Israel as a " patriotic problem," with everybody and anybody suggesting (useless) ideas which nevertheless had to be dealt with. Almost all developments turned out to be of potential use, but not under conditions prevalent in Israel: small power units, with turbines, in the 0.2 to 1 kilowatt range might find important applications in Asia or for pumping ground water up to deserts; the " solar pond," in the 500 to 5,000 kilowatt range, with electricity generating costs around 2 cents per kilowatt-hour, would not be economic in Israel, which has no region isolated from the general electric grid, but could be applied in countries where power is now generated in remote areas by Diesel engines (costs 20 to 30 cents per kilowatt-hour for smaller engines, and 2 to 8 cents per kilowatt-hour for large Diesel stations); finally, the production of salt from " solar ponds " by flashing the solution is of no interest in Israel, which has enough salt from its potash production, but could be applied elsewhere. Although most of the developments in the solar energy field have thus become unfeasible for Israel, a fair-sized development effort is maintained for possible innovation in developing countries as part of a technical aid programme.

I.5.6. STRUCTURAL CHANGES IN INDUSTRY CAUSED BY TECHNOLOGICAL INNOVATION

Technological innovation not only changes the surrounding world but introduces a dynamic element into the structure of industry not previously experienced to such an extent. Where technology is pushed close to its ultimate limit it tends to revolutionise profoundly the environment from which it sprang.

Long-range technological forecasting, by looking at the total system of industry, is capable of revealing a dynamic picture of interaction and interwoven directions of change which is only gradually being recognised today and is, as yet, rarely taken into account in long-range planning.

Non-functional diversification, by which we mean diversification that does not organically grow from actual business, is not the most important factor here, although rapidly increasing. Such diversification is often deeply rooted in science so that a special advantage may be gained for the start.

However, the ***activity of industry*** is more drastically affected by ***functional diversification*** which grows directly out of changes caused by technological innovation. It often takes the form of forward or backward integration along an input/output chain of industrial activity. Aerospace companies felt an incentive to go into electronics, electronic industry is faced by the problem of entering or staying out of data processing, etc. There are decisions of very far-reaching consequences to be made in many industrial sectors today. Even if the corporate objective is well defined, it is often difficult to foresee the changing pattern of technologies and their relevance to the overall objective, as James B. Fisk (quoted in ***lit. ref. 44)*** testifies with respect to Bell Telephone Laboratories: " To make the right choice, and then adhere to it, may not be as easy as it sounds. For example, one may have to decide rather frequently whether entrance into a new field is, in fact, compatible with the long term objectives of the organisation. We have occasionally, in the past, had the even more wrenching experience of withdrawing from promising areas in which we were already well established because they threatened to lead us too far away from our primary objective of providing even better communication service. However, such mission definition is necessary if the organisation is to develop the ' enduring themes ' and flow of technology which I have described. In the long run, it is the best means of giving the organisation continuing purpose and vitality. "

The ***" stay in business " attitude,*** which was mentioned above in connection with IBM's entry into the computer field (and is an acutely felt issue in many electronics companies today in relation to their decisions about their position in the computer field), is also taken very seriously by the big oil companies in view of long-range changes in the pattern of primary energy sources. For example, fuel cell research and development is carried out at a low or medium level of effort in oil companies as well as by car manufacturers. One oil company or another is preparing diversification into nuclear energy.

More imminent consequences may spring from a ***" Do critical things yourself" attitude:*** IBM's Chief Scientist **E.R.** Piore foresaw the trend towards integrated circuits correctly in 1957-58 (five years before the first realisation). His presentation to the management of the company led to the recognition of the structural changes to be expected from the growing together of components and systems manufacturing. The decision to include a component line in the company was then taken in order to build up know-how for the time when monolithic integrated circuits would be incorporated into computer technology, i.e. 10 years after the initial long-range forecast.

Sometimes new activities have to be added simply because no supply is available of the desired quality. Aerospace companies often have to develop new materials, which sometimes are then taken over by chemical industry for production. Through both incentives—to be master of the ship and to ensure the required quality—chains of interest are created by new technologies in an organic way. The example of such a chain of activities, growing from Varian Associates' engagement in nuclear magnetic resonance for scientific instruments, may illustrate this point:

Nuclear magnetic resonance
↓
Electromagnets (because one needs homogeneous fields)
↓ ↓
Superconductivity
↓
Cryogenics → Cryopumps ← Vacuum technology

The application of special competence and skill, essentially a horizontal technology transfer for the principal aspects, leads to surprising forms of diversification. All the big American aerospace companies are taking an active interest in hospital management; it is significant that Boeing does not call this a diversification because it is functionally in line with the normal tasks of its Missiles and Information Systems Division, namely data processing. All American aerospace companies, as well as Sud-Aviation in France, are interested in oceanics, especially deep submersibles. Traffic control, also mentioned in the American aerospace industry, would fall into the same functional diversification group, whereas water desalination may represent some deviation from an organic development. However, the adoption of nuclear energy by North American Aviation in the early 1950's (Atomics International) was a measure taken together with the creation of a rocket division (Rocketdyne) and a guidance division (Autonetics) and formed part of a long-range plan for rocket development.

Even more revolutionary than the impact of new technologies on individual companies will be the structural changes in industrial patterns caused by the impact of future technologies.

The growing together of industrial activities where technologies are approaching their ultimate limits will become a factor of primary importance. It is visible already in the integrated circuit stage of microminiaturisation of electronics, where components and systems manufacturers' tasks are starting to become indistinguishable (see lit. *ref.* 333 and for a European discussion of this problem, see *lit.* ref. 26). This trend will continue with large-scale integration (1,000 to 10,000 entries), to be introduced in 1968 or 1969. Another example is hypersonic (Mach 5 to 7) aircraft, expected for 1975 to 1980, which will obscure the dividing line between the functions of the air frame manufacturer and the propulsion unit manufacturer. A hypersonic plane is described as a big intake and a big exhaust, with a connecting slot which carries a cabin on top; there will be no gas turbines or the like.

Another factor of utmost importance, causing structural changes in the industrial pattern, is invasion of one (usually stagnant) sector by another (dynamic) one. An A.D. Little report (*lit.* ref. *45*) provides an excellent study of this phenomenon, which may be considered as a positive selection factor, as seen from the point of view of national economies. Examples are the invasion of the textiles by the chemical sector, of the chemical by the petrochemical sector and vice versa (also an independence position with respect to the raw material constitutes an added incentive here), etc. In the agricultural chemicals sector, three factors have revolutionised the picture since 1963: invasion by the oil companies, the trend to bigger farms (in the US), and the backward integration of the food industry (influencing farmers in their activity).

The gradual replacement of natural materials by synthetic materials may be regarded as another form of invasion. The recognition that human population grows faster than animal population, and that people will increasingly shy away from employment in the preparation of skins (an unpleasant type of work), was at the bottom of Du Pont's decision to develop artificial leather (Corfam).

In view of the far-reaching consequences of structural changes in industry and in industrial patterns caused by technological innovation, one may expect that this aspect will become one of the main concerns of long-range technological forecasting. The problem is recognised by some of the advanced companies which have already established a systematic long-range forecasting and planning function. It would also seem to merit attention, however, at national and international levels in view of both its impact on the structure of national economies and its relevance to national competence.

I.5.7. CONCLUSIONS

The following principal conclusions have been drawn in the individual sections of this chapter on technological innovation, which is central to the problem of technological forecasting:

The inherent nature of technological innovation generally favours a normative approach, which can be greatly enhanced by the application of technological forecasting with a strong normative component to provide spur and guidance to the technology transfer process;

Technological forecasting is the most effective available means of filling the "gap" so as to maintain continuous fast growth;

Technological forecasting will strongly influence the pattern of vertical technology transfer, especially by greatly improving the systematic exploitation of "communalities" and by focusing and accelerating the development of complex technological systems;

The horizons of application and service engineering will be widened considerably by technological forecasting, and the trend towards greater emphasis on horizontal technology transfer will be strengthened thereby;

The forecasting of structural changes in industry and, most important, in industrial patterns, as a result of technological innovation—especially in advanced fields, where technologies are pushed to their ultimate limits—will become one of the foremost concerns of long-range technological forecasting, possibly also at national and international levels.

Chapter 1.6

TECHNOLOGICAL PLANNING AND FORECASTING

The literal situation of no-forecast... implies that each action taken is unrelated to any past experience, present situation, or future intended action. The price of this insanity is non-survival, yet it is practised to some degree in organisations prone to frequent changes in management. The obvious error in a ' no-forecast ' is that all action is random, limited only by the extremes of possible alternatives.

Ralph Charles LENZ, Jr.

Luck is a residue of careful planning.

Popular saying in American industry.

I.6.1. THE INCREASING INTEGRATION OF TECHNOLOGICAL PLANNING AND FORECASTING

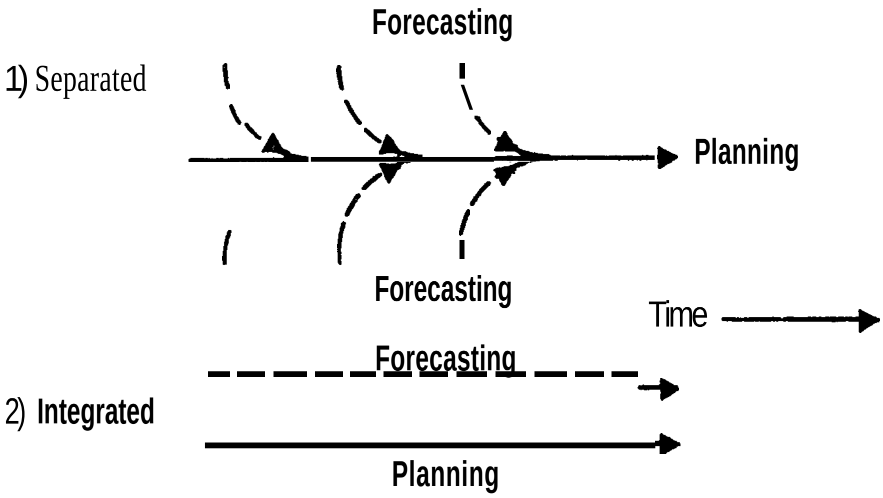
The intimate relationship between forecasting and planning, generally well recognised today, was much less evident as long as technological forecasting was mistaken for a purely exploratory exercise. The general view which was widely held before 1960, and which stressed an artificial separation, was expressed in a review of technological forecasting made by the Battelle Memorial Institute in 1959 (*Zit.* ref. *90*) : " It is clear that prediction is not presently feasible. The requirements for measurement, for a theory of change, for defining present and future environmental effects, and for quantitative communicability have not been satisfied. At the next lower level of sophistication, the requirements for projection are similarly not satisfied. The present situation in regard to attempts at anticipating and controlling the future in the research and development process appears to be one of programming toward predetermined goals... Programming is equivalent to projection, or even prediction if the problems to be solved in the programmed research or development are accurately anticipated, and if the measure of effort applied is explicitly related to the time involved. "

Only a short step separated the recognition of the potential of " self-fulfilling prophecies," implied in the above statement, from an attitude focusing on the purposeful exploitation of this potential—but this short step, consciously taken when the dominating role of normative thinking in technological innovation became more generally known, means a revolution in technological planning. The fundamental change is apparent when one compares the above with the following statements by the Battelle Memorial

Institute (lit. ref. 212) : " Obviously, the first step in conducting a technological forecast is to determine the objective to be served... The second step is to decide what is to be forecast. This is an important question which might involve the study of trends in areas pertinent to the business of the company or organisation involved. According to our definition, the forecast will take into account the influence of foreseeable forces, with the goal of identifying probable future needs and wants based on these interacting environments."

Today, all leading forecasting institutes and consulting firms producing technological forecasts—Arthur D. Little, Battelle Memorial Institute, Stanford Research Institute, Illinois Institute of Technology (Corplan), Quantum Science Corporation, etc.—regard their forecasting function as closely related to their consulting function in corporate planning. With the partial exception of the Stanford Research Institute, which was the first to start a regular forecasting function (in 1958) and maintains a basic "editorial" staff for it, the forecasting and planning functions in these institutes are fully integrated and are performed by the same people.

One may represent the difference between separated and fully integrated forecasting and planning functions graphically. Separate forecasting attempts to apply "bounce" and direction at discrete planning steps; in the integrated approach, forecasting provides continuous stimulus and guidance to planning.



The integrated approach is based on the attitude that "technological forecasting is only as good as it adds to planning action today" (statement by TRW Systems, Redondo Beach, California, but in an equivalent formulation encountered in many well-organised firms). Georges Doriot's appeal for more action and less analysis— " The United States will kill itself with analysis"—makes a strong point in this direction[1].

A schematic example of how long-range forecasting may influence action today is provided by the planning for a Mars mission by NASA, the US Natio-

1. It has been pointed out that projections of a chiefly exploratory nature are sometimes made to evade planning. The extreme attitude in this direction has been formulated by a high European government official who attributed the hesitation of his country, despite its having a socialist government, to a general fear that "planning will force to act."

nal Aeronautics and Space Administration. The timing, envisaged at present, is as follows:

1966	Project technology assessed by 10-year technological forecast (requirements, state-of-the-art projections, alternatives, focus points for research, etc.);
1966-1975...	Preparation of technical options by medium-scale fundamental and applied research effort to substantiate along the lines of the 1966 forecast;
1975	Decision about the Mars mission;
1975-1985...	Full-scale development work;
1985	Mars mission.

The main objective of the 20-year forecast added to the French National Plan, starting with the Vth Plan now in effect, is also to outline general trends and point out the major options to be taken into account for the formal five-year plan. The same scheme of a 10- to 20-year forecast, pointing out long-range requirements and technical options to meet them and serving to focus research, with its " short end " moving into formal planning and " hardening " to become part of a concrete corporate five-year plan, is also typical of industry with established long-range corporate planning.

A.T. & T. (American Telephone and Telegraph Co.) assesses requirements now for 2000 AD. On the basis of a US population of 300 million, and an estimated 400 million main telephone lines (a 10-fold increase over 1966—and far surpassing corresponding European estimates which assume saturation at 60 to 70 per cent of the population figure), F.R. Kappel, A.T. & T.'s Chairman of the Board, recently announced that telephone switching in the Bell System will be all-electronic by 2000 AD. This goal alone implies a total commitment of $ 21 billion. Broad technological missions, such as the picture-phone, are now taking shape and are reflected in overall planning, but the specific technologies which will be applied are not yet determined; a number of technical options are at present being prepared for the picture-phone (digital transmission, which is used for the test runs now, will probably be too expensive).

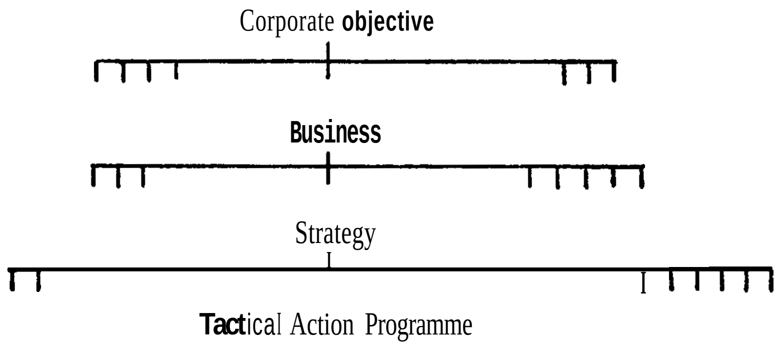
The " Industrial Dynamics " concept by Forrester (*lit. ref. 198*), which has become most fruitful for industrial planning, incorporates a technical function and a business planning function which correspond to the integrated approach outlined here.

One may discern a " natural " trend towards the fuller integration of forecasting and planning so that in the 1970's the technological forecasting function may be increasingly " dissolved " in the planning function. We shall probably no longer speak of technological forecasting ten years hence. As long as it is an ill-defined function and an immature art it will gain from special attention and separate development. But there can be no doubt that it is only auxiliary to planning and will ultimately mark a significant enrichment of the planning function. Examples of this can already be studied (see Chapter 111.2. on industry). These examples also point to a probable important consequence: namely, that planning, which has become product-oriented in the course of the strong verticalisation of big industry (a marked feature over the past 20 years), may become function-oriented, at a level of comprehensive control over the interactions in technology transfer. This general trend will probably be accelerated and strengthened by the advent of future management information systems which include the technological forecasting function (see also section 11.5.2.).

I.6.2. THE NORMATIVE CHARACTER OF PLANNING

The title of this section seems almost tautological. However, a few important points in this area are not so self-evident.

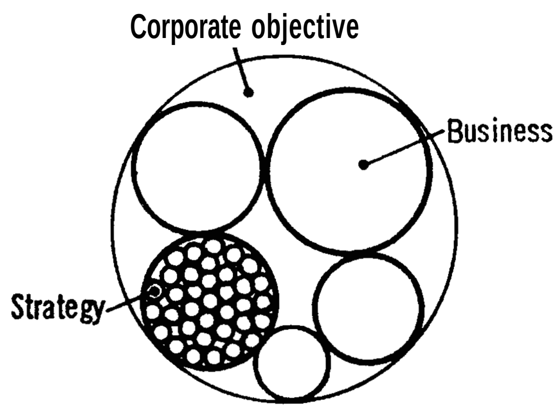
A corporate planning structure may identify the normative relationships by representing them in a relevance tree scheme (see also lit. ref. 204) :



The most difficult task in planning is to maintain communication between technologies at the lower levels. Efficient planning must include " communalities " in a comprehensive and optimum way. The communication problem, not only between technologies but, above all, between people, is only gradually becoming recognised as the most important problem a company has to solve in its organisation (see, for example, *lit.* ref. 209).

The Planning-Programming-Budgeting System of the US Department of Defense (see Annex A.2.4.) is, analogously, also based on a decision tree scheme and stresses " communalities " (the multi-purpose aircraft F-111, etc.).

One of the aims of good planning, then, is to fill the area under the corporate objective increasingly with planned action by reducing the gaps representing action which evades planning.



It can be seen that, with planning approaching complete coverage of the corporate objective area, normative thinking will be more and more aligned to a uniform corporate objective, i.e. to the top of the relevance tree—as is undoubtedly desirable from a general point of view.

Planning in industry today is usually far from having arrived at this ultimate stage, even in companies which are consciously developing sophistication in planning. A number of companies have adopted a policy for assessing and preparing projects (perhaps also involving some research effort) and putting them "on the shelf." For inclusion in a formal medium-range plan, the top projects are screened and a few are selected for full-scale development, taking into account, resources, market and other factors. Examples may be found in sectors where flexible "capture strategies" play an important role, for example in the aerospace sector (Boeing, etc.), and in the consumer-oriented sectors (3M Company - Minnesota Mining and Manufacturing Company).

The various simple decision-making and ranking techniques (see especially sections II.3.10, and 11.4.1 through 11.4.4) have been developed in connection with planning of this type, i.e. where an abundancy of projects to select from, and the applicability of normative forecasting, are given at any level. The integrated schemes on a relevance tree basis (section 11.4.5.) suit planning environments where normative thinking starts at the top level and determines the choice on the lower levels by going down step-wise.

In a few remarkable cases, the clear recognition of a corporate objective leads to the adoption of supreme social goals to guide decisions in a company or an organisation. It is necessary in this connection to distinguish between lip service paid to such goals and the authentic attitude. An outstanding example of planning aligned to ultimate social goals, which can be cited here in good faith, is A.T. & T. (American Telephone and Telegraph—the Bell System)[1]. Its explicit policy to that end has played an important role, for example, in cost reductions in social areas, such as the reduction of investment cost per mile of distance in telecommunication systems from $ 200 to $ 25 over the past 20 years (achieved through the development from open lines over coaxial cables to microwave relay systems). In the absence of effective competition, the principal normative incentives are derived from the challenge of social goals. North American Aviation's Space and Information Division has recently developed an ambitious matrix concept (see section II.4.2.) to link its forecasting and planning functions to the social goal of "space as an environment to benefit man." In the McNamara era such "social" thinking also increasingly dominates the technological decisions made in the US Department of Defense.

Another aim of good planning, obviously linked to the clear recognition of corporate objectives and social goals, is embodied in the concept of synergy, whose meaning has been succinctly expressed in the suggestive formulation "2 + 2 = 5 effect" (see lit. ref. 192).

How profound the influence of a strongly normative technological forecast on long-range planning can be—the "self-fulfilling prophecy" again—was demonstrated by the jet transport forecast (lit. ref. 311) prepared by ICAO, the International Civil Aviation Organization, in 1957-58, before any large-scale introduction of commercial jet aircraft. It is generally agreed today that the forecast accelerated the introduction of jet traffic considerably, and that a number of airlines made their decisions on the basis of this study. A certain "contagion" effect may have been partly responsible for this, but the clear formulation of a goal, and the assessment of the economic consequences acted as a most important "trigger" in setting off a volley of decisions in the same direction.

1. For some of the organisational implications, see section 111.2.5.

1.6.3. PLANNING STRATEGIES

One may distinguish three basic strategies which are aided by technological forecasting of quite different types:

1. "Defensive" strategy, with research and development effort undertaken as a precaution against any surprise from a competitor. Technological forecasting here is predominantly exploratory and aims at a comprehensive view of opportunities, even unlikely ones. General Motors has adopted a "defensive" policy.
2. A strategy aiming at complete harmony with acceptance cycles (both technological and business cycles). The computer development of IBM, or Bell Telephone Laboratory (A.T. & T.) strategies, can be cited as examples here (see also the description of the development of the TH microwave relay system by Bell in *lit.* ref. 52). "Capture strategies," typical of US government contractors today, find their optimum applicability here, too. A smaller competitor may also find an optimum strategy in bringing out slightly improved products one year after the big caesuras of the acceptance cycles. Acceptance testing may be used to derive projections of the demand and aid decisions concerning alternative technologies (A.T. & T. put a picture-phone service at the disposal of Union Carbide connecting their New York and Chicago offices, to test the incentive in the business area). An important objective under this strategy is also to determine an optimum strategy between research to develop an independent technology and adaptation (by licence, etc.) of known technology. The example of silicon chemistry, developed in the United States by the big companies, shows that one company "left it in research too long" (while the other two were already in the market.)
3. A strategy aiming at domination of one or both of the acceptance cycles. Examples of an attempt to dominate the technological acceptance cycle (pressing technological frontiers as far as possible) are provided by the Xerox Corporation—which introduced LDX (Long Distance Xerography) a little too early[1]—or by those small and alert companies which try to follow a "leap-frogging strategy" by working on a small scale far ahead of their competitors. Domination of the business cycle is the aim of General Electric's strategy in the nuclear energy field. One has to distinguish between a position of complete domination of the field on the basis of a monopoly, and a form of domination over a business acceptance cycle which amounts rather to regulation and optimisation, and is perhaps also desirable from a more general point of view and for society as a whole.

Mixtures, of course, may also be found in companies with diversified interests. Olivetti (Italy), for example, distinguishes sharply between business areas where a world market share of 30 per cent suggests strategy 3) above, and business areas which are "led" by "precursive" or other factors not controllable by the company, bringing into play a cautious strategy 2). Unorthodox strategies, such as concentrating pharmaceutical development on

1. The technically perfect LDX system, introduced in 1965, is now catching up in 1966 sales.

cheap processes instead of new compounds (Bofors, Sweden) or making highly concentrated fertilizers for cheap transport (Israel Mining Industries) can lead to remarkable success.

Alignment of strategies to "precursive" developments can be a sign of wisdom as well as of lack of imagination. European industry frequently employs an assessed phase shift between US and European development to design a strategy. The same was true for the long-range forecast ("Groupe 1985") prepared for the Vth French Plan. In the telecommunication area this phase shift is particularly pronounced and aids considerably in the planning of future European systems—both as regards demand estimates and future technologies, which generally follow the American development by five or six years[1].

Technological forecasting is capable of aiding strategies in all areas: product development, market development and market penetration. Its intimate relationship with market research will be pointed out in greater detail in Chapter 11.2. on industrial technological forecasting.

"Sliding" plans, revised every year, can usually be found in industry. It is surprising that some of the military technological planning (for example in France and UK) is performed within the framework of a "rigid" five-year plan.

1.6.4. THE QUANTIFICATION OF PLANNING

Planning usually needs quantifiable input from forecasting. A descriptive scenario may indicate general planning objectives, but will generally not help much in setting up a strategy and assessing the steps to be taken. A sliding five-year plan is usually the framework for which comprehensive quantification of a technological forecast is required.

There are planning jobs which do not need precise quantification because of the scaling effects to be expected. The big car manufacturers, such as General Motors, point out that economic analysis for their research and development projects is of marginal value only due to the large number of cars which will render projects successful if they are technically and economically sound. Integrated circuits were recognised by Fairchild as a breakthrough of such far-reaching consequences that a "Make them, then sell them" attitude was adopted during the development without much trouble being taken with quantitative assessments of the impact or even with formal market research at that stage[1].

An examination of the forecasting environments distinguished in section 1.5.3. will reveal a heterogeneous picture as regards the approach to quantification:

Military area: Cost/effectiveness assessment (pioneered by the US, followed by the UK, Sweden, etc.);

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1. No phase shift exists for telephone exchange technology. The fully-electronic exchanges in Morristown, Ill. (US), and Highgate Wood (UK), installed in 1960/61 and 1963, respectively, had to be dismantled after temporary operation. The oldest of the semi-electronic exchanges of which seven existed by the end of 1965, is the Färbergraben (Munich) exchange in Germany. Semi-electronic exchanges have been installed in Germany, Italy, UK, and US.

1. A sophisticated market research function was established after the breakthrough.

Economic area: return on investment, usually as net present value of a project (see section 11.3.10.);

Social area: first attempts to quantify on a cost/effectiveness basis by the introduction of the PPBS (Planning-Programming-Budgeting System) in US Government agencies in social areas, and by Resources of the Future, in Washington.

The common basis which is being developed is thus value expressed in monetary terms—not a superficial solution, as may appear at first sight, but an immensely practical one. It means that integrated technological forecasts, reaching over many development and impact levels, and bearing on all three areas, may be expressed and processed in a uniform language of quantities.

The development of even greater uniformity may be expected. Return on investment is regarded less and less as a sufficient criterion to justify research and development in the economic area. The various simple techniques for introducing other factors into decision-making (see sections II.4.1. through 11.4.4.) indicate the growing need for criteria which, going beyond simple economic analysis, take into account the " effectiveness " of projects in relation to corporate objectives broader than that of profit maximisation, or which reflect more sophisticated ways of ultimately achieving maximum profit.

Technological forecasting and planning in the economic area might gain significantly by being based on the assessment of the cost/effectiveness relation as exemplified in military (and in future also social) forecasting and planning. It has been stated in section 1.6.2. that supreme social goals are also applied—and will gain in importance—in the economic area. Cost/effectiveness analysis may become the basis on which they could be introduced into quantitative planning.

In any event, a trend towards increased compatibility between forecasting and planning in the military, economic, and social areas appears to exist.

I.6.5. CONCLUSIONS

The principal conclusions drawn in this chapter can be summarised as follows:

Technological forecasting and planning exhibit a marked trend towards fuller integration—integration which may result in the eventual disappearance of technological forecasting as a distinguishable discipline in the 1970's.

The trend towards integration will favour a change from product-oriented towards function-oriented planning.

The normative character of planning is enhanced by adapting it to the hierarchic relevance concept which forms the basis of normative technological forecasting (or vice-versa); normative criteria are then introduced at the top only, at the level of the corporate objective which may comprise supreme social goals and may link economic or military planning to the requirements of society.

The quantification of planning in the military, economic, and social area is about to find a common measure in monetary value; it may become more homogeneous through a uniform cost/effectiveness approach in all three areas, which would greatly facilitate the integration of technological forecasts over a multitude of technology transfer levels and areas.

Chapter 1.7

SOCIAL TECHNOLOGY AND TECHNOLOGICAL FORECASTING

To believe in the human condition might be regarded as the attitude of a fool, but to despair of it is the act of a coward.

René DUBOS.

Till now man has been up against Nature; from now on he will be up against his own nature.

Dennis GABOR.

In the preceding chapters, especially Chapters **1.2.** and **I.4.**, it has become amply clear that a large part of technology can be classified as social technology—implying a significant impact on society—and that all mainstreams of technology can ultimately be placed within a broad social context. Technological forecasting has been shown capable of serving as a bond between science and technology on the one hand and social issues on the other. Techniques for integrating technological forecasting over the different levels of technology transfer and within the entire technology transfer space can be applied to align research and development, including fundamental research, with social goals. The key to the successful application of technological forecasting to these ends is the introduction of a strong normative component which starts from a set of defined goals or avowed purposes.

The ***selection** of goals* is the most difficult task for social technology (see also the discussion in Chapter **1.2.).** This is being recognised more and more clearly and is at the bottom of the present attempts to create "Look-out institutions " (see Chapter **111.6.)** and to prepare techniques for improving intuitive thinking and expert consensus. The " Delphi " technique (see section **11.2.3.)** has recently aroused great interest in the application of intuitive thinking.

A number of outstanding scientists of various disciplines constitute the idealistic and deeply concerned body which serves as the vehicle for this development at present. Some of their names are frequently cited in this report. However, much will depend on the striking of a spark in environments which are entrusted with responsibility in social areas—in particular, governments (among which the United States and the Swedish Governments are perhaps farthest advanced along this line in the recognition of their tasks.)

Ozbekhan (*lit. ref. 76)* emphasises that the set of goals to be pursued undergoes dynamic changes and is even coupled with technological advance in a feedback cycle:

" The technological battle is almost won, and we must begin to comprehend or at least face our victory. Our victory consists of the fact that we have overcome—on a relative scale but with enough potential margin for us not to have to worry about it—'scarcity,' namely, the fundamental constraint of our natural environment, which ever since our biological beginnings has shaped human outlook and behaviour. We have overcome scarcity by multiplying our means, by discovering ways of using them efficiently, that is economically, by getting to understand the nature of maximising processes, by expanding through cumulation and substitution the ensemble of our techniques. This achievement was an end toward which humanity strived. The successful outcome, however, cannot be an end —and this point constitutes the crux of the problem. For if we accept our impending victory, much of which has already been achieved, as the ultimate goal of human destiny, then clearly (as Ellul maintains) we shall perpetuate beyond the meaning of the original end of survival our search for the next, the better, the more efficient technique. And if we do that, technique—not man any longer—will have become an end in itself. Hence, in human terms, we shall have lost meaning and reduced purpose to irrelevance. The problem is to redirect our energies and all the technology which is at our service toward renewed human ends—ends which are not given, as was survival amid scarcity, but are now in need of being invented. "

Siu (*Lit. ref. 16*) has provided a graphic formulation of the same problem: " The reason that the present century is fittingly called the Machine Age is not the abundance of machines, nor is it man's dependency on them. It lies in man's changed attitude... Consequences are taking the place of purposes. "

The principal danger in the selection of goals lies in the powerful effect of " self-fulfilling prophecies "—which has been mentioned previously in this report mainly in connection with its positive value, but which can obviously be harmful if the prophecy points in a direction which does not conform with the best attainable goals.

The particular danger in the area of social technology is the conscious or unconscious selection of goals which are representative for the present and not for the future—the problem of the " perpetual present " (Ozbekhan) or of "timeless time" (F.L. Polak). The best available means of avoiding this dangerous imprisonment within a restricted outlook is the systematic creation of feasible anticipations which represent " possible futures " or " futuribles."[1] The problem is to break out of the extended present, the " logical future," and to select, for a normative approach, the best feasible anticipation in order to make it the " willed future " (Dubos). To achieve this most difficult task, a feedback system must provide the framework for the evaluation of the alternatives. The basic structure of such a feedback scheme—which can be an underlying attitude or an elaborate technique—is outlined and discussed in greater detail in section 11.5.2.

Ozbekhan (*Lit. ref. 76*) condenses the proper viewpoint to be taken in the selection of social goals into four points:

1. The term " futuribles," first used by the theologian Molina, has become the label of Bertrand de Jouvenel's SEDEIS and of future-oriented thinking in France generally.

1. The future should be viewed as a solution to the present, not an extension of it, and desirable ends should never be confused with the means that make them feasible, but should be subordinate to the outcome.
2. Redefinition of long-term universal goals should be attempted in balance throughout the whole space of a system (e.g., within a given system, freedom, rights, abundance, education, etc., should be generalised and not localised to parts of that system).
3. At the present juncture of history any human future ought to be conceived in relation to a larger system rather than to a limited one (i.e., it is better to view a system as the integrative entity for a region than for a city, for a nation than for a region, for a grouping of nations than for a nation, and finally for the whole world than for any portion of it).
4. The spectrum of alternatives considered in visualising the future should be as large, and its elements as numerous and different in value content as modern information processing techniques can ensure (i.e., moral choice must be free to operate beyond the limitations that tradition and lack of means have always imposed upon it).

An important prerequisite for the understanding of social goals and the possibility of arriving at valid anticipations is the development of ***environmental sciences.*** Dubos (*lit. ref.* 67, ***68)*** has given a framework for environmental biology, which is probably the most important of such sciences, but —like all of them—has not yet advanced very far. Dubos points out, for example, that " there must be limits to the range of human adaptability; it would be of the utmost importance to determine its limits and thresholds." He also foresees a very profound impact on fundamental research and its methods: " In order to deal with problems of organised complexity, it is... essential to investigate situations in which several inter-related systems function in an integrated manner. Multifactorial investigations will naturally demand entirely new conceptual and experimental methods, very different from those involving only one variable, which have been the stock in trade of experimental science during the past 300 years."

The example of environmental biology serves to stress, again, the importance of an objective. So far, according to Dubos, research in environmental biology has mainly been stimulated by the need to investigate problems related to the training of combat forces for operation in the tropics or in the arctic and the preparation of human beings for space travel, or to enquire into the effects of solitary confinement.

McLuhan's research project on the sensory profile of man (see section **11.2.5.)** can be expected to become particularly valuable for the anticipation of future environments.

The ***aims of normative forecasting*** in the area of social technology can best be illustrated by a list presented by Gabor[1]:

" I should put first and foremost the removal of dangerous tensions in our international and social systems. There are three types of tension:

a) International political; capitalist-communist, East-West.

b) International economic; underdeveloped versus highly developed nations.

c) Alienation of individuals from society.

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1. **Prof. Dennis Gabor, in his letter of 13 January 1966 to the author.**

The first two are of prime urgency, but we know so little of the third type of tension that it is high time to devote serious study to **it.** Alienation in our society reveals itself in crime, and in tensions in the home. The most disturbing feature of it is that it seems to **grow** with prosperity.

Serious study is required on the problems:

i) Youth.
ii) Criminality, in particular the influence of education on criminality.
iii) How many people are capable of lifelong education.
iv) How to create new outlets for worthwhile adventure.
v) Conditioning and drugs."

It is essential to note that Gabor's list refers to technological forecasting and is not a programme for the social sciences alone. It reflects an anticipated integration of research in the natural as well as the social sciences.

The subjects which emerged from the Engineers' Joint Council report on "The Nation's Engineering Research Needs 1965-1985" (*lit. ref.* 264) are most revealing concerning to what such an integration might amount in the engineering area. The following sub-fields were selected "for which existing institutions and programs have appeared inadequate":

Allocation of Research and Development Resources in the **USA;**
Energy and Mineral Resources;
Physical Environment Control;
National and Metropolitan Transportation;
Engineering in Medicine;
Engineering, Science and Education;
Technological Problems of Developing Nations;
Information Handling Systems;
Engineering Applications of Biological Processes or Systems;
Engineering Education;
Technical Information Flow;
Professional Societies.

One of the four overall conclusions drawn in the final report that resulted from this effort, apart from the statement that "the needs of people and society are not given sufficient attention in the allocation of research and development funds," stresses the need to link industrial objectives with social goals (see also section 1.6.2.): "The fragmentation of most industries has led to concentration on materials and devices with little relationship to the technical and socio-economic systems within which these materials and devices must function. Only those industries with large, integrated responsibilities, and that have been organised in the past few decades in co-operation with the public interest have developed effective systems providing service to the general population. Increased attention should be given to systems studies on problems affecting economic growth and the welfare of the population in order to optimise the use of highly developed materials and device technologies." Examples of the positive exceptions are the communications field, power distribution, and fuel distribution.

The difficult problem of *quantification* in social technology, which involves —to some degree—negotiability of values, has been briefly discussed in section 1.6.4. The cost/effectiveness approach is attempted in the few pioneer efforts that can be discerned at present.

Chapter 1.8

INFORMATION SCIENCE AND TECHNOLOGICAL FORECASTING

Information in itself is silent; it is the use to which it is put, in terms of inferring, interpreting, projecting, analyzing, manipulating, computing and decision-making, that is important.

Oskar MORGENSTERN.

Siegel (*lit. ref. 62)* remarked, in connection with the problem of technological forecasting, that information had become fundamental economic and technological " stuff," comparable to energy and matter, which connects entities such as concepts and phenomena.

The basic obstacle today to a better use of information for technological forecasting is the absence of future-oriented categories in current classification systems. The search for information pertinent to forecasting tasks—information in technological, economic, political, and social areas usually has to be combined—proceeds along lines of cross references, personal hints, inference, and chance, much as the search for scientific and technical information was conducted in most cases 10 years or more ago. There is even one additional obstacle in the present case: there exists nothing which resembles a systematic abstract service.

Two abstracting services, covering a primarily socio-economic-political publication sector dealing with the future, have been, or are shortly to be, created:

A series of six issues, in French, under the heading " Les futuribles à travers livres et revues " (Possible futures, through books and periodicals), that have appeared from 1963 to 1965 within the framework of the irregular series " Futuribles," which in turn formed part of the " Bulletin SÉDÉIS, " published by SÉDÉIS—Société d'Études et de Documentation Économiques, Industrielles et Sociales, 205, bd. Saint-Germain, Paris-7e (France). The corresponding numbers and dates of the "Futuribles" series are: No. 61 (1 July 1963), No. 67 (10 Nov. 1963), No. 77 (10 May 1964), No. 83 (1 Nov. 1964), No. 104 (10 Nov. 1965), and No. 107 (20 Dec. 1965). They contain approximately 200 thorough and informative abstracts (one page on the average) of a world-wide selection of pertinent articles. Few of them have a direct bearing on technological forecasting. As of 1966, the " Futuribles " series is being continued within the framework of a monthly publication, " Analyse et Prévision."

A quarterly bibliographical review, "Horizonte," in German (later perhaps also in English) with short indicative abstracts, planned by the "Institut für Zukunftsfragen", Goethegasse 1, Vienna 1 (Austria). Here, too, the contents will be more particularly in the socio-economic-political area. The first issue is planned to appear in 1967.

Only one freely accessible, but not yet fully organised, ***documentation centre*** on the future exists at present: the "Institut fur Zukunftsfragen" (Institute for Questions of the Future) in Vienna, founded in February 1965, and comprising 5,000 titles at the beginning of 1966. The file will be classified in accordance with the system used by the CEDESA Africa file in Brussels.

The Stanford Research Institute in Menlo Park, California, maintains a comprehensive future-oriented information centre, called the Planning Library, attached to its Long Range Planning Service (LRPS), which is accessible to the staff of the institute, subscribers to the LRPS, and selected guests. Its principal advantage is that it keeps the original articles or photocopies in the files, which are arranged according to the LRPS report (a thick file for each of the reports—more than 280 by mid-1966—containing an annotated copy of the report and all the background material used for it), and also according to a number of general subjects such as "forecasting," "planning," "analytical methods," etc.[1]). The Planning Library represents the future-oriented contents of 600 periodicals which are followed regularly by the LRPS staff. The establishment of a computerised information retrieval system, requiring, as an initial step, subject-matter classification by multiple indices, is under consideration for 1968 or later.

There is no doubt that future-oriented information centres will assume great importance within the next decade on the broad social and economic areas. They will help in coping with the forecasting tasks arising on the national level. Industry will use them as a source of inputs to its comprehensive management information systems (see section 11.5.2.) which will probably come into use in the second half of the 1970's. Public information centres devoted exclusively to the needs of technological forecasts are unlikely to come into existence.

The only operating computerised ***information retrieval system*** for the purposes of technological forecasting found during the present investigation is the reporting system of Samson Associates, New York/Quantum Science Corporation, Palo Alto, California, for the preparation of "Samson Trends" and "MAPTEK" (see section 11.3.11. and Annex A.1.12) as well as for corporate consulting work.

The potentialities of information retrieval, as well as future developments in the area of information technology, will be outlined in greater detail in section II.3.1., and particularly in section 11.5.2.

At present, technological forecasts are usually not based on systematic literature evaluation. This astonishing fact is due not only to the lack of a readily applicable classification system, but also to the organisational gap that usually separates forecasting work from research and development, which has recently learned to make use of advanced techniques in the utilisation of literature. Apart from forecasting institutes, literature is systematically—but not comprehensively-evaluated only in military environments, where 100 to 200 periodicals are regularly followed.

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1. **This report profited considerably from the use of these general files.**

In Europe, a desire is often expressed for an "*early warning system,*" meaning a systematic screening of new scientific results and tentative interpretations, at an early stage, of a potential vertical technology transfer. This approach, sometimes also called "scientific forecasting" because it tries to bridge the gap between fundamental science and future technological application, is more or less systematically followed by the periodical "New Scientist" (UK), which is a lone fighter in this area and depends primarily on the imagination and expert knowledge of its staff and regular contributors. Evidence of how welcome such an effort is may be found in the statement of the Swedish Defence Research Establishment (FOA) that the "New Scientist" is the most valuable of all literature sources used for technological forecasting at FOA.

It is frequently suggested that an international organisation should assume the responsibility of providing, on a more comprehensive basis, such an "early warning system" as well as bibliographical references pertinent to "scientific" and technological forecasting, with periodic updating. Such an effort would require the part-time services of a relatively large number of scientists from various disciplines.

It should be emphasised here that an "early warning system" would constitute an entirely exploratory element in the technological forecasting of its users. It would point out opportunities which—as has been shown in the previous chapters—do not, in themselves, provide much incentive for innovation. Such an "early warning system" can become fruitful only in user environments where technological forecasting with a clear normative component is already established. Furthermore, it seems essential that the "early warning system" be as unbiased as possible so that it may open up the broadest number of possibilities for normative thinking; consequently, it should present opportunities on a fundamental level.

Information on forecasting techniques is, in general, exchanged without proprietary considerations. Section 11.1.1. will discuss this point in greater detail. However, contact between people active in this area does not yet seem to be very close. The desire for improved exchanges of views, of proposed techniques and of experience is frequently expressed.

The openness of the discussion in this field in the United States is illustrated by the fact that United Aircraft, preparatory to starting formal planning in 1962, attended nine seminars on the organisation of planning, the majority of which were held by industrial companies for their internal purposes with United Aircraft as "guest."

Finally, in the field of forecasting and planning techniques on the ***aggregated level,*** the newly created Centre for Planning and Projection in the Research and Planning Division of the Economic Commission for Europe (ECE), a United Nations agency, could potentially become a "clearing-house" for such techniques used at national level or within governments. It might also become the vehicle for some East-West exchange in this area.

Chapter 1.9

ACCURACY OF TECHNOLOGICAL FORECASTING

Never measure the height of a mountain until you have reached the top.
Then you will see how low it was.

Dag HAMMARSKJÖLD.

Technological forecasting within the framework outlined in the preceding chapters is only a few years old. Its greatest value lies not so much in its accuracy, but in its contribution to planning strategies. The judgments passed upon it are usually based on earlier examples which typify the premature stage and are characterised by the lack of ***systematic and comprehensive analysis.*** Frequently such older forecasts reflect opinion rather than study. This had a devastating effect on the art of forecasting, a subject on which almost everybody believes he is capable of forming an opinion. There was often a failure to resist "wishful thinking," and forecasting has sometimes even been regarded as a means of impressing the public[1].

Another important difference between earlier forecasting and its present form is due to the changing ***nature of technological innovation and planning*** (discussed in some detail in Chapters 1.5. and 1.6. above) and also, to some extent, of fundamental research (Chapter **1.4.).** The self-fulfilling power of a prophecy makes itself felt much more dramatically today when technological change has become so swift and reacts to changed attitudes and goals much more sensitively than ever before. In addition, the conditions for normative forecasting have really existed for only the past 25 years (see Chapter 1.2.). Earlier forecasts constitute a more or less helpless, purely exploratory attempt to grasp trends and to extrapolate them by implicitly assuming a certain inertia of specific developments and of historical movement in general. That the inertia of society can be influenced by technological developments did not generally occur to the early forecasters.

A third difference lies in the fact that ***alternatives*** were rarely taken into account and ***evaluated systematically.*** Where this point was not neglected, valuable technological forecasts were achieved a relatively long time ago. For example:

The " Von Kármán Report " in **1944** ***(lit.*** ref. ***319),*** which considered its main purpose to lie in the search for alternatives in gas turbine

1. In big companies " popular " technological forecasting has sometimes been found on the same executive floor on which serious forecasting is evaluated for its incorporation into planning. For example, the Chairman of the Board of General Electric (who forecast, in 1955, the widespread diffusion of the " electronic kitchen " and other forms of household automation within 10 years), and of RCA (see lit. ref. 279), have each indulged in " popular " forecasting.

development for aircraft propulsion, and subsequently became **a** useful tool for action programmes for several years; it even assessed future supersonic aircraft fairly correctly. In **1940,** a committee appointed by the **US** National Academy of Sciences to evaluate the proposed gas turbine (quoted in ***lit. ref. 89*),** with von Kârmân, Kettering, Millikan, and other prominent members, apparently took a one-track view and arrived at a forecast for the weight to power ratio which was too high by a factor of 35. One year later the first gas turbine flight was achieved in Germany.

Schurr and Marschak's ***(lit. ref.*** 336) assessment of the economic aspects of nuclear energy in **1950** (at a time when no physical and technical information had yet been released), which went somewhat astray in the assessment of electricity generating costs from nuclear power on the basis of rare hints regarding the technology involved, but achieved remarkable results following a thorough discussion of potential impact on nine technical sectors. In contrast to this, at about the same time, a study sponsored by the US-AEC ***(lit. ref. 331*),** which had access to the necessary scientific and technical input information, went completely wrong because of the superficial and oversimplified view it took of the potential impact.

Harrison Brown's " The Challenge of Man's Future " ***(lit. ref. 258)*** in **1954,** and the summary account of symposia held at the California Institute of Technology in **1955-56 (*lit. ref. 259*),** both of which have proved to be valuable because they took the approach of discussing alternative uses of natural resources on the best available basis.

To some extent, a project that probably represented the first ambitious technological forecasting attempt at national level, carried out by the **US** Natural Resources Committee in **1936-37 *(lit. ref. 284)*** and having the advantage of Gilfillan's participation. This effort was valuable in pointing out trends and potential impacts in economic sectors; however, its technological assessments were based on opinion, not on analysis.

It is not the purpose of the present report to survey the numerous instances of incorrect, and the probably less numerous instances of correct, technological forecasting in the past. What is important, however, is that most of the shortcomings of such forecasts can be rationally explained[1]. The much more rigorous framework which has made a serious art of technological forecasting—though not yet anywhere near an exact discipline—makes it possible to avoid them. Although, from a certain point of view, the end of the "poetic" era may be regretted, the requirements of planning today necessitate a more analytical, unprejudiced—and also a more painstaking—approach.

Most of the ***"first ideas " of possible inventions*** do not represent thinking on a solid scientific or technological foundation, but point rather to anticipations of future needs and desires; in this respect, they can be compared to the use of intuitive thinking for the recognition of social goals. It would

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1. Dr. Mordechai Kurz of the Hebrew University in Jerusalem (Israel) recently undertook a study of past innovation from the point of view of possible courses of action had the potential been recognised as soon as the elements for a correct forecast were given. The results of this study were not available in time for this report, but will be published in the Stanford Research Institute's Long Range Planning Service.

probably be worthwhile to evaluate these " forecasts " as reflections of changes in expectations, hopes, fears, and disappointments. Such an evaluation would certainly show, for example, that the social context was almost always grossly misjudged through a naive expectation that the impact of technological change would be sufficient to improve the social system. Almost all early forecasters of nuclear energy adhere to one of two extreme conclusions --cheap or free use of energy bringing about a Golden Age of abundance for all and the end of a competitive economy, of wars and tensions, etc., on the one hand, and a gloomy picture of the destructive uses of nuclear energy, on the other. (See also Chapter 1.7. regarding the more recent recognition of the necessary effort to make technological and social developments converge.)

Some of the early forecasts by " experts," as we would call them today, bear testimony to a remarkable ability to ***recognise ultimate potentials***. Perhaps the most outstanding example here is the German engineer Plessner who, in 1892, forecast technological developments (supercritical steam and metal vapour turbines, for example) and functional capabilities (voice-operated typewriters, television, etc.) which were—and to some extent still are—far in the future. Such ultimate potentials play an important role today in technological forecasting if used in a discriminating way and assessed in a feasible time-frame. It would be indeed easy to forecast hundreds of possible future developments in Plessner's manner—but the primary task has now become that of selecting technological and end-use goals from among an abundance of opportunities. Our knowledge in the fields of astronomy, mechanics, thermodynamics, and nuclear fission, for example, now enables us to make projections of the potential of nuclear rockets—even in a fairly descriptive way regarding the technologies involved—sufficient for a space programme reaching far into the 21st century. And our recognition of further options for rocket propulsion—up to the ultimate potential of photon propulsion—permits us to speak, in vaguer terms, of any space mission man could ever hope to accomplish.

That some of the early " expert " forecasts turned out to be fairly successful has been proven by Gilfillan ***(Zit.*** ref. 243) who, in 1936, assessed the outcome of earlier broad forecasts:

The forecasts contained in an article in the " Scientific American " of October 1920 ***(lit. ref. 280),*** aiming ***75*** years into the future, read as a " very reasonable, clear-sighted preview " 16 years later. The status of the 65 definite preductions of future inventions was as follows in 1936:

38	per cent	already verified
29	»	nearly certain to be verified
8	»	proved wrong
3	»	will probably be proved wrong
22	»	uncertain

Assuming a 50/50 chance for the uncertain items, Gilfillan concludes that 78 per cent of this broad technological forecast was successful —and for the bulk of the items long before the set time-depth. Omissions, such as radio-telephone broadcasting and talking pictures, are explained by Gilfillan as failures to foresee the usefulness of known inventions rather than as failures to recognise technological feasibility.

Steinmetz, the eminent "chief scientist" of General Electric, made 25 predictions relating to housekeeping in 1915. By 1936, their status was the following:

28 per cent fulfilled
48 » destined to be fulfilled
24 » doubtful
0 » proved wrong

Edison's broad forecast of 1911 had similar success; many items were still in the future in 1936.

Analogous results could be demonstrated for three or four other broad forecasts, including a series which Gilfillan (who does not consider himself a technical "expert") had ventured in 1912 and 1913.

As some sort of a test of what a technically untrained man could achieve through a systematic approach, Gilfillan included in the same report (1936-37) his own list of 25 dissimilar methods, invented or under exploration, by which airplanes could cope with fog, and predicted that at least some of them would come into use in view of the obvious incentive. Sixteen years later (*lit. ref. 40)* he could state that nine of the 25 methods were in use. The most important invention in this field, however,—radar— had not been forecast because Gilfillan did not know of the (secret) development underway in 1936.

Ayres *(lit. ref,* 89) gives a list of potential ***pitfalls in technological forecasting*** which holds equally for past and present forecasting:

1. ***Lack of imagination and/or "nerve"*** which tends to make forecasts over-pessimistic. Lenz *(Zit. ref. 151)* mentions several examples of incorrect forecasts which could have been correct with unprejudiced extrapolation of time-series.
2. ***Overcompensation,*** illustrated by Clarke's statement (*lit. ref.* 262) that "anything that is theoretically possible will be achieved in practice, no matter what the technical difficulties, if it is desired greatly enough"[1] and the typical Soviet attitude that "in our day man's genius can accomplish anything."
3. ***Failure to anticipate converging developments*** and/or changes in competitive systems. One widely-publicized forecasting failure can be explained in this way: in 1945, both Lindemann (later Lord Cherwell) in the UK and Vannevar Bush in the US predicted that ICBMs (intercontinental ballistic missiles) would not become competitive with manned bombers in the foreseeable future. They did not foresee the development of the H-bomb (although the potential was well known at that time) and its consequences for warhead miniaturisation which makes it possibles to *(a)* transport high explosive power by an ICBM, and (*b*) ease the stringent requirements for the precision of target-hitting. Similarly, the recent disappointment with a failure of this type has contributed to the present hesitation of ODDRE (the Office of the Director of Defense Research and Engineering in the

1. Following his own advice, Clarke forecasts that gravity-control will be achieved by 2050 AD and human immortality by 2100. G. H. Stine (as quoted by Ayres), by extrapolating exponential time-series and envelope curves, finds that—with a deliberately radical attitude—one would forecast that by 1981 an individual man will have available under his control an amount of energy equivalent to that generated by the sun, the speed of light will be attained by man in 1982, and anyone born after 2000 A.D. will live forever (barring accidents).

US Department of Defense) to build up a systematic forecasting activity: project "Principia," an attempt to forecast rocket potentials on the basis of fundamental and ultimate potentials in rocket fuel, was virtually "overtaken" by actual rocket design which became possible through advances in other factors, such as higher nozzle temperature, etc.

4. ***Concentration on specific configurations,*** rather than extrapolation of aggregated figures-of-merit (macrovariables). In this context, Ayres points out the dangers of too much "expertise." One may add here the powerful effect of scientific "cliques" (or schools of thought), which can be held responsible for another failure by Lindemann, the notoriously erring scientific advisor of Churchill. He was a member of the "clique" which believed exclusively in solid-propellant rockets—as a consequence he declared that the German liquid propellant rocket V-2 just could not fly when shown photographs of it prior to its use against London.
5. ***Incorrect calculation.*** Astronomers seem to provide the show-window examples of this category of failure. Simon Newcomb, eight weeks before the first flight of the Wright brothers in 1903, called flight "one of the great class of problems with which man can never cope" on the grounds that the physics of lift and drag ruled out flight by heavier-than-air craft (the correct calculation was made only after the demonstration of flight, although the theoretical elements were available before). Also incorrect was the calculation by the Canadian astronomer J.W. Campbell in 1941 (quoted by Ayres) that a moon rocket would have to weigh one million tons in order to carry one pound of payload (an error of six orders of magnitude, due to unrealistic assumptions). The statement by the British Astronomer Royal that space travel was "utter bilge," made in 1956, only one year before Sputnik I, is still fresh in one's memory.
6. ***Intrinsic uncertainties and historical accidents.*** Ayres discusses an interesting list of "What, if..." questions which could be asked in fundamental science as well as technology. However, historical accidents would not appear to be a primary cause in changing the paths of development. The numerous cases of multiple inventions achieved independently and at about the same time indicate that there is something like a mainstream of technological development which is not radically influenced by individual action.

The general experience of industry with well-established forecasting functions is satisfactory and seems to prove that, within the limits of practical requirements, ***correct technological forecasts*** can be made. Practical requirements often mean—as has been pointed out in the preceding chapters—that precise estimates have to be made for the advanced development stage only, or the coming five-year plan, respectively, whereas the recognition of technical options is the aim of longer-range forecasting.

Marschak ***(lit. ref. 52)*** evaluated the development of the TH microwave relay system at the Bell Telephone Laboratories. The priorities set were: 1. Performance objectives, production and operating costs. 2. Development time. 3. Total development effort. Accordingly, the first two points were attained completely, whereas development effort was underestimated (401 actual man-years against an estimate of **236)** at the beginning **of** the five-year development. Two " rounds " of technological forecasting were carried out. The first of these, two years before full-scale development started, aimed at formulating broad objectives and requirements for certain " key " components, at identifying alternative sets of major systems characteristics and at an assessment of economic demand. The second, before the start of full-scale development, included precise systems objectives, costs, time, and the detailed development schedule.

In general, there is a ***strong interdependence between technical performance, development time, and development costs*** (and also production costs which may be regarded as belonging rather to performance). Marshal1 and Meckling ***(lit. ref. 246)*** and Peck and Scherer ***(lit. ref. 248,*** referring also to Marshal1 and Meckling), concluded from evaluations of case histories from American weapon system developments that cost and time estimates were grossly over-optimistic, whereas performance estimates were more nearly correct. The ratio of actual to estimated values was found to be on the average:

Development costs	**2.4** to **3.2**
Development time..	**1.6**
Performance factors..	0.8 to **2.0**

The most interesting fact here is that estimated performance was almost always attained, and often surpassed. This reflects the typical attitude of the pre-McNamara era in the **US** Department of Defense (for which these evaluations were made), which stressed the priority of performance and normally led to an extension of cost and time when the attainable performance limit was pushed higher and higher in the course of development. At the same time, the estimates prepared by industry were often deliberately over-optimistic in order to " sell " a project, or to help an agency " sell " it. Since 1960, cost/effectiveness has replaced the drive for best attainable performance, and incentive-type contracts are favoured for developments in an advanced phase. It is obvious that technological forecasting by government contractors has to be fairly accurate for advanced development under an incentive-type contract with substantial penalities and bonuses attached to each scheduled development step, **In** spite of the hard life this implies, the **US** aerospace industry generally likes the incentive-type contract principle. Incentive contracts and fixed price contracts are usually coupled with cost plus fixed fee **(CPFF)** contracts (for the exploratory development phase); however, incentive and fixed price contracts accounted for more than two-thirds of the total value of **US** Department of Defense and **NASA** contracts in 1965. **In** this context, independent research and development **(I** R & D), initiated by the contractor, is also officially encouraged ***(lit. ref. 238).***

The general experience of industry in the civilian sector, which is under less stress, indicates that estimates of ***technical performance and economic demand,*** and often of development time as well, tend to be ***over-pessimistic,*** whereas development cost is assessed correctly or slightly over-optimistically. The ultimate technological potentials and limitations, which largely determine the extrapolation of time-series (see section II.3.3.), also tend to be estimated on the pessimistic side—a factor which is giving rise to fundamental research programmes to improve the fundamentals (see Chapter 1.4.).

Examples of over-pessimistic assessments of economic demand on new technologies are:

IBM's estimate in 1955 of installed US computer capacity in 1965: the estimate was 4,000 units, as against the actual number of 20,000.

General Electric's forecast of nuclear power capacity in the United States in 1980:

1962 as contribution to US-AEC forecast	67,000 MW	
(US-AEC modified it to)	40,000	»
1964 revised forecast	80,000	»
1966 revised forecast	105,000	»

United Aircraft's estimate of jet aircraft utilisation for 1970, made at the beginning of large-scale commercial jet transport (around 1958): it was out by a factor of 3 on the pessimistic side.

The Chairman of the Board of United Airlines, which today is the free world's largest airline, recently *(Ut. ref. 247)* admitted that he had "never visualised the speed and comfort of today's jet travel, the volume of air traffic, or the role of air transportation in American national life."

Remarkable examples of ***correct assessments of economic** demand* are:

A.T. & T.'s 1950 forecast on telephone installation and traffic, still "pretty close" for 1966.

ICAO's (International Civil Aviation Organisation) jet air traffic study of 1957-58, before commercial use, representing a rather bold forecast on the basis of somewhat insufficient information; it has proved to be surprisingly correct up to the present (1966).

A number of forecasts concerning the development of integrated circuits, starting in the mid-1950's. Apart from such leaders in this development as Fairchild (which did not bother with economic demand until success had been achieved because of the general recognition of tremendous impact potential), a number of "outsiders" claim to have made correct forecasts: IBM (1957-58, general potential and time-frame); Arthur D. Little (1959, general potential; 1962, thorough study, with price and demand projection through 1970, good "on line" so far); ITT (1961, price development, correct to $\pm$ 10 per cent so far); FOA, Sweden (1961, correct forecast of military implications; 1963, Sweden among first users); Samson Trends (published 1963, price and demand development, good "on line" so far). Considering this list, which starts 6 years before the first delivery of integrated circuits, one cannot help feeling that part of the European industry was taken by surprise quite unnecessarily[1], in view of the potential of technological forecasting.

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1. There was a widespread belief in Europe that integrated circuits were a typical defense and space development which would only gradually make an impact on the civilian market, and that this time was relatively far off. However, integrated circuit development was primarily aimed at the civilian market by Fairchild and others. The effects of this misjudgment by "gross neglect" are hitting the United Kingdom—the second largest electronic systems producer in the free world—fairly hard. The first technological forecasting in the UK to recognise the potential of integrated circuits was made by Elliott-Automation in 1963/64, after integrated circuits had already reached the military market, and prompted the procurement of a Fairchild licence. Other companies, and the British government, realised their neglect only in 1965. On the European continent a number of companies assessed the potential correctly in 1963/64 and adapted their policies accordingly.

A striking example **of *over-pessimistic assessment of development time*** is that of fast reactors. The estimates of the time when the **first** big **proto**type of an economic fast power reactor would be ordered have evolved **as** follows:

About **1955-1960,** general belief	**1990-2000**
1962, US-AEC..	**1985**
1962, Westinghouse (US)	**1980**
1962, General Electric **(US).**	**1975**
1964, General Electric **(US).**	**1970**
1965-66, CEGB **(UK)**	**1970**
1966, General Electric **(US)**	**1969**

Technological forecasting provides, of course, no guarantee of knowledge of the future. The case of two large American computer manufacturers is at present a source of amusement to "insiders": both have tried to assess, by thorough technological forecasting, the future potential of cryogenic memories for computer storage systems—with the result that one company **has** terminated its project in this field, while the other is pushing its project with the greatest vigour. Evidently, one of the technological forecasts must be wrong, as carefully and expertly as it may have been carried out.

The success of technological forecasting is reflected statistically. **The** number of "flops" is reduced, but not to zero. The general confidence encountered in almost all companies with systematic technological forecasting will be more solidly based after ***evaluation of past case histories*** permits statistical conclusions. Quite a number of compaoies have incorporated such an evaluation—and feedback—system in their forecasting function. Examples are Plessey (UK—the experience with five-year forecasts over the past 10 years is described as very satisfactory), Standard Oil of New Jersey **(US),** ASEA (Sweden—starting now), and Royal Dutch/Shell (mainly in aggregate terms).

The general *conclusion* may be drawn that industrial technological forecasting in a modern sense—which has been spreading widely **only** since the end of the 1950's—gives results which are encouraging and that, in companies with greater sophistication in this area, the desired results from the point of view of accuracy, awareness, and long-range implications can be attained in the form of marked statistical improvement over a state of no-forecast.

Part II

TECHNIQUES RELATED TO TECHNOLOGICAL FORECASTING

Chapter II.1

TECHNIQUES IN PERSPECTIVE

The key to progress in forecasting is not yet the use of a particular tool. It is, as in other fields of intellectual inquiry, the maintenance of a proper viewpoint—a viewpoint expressed in Whitehead's succinct injunction to seek simplicity and also to distrust it.

Irving H. SIEGEL.

II.1.1. INCENTIVES AND OPPORTUNITIES

Siegel's words, written in 1953 *(lit. ref. 176),* still characterise the situation today and will be valid for quite some time to come. It may even be generally stated that techniques at present are not developed to replace the " viewpoint " emphasised by Siegel but to enforce and improve the selection of proper " viewpoints. " Even with techniques, technological forecasting today is much more an art than a science. Virtually all users of special techniques in technological forecasting stress an aspect of their experience which they invariably consider to be the most valuable: that the use of techniques greatly enhances the recognition of relevant factors, their relationships with the problem in question, and their inter-relationships.

The bulk of technological forecasting today is done without the explicit use of special techniques. However, it would be difficult to draw a clear dividing line between use and non-use. The adoption of a " viewpoint, " or a general attitude towards the forecasting problem, structures thinking and " informed judgement " in a characteristic way and may imply qualitative or even quantitative relationships between factors. If these elements are stated explicitly, they may add up to a simple formal model which can be used for the simulation of the partial processes involved. Almost every practical intuitive forecast uses implicitly one or more iterative steps between exploratory and normative thinking, with cross-checking against an " environmental matrix. "

The need for formal techniques was not felt until a few years ago. While the beginning of systematic technological forecasting can be situated at around 1950, with forerunners since 1945, the existence of a more widespread interest in special techniques first made itself felt about a decade later, in 1960, with forerunners already experimenting in the late 1950's. Now, in the mid-1960's, a noticeable interest is developing in more elaborate multi-level techniques and integrated models that are amenable to computer programming. The first tentative ideas for an integration of technological forecasting models into future systems of information technology are being sketched in informal papers.

Just as, during the past few decades, and even in past centuries, there has been occasional technological forecasting, in similar fashion, a few very simple techniques—corresponding to basic attitudes rather than to simulation—have long found occasional use: trend extrapolation on a phenomenological basis, brainstorming, and possibly some early versions of "scenario-writing." An elaborate multi-level technique formulated in 1942—Zwicky's "morphological approach"—did not receive wide diffusion and has continued to suffer an unfortunate fate ever since, although it is complementary to other more recently developed elaborate techniques and fills a "gap" that can be recognised today.

Technological forecasting is one of the latest additions to a family of systematic forecasting activities. If the very old art of weather forecasting is omitted from consideration, a number of "precursive" activities are encountered as part of this family such as economic and business forecasting, while forecasting in the political and social areas is more or less developing parallel to technological forecasting. From the techniques point of view, there is considerable "cross-fertilization," but perhaps less than one might expect or than would appear feasible. Economic analysis on the basis of discounted cash flow methods is a valuable addition to technological forecasting, as is the use of certain matrix techniques. More elaborate econometric and business models can be adapted to problems of technological forecasting only within certain limits; in general, the economic and business areas have developed sophisticated techniques only for short-range forecasts, whereas the main interest for technology is in long-range forecasts. However, there are numerous refinements which have arisen from the concentrated effort on the economic and business forecasting techniques that may be adapted, such as risk evaluation and various forms of probabilistic forecasting.

On the other hand, forecasting techniques developed in the political, social, and technological fields—especially those centering on "social technology"—can to a considerable degree mutually benefit from each other. Military forecasting in the non-technological areas may also produce some "spin-off" in the form of techniques.

The two basic approaches that are making the deepest impact on technological forecasting techniques—operations research and system *analysis*—were first explored and developed in response to military incentives. Operations research dates back to World War II developments in the United Kingdom and the United States, and systems analysis has been pioneered by the RAND Corporation in the United States since 1948. Critical path and PERT methods (the latter developed for the Polaris missile program) also sprang from military planning requirements.

These developments would seem to constitute a vast source of technological forecasting techniques which has so far been exploited only to a small degree. While the possibilities of reasonably sized tasks for operations research and systems analysis are nearly exhausted in the military field—there are almost no problems left in US defense that can be solved with linear programming—technological forecasting is only starting to explore them for its own purposes.

Another very important area of "precursive" activity is *computer* development and the vast evolving field of *information* technology. Technological forecasting has not yet acquired sufficient "status" to inspire developments in these areas, but in a few years it will find a ready-made framework for decision-making in business, military, political, and possibly social environments, and will be accommodated without difficulty.

The *mode of diffusion* of ideas and concepts in the area of technological forecasting techniques is comparable to modes that can be observed in early research phases in many fields. A glance at the bibliography at the end of this report, in particular at its sections dealing with techniques, will confirm the impression that a relatively large number of significant ideas are first communicated by internal reports, informal papers, unsolicited proposals, conference papers, preprints of tentative versions of manuscripts, and other forms outside the realm of " open literature." Generally, this has nothing to do with the possibility of these ideas being of a confidential nature. Rather, the tentative and exploratory nature of many of the ideas prompts their authors to communicate through informal " progress reports " material which will later be written up in generally accessible publications.

A company such as Honeywell (US), with justifiable pride in its PATTERN scheme (*see* section 11.4.5.) after two years of testing and the first year of successful full-scale operation, adopted a policy of encouraging publication and conference contributions. As the inclusion of a technological forecasting function is regarded, by a number of companies with a modern public relations concept, as a positive " image "-creating factor, the use of special techniques is also bound to be so regarded. The open attitude encountered in this connection played a decisive role in the collection of information on forecasting techniques for this report.

Among periodical publications, the " IEEE Transactions on Engineering Management " (Institute of Electrical and Electronics Engineers, New York—until 1962 published by the Institute of Radio Engineers as " IRE Transactions on Engineering Managment ") have become the " home " of papers on ranking procedures for research and development projects, based on economic analysis, operations research, and decision theory approaches. More recently, the Battelle Memorial Institute, which follows a policy of open publication of techniques in this area, has chosen the Design Engineering Conferences of the ASME (American Society of Mechanical Engineers, New York) as a vehicle for discussion, with previous publication in the series of ASME Papers, and subsequent inclusion in ASME periodicals. Occasionally, techniques are discussed in the " Harvard Business Review " and in scattered operations research journals.

The course of Professor James R. Bright at the Graduate School of Business of the Harvard University in Boston, Massachusetts, contains the first attempt systematically to teach technological forecasting techniques to management students.

Two American institutes in the general area of management sciences are now including discussions of technological forecasting techniques in their courses on long-range corporate planning:

The American Management Association (AMA) in New York, in long-range planning courses held in December 1965 and April 1966, included sessions on technological forecasting, with background papers contributed mainly by the Battelle Memorial Institute. AMA is also active in Europe and could become instrumental in spreading techniques there;

The Institute **of** Management Sciences in Pleasantville, New York, within the framework of its " College on Planning, " seems to take technological forecasting techniques into account.

Special conferences and conference sessions, attempting to survey **the** advancing frontier in the state of the art of techniques for technological forecasting, bear testimony to the rapidly growing interest in this area:

The French periodical *Réalités,* on the occasion of its 20th anniversary, sponsored a " Colloque de l'Avenir " (" Symposium on the Future ") on 29th and 30th March 1966, in Paris, purporting to be devoted entirely to the methodology of long-range forecasting and anticipation. Forty of the best-known experts in this field attended the conference, which apparently concentrated on methods suitable to " social technology "; unfortunately, the published account in ***Réalités*** is very poor and has obviously suffered from the process of filtering down to a journalistic level.

The **US** Air Force sponsored a Symposium on Long Range Forecasting and Planning, with emphasis on techniques, on 16-17 August, 1966, at the Air Force Academy in Colorado Springs, Colorado, with attendance mainly from the armed forces; the proceedings are unclassified and are available from the **US** Government Printing Office in Washington, D.C.

Prof. James R. Bright is organising a conference on " Technological Forecasting for Industry " to be held on 22-25 May, 1967, at the Industrial Management Center, Lake Placid, New York. The results of this conference will be made available in book form (Prof. Bright has formerly published two books *(lit.* ***ref. 32, 195)*** which partly grew out **of** symposia in closely related areas.)

The National Security Industrial Association (NSIA), in Washington, D.C., is planning for autumn 1967 a classified symposium on research and development in the 1970's which is expected to include a " brilliant " session on technological forecasting, with particular emphasis on techniques.

II.1.2. TYPES OF TECHNIQUES AND THE STATE OF THE ART

The following three points are to some extent dependent on each other and are characteristic of all existing techniques for technological forecasting. They

have been developed for a " man-technique dialogue " and are very sensitive to man's knowledge and his capacity for imaginative thinking, technical and value judgment, and synthesis. Essentially, human forecasting is not replaced, but structured and enhanced, by these technique; in particular, the human forecasting potential is extended where large input and complex relationships are involved.

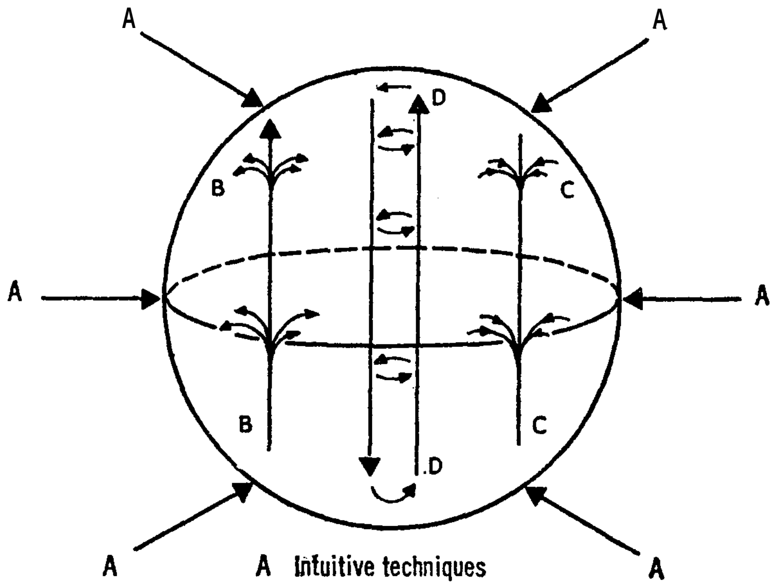
are partial techniques which cover only **a** fraction of a complete technological forecasting process; their combination may result in more highly, but not yet fully integrated techniques (on the basis of today's state of the art).

are auxiliary aids to decision-making, which normally has to be based on broader information than can be provided by these techniques.

Roughly 100 distinguishable techniques or elements of techniques are briefly reviewed and, as far as possible, outlined in the following chapters. Not all of them can be called " technological forecasting techniques " or were intended for this purpose; however, they are all related either to the entire complex of technological forecasting or to some of its aspects.

No fundamental distinction is made in this report between ***qualitative*** and ***quantitative*** techniques because there is no clear boundary line in many cases, and the same technique can take either approach. Qualitative assessment, in many respects—mergers of technologies, impact of complex systems, scenarios and anticipations of the future, qualitative goals and objectives—has attained equal importance with quantitative assessment.

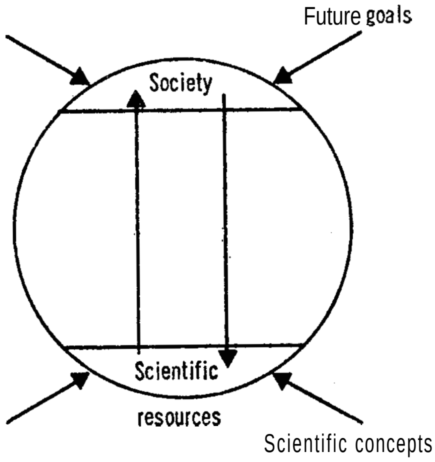
The many approaches—whose large number characterises the present experimental phase in this area—can be classified by different criteria. In line with the findings of Part I of this report, a fundamental distinction is made between exploratory and normative technological forecasting. In the technology transfer scheme, which has been introduced in Part I for the representation of the direction and levels of technological forecasting, exploratory forecasting techniques simulate movement in the direction of technology transfer, and normative forecasting techniques screen technology transfer by running against its movement. A fully integrated forecasting process is a feedback process, employing both directions. One class of techniques defies classification by this scheme: direct applied intuitive thinking, which in some way represents " a view from outside. "



A Intuitive techniques
B Exploratory techniques
C Normative techniques
D Feedback techniques

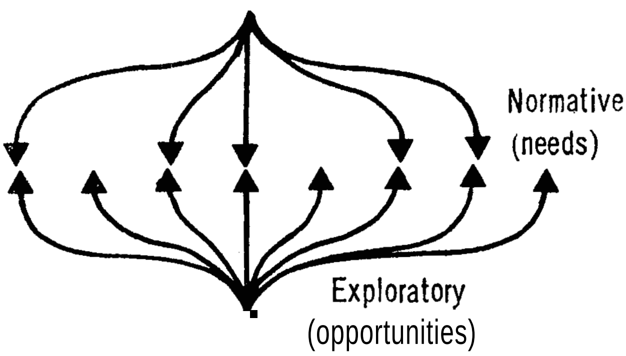
The main transform directions of these four types of techniques can then be illustrated by the use of the " technology transfer sphere, " explained in Part I. A sphere characteristic of a closed society is chosen here because normative and feedback techniques find their full use only in such closed spaces. The other techniques, on the other hand, can be fully used also in tulip-shaped spaces, characteristic of an open society (normative and feedback techniques could be used in such spaces only at the lower levels).

In the technology transfer space, the lowest and the highest levels, i.e. the " starting levels " for exploratory and normative forecasts respectively,



can be imagined to receive continuous streams of " spiritual energy " flowing in from the irrational surrounding space. These streams become visible in the form of scientific discovery and of social goals and their ethical background. (This is a very simplified picture, of course, serving only to illustrate a specific point here). No fully integrated forecasting is possible if these inflows cannot be assessed. There is no formal technique for dealing with scientific discovery through systematic exploratory forecasting in sight; normative forecasting, however, can stimulate scientific discovery and guide fundamental research. The forecasting of broad social goals and ethical patterns of the future is not a completely hopeless undertaking; as a matter of fact, schemes to improve intuitive thinking to this end, for example the " Delphi " technique (see section II. 2. 3.), and to stimulate systematic anticipation and evaluation of future goals for the sake of present as well as future action (see section II. 5. 1.), are being actively developed and tested.

In the past, technological forecasting techniques have aimed primarily at forecasting. in the exploratory direction, technology transfer up to the



level of " Elementary Technology " (still below the " equator " of the sphere) and only in the two-dimensional vertical cross-section representing the technological process itself. For the purposes of industrial product planning, a number of short-strech techniques, bridging the " equator " in the exploratory, and later in the normative, direction have been added. The extension to the higher levels, the recognition of the full potential of normative techniques, and the extension to the non-technological dimension, have been accomplished only in the past few years, and are still in a very early, experimental phase. Feedback techniques are not yet operational.

A complete technological forecast today has to match normative forecasting (needs, desires) against exploratory forecasting (opportunities).

Intuitive techniques have only recently found a first critical approach in the " Delphi " technique. Such techniques permit, in principle, " random access " to all levels. In particular, they represent at present the only hope of finding sets of valid starting points for normative techniques at the highest levels (" social goals "). The alternative—reaching up to these levels by exploratory techniques (scenarios, etc.)—would yield some sets by laborious iteration and alternative approaches, but is not sufficiently comprehensive to be considered satisfactory.

Exploratory techniques can be sub-divided into two classes which indicate their potential application:

Techniques ***generating new technological information,*** comprising the following groups: extrapolation of technical parameter and functional capability trends, " learning curves, " extrapolation of contextual mapping, morphological research, possibly also scenario-writing (not yet demonstrated);

Techniques ***structuring and processing given technological information,*** comprising the following groups: historical analogy, scenario-writing and iteration through synopsis, probabilistic transform methods, economic analysis, operational models, techniques dealing with the aggregated level.

This distinction is most important, since any complete technological forecasting process has to include one or more techniques for generating new technological information—in other words, for specifying the nature and/or some of the essential characteristics of future technologies. Although this aspect constitutes the oldest concern of technological forecasting, its state is not at all satisfactory, and may even be said to be underdeveloped in relation to other forecasting aspects. The art of trend extrapolation, which a number of enthusiastic forecasters have accepted as a challenge, deals only with a small part of the desired new technological information. Technical parameters and functional capabilities are not sufficient for forecasting impact in economic and social environments; they are more useful for military purposes for which trend extrapolation is a very valuable tool today. In the future, the art of trend extrapolation will be severely affected by feedback effects from better technological forecasting and planning. The " historical inertia " inherent in any trend forecast may be influenced significantly by this feedback; after all, such a feedback effect constitutes the very incentive for undertaking technological forecasting. On the other hand, the feedback from planning that has already accelerated progress in the military field may not be maintained at the same rate, and the trend towards more horizontal technology transfer in the civilian sector may act as a decelerating factor. We have not yet measured the dimensions of technology transfer, and to attempt to forecast the vertical component as if it were isolated constitutes a doubtful approach.

The most systematic approach to the generation of new technological information is " morphological research, " a technique for obtaining a comprehensive and unbiased spectrum of functional technological systems. sub-systems, etc. The feasibility evaluation which imparts operational value to this approach can be aided by trend extrapolation and other information-generating techniques.

If normative forecasting, which is rapidly growing in importance, is adequately to realise the promise inherent in it, it will have to be supplemented by techniques which provide as complete a spectrum as possible of technological opportunities. " Morphological research, " aided by trend extrapolation, is the best available possibility (but **is** not yet widely applied); trend extrapolation used alone is the second best (and is already being applied systematically in connection with Honeywell's PATTERN scheme for normative forecasting). Outside the realm of techniques, intuitive thinking is the reliable and still " natural " alternative as well as the indispensable cement for all insufficient and not fully integrated techniques.

The other class of exploratory techniques, those structuring and processing given technological information, are relatively abundant. Their importance will increase with the extension of exploratory forecasting to the upper (the impact) half of the " technology transfer sphere, " and with the use of large-scale forecasting to evaluate large amounts of input data and programmed relationships. **One** has only to look at the difficulties which the correct assessment of the influence of the time factor on economic benefits presents without discounted cash flow methods, to appreciate the role **of** this class of techniques. They will be essential for future feedback systems. Nevertheless, they will attain their full importance only when the modest start made at present with computer models has led to the inclusion of technological forecasting in future systems of information technology.

The application **of** ***normative techniques*** depends on a greater abundance of opportunities, primarily in the technological areas, than can be handled under given budgeting or other constraints. This is the typical situation today; however, it cannot be assumed automatically for an indefinite future as, up to now, it could not be assumed throughout man's history. *Also,* normative techniques are meaningful only in a sufficiently closed society, or for those levels of technology transfer which can be assumed sufficiently closed. This prerequisite is fulfilled today for reasonably well-defined technological programmes, such as, for example, those in the defence and space fields, and is beginning to be met for burning social or national issues in countries that are future-oriented by inclination or necessity (leaving aside the question of dictatorships in this context): the United States, France, Sweden, followed at a distance by Italy, the Netherlands. Canada, and a few others. The majority of Western industrialised countries have not yet matured to this stage (and, it will be emphasised in this report, such maturity is most necessary if dirigism is to be avoided).

In the United States, Vice-President Hubert Humphrey, then **a** Senator, introduced a resolution in the Senate on 10 September **1964,** calling for the establishment of a Presidential Advisory Staff on Scientific Information Management. On that occasion he stated: " There is an urgent need in industry and government alike for new techniques and systems for management information in assisting officials responsible for crucial policies and decisions of our society. Upon the discovery and use of such new techniques and systems depends not only the solution of many current problems, but our continuing status as a world leader... (It has become) abundantly clear that many of the current and impending problems of our society will remain insolvable until we discover and adopt information management and decision-aiding techniques which are commensurate with the changes which have occurred and will occur in our national and international environment. " **This** statement was made in the light of the favourable impression created by the successful operation of the newly-born PATTERN scheme, the most elaborate of the normative technological forecasting techniques. The " Delphi " panel on " Automation " forecast the widespread use of computerised techniques aiding decision-making in the **1970's.**

Normative techniques benefit from the present emphasis on the development of operations research, decision theory, and systems analysis[1]. A general appraisal of the value of decision theory for engineering management has been made by Combs *(lit. ref. 180).* Brandenburg *(lit. ref. 97)* and Baker and Pound *(lit. ref. 91)* have summarised and critically discussed a number of simple two-level (in terms of technology transfer levels) normative techniques, which are often referred to as " ranking procedures for research and development projects " (by which term the exploratory economic analysis approaches are usually also covered).

The best and most flexibile principle available for normative forecasting today is the relevance tree, which is the basis for **PATTERN** and a number of other techniques. **It** is also the most " transparent " principle, providing a wealth of additional insight. **A** certain limitation to the number of levels and branching points is imposed by the preparatory and updating effort, which quickly increases; the calculation work, which can be easily programmed for a computer, does not constitute a bottleneck. A particular advantage **of** relevance tree concepts, which may differ in the evaluation schemes and refinements applied to the lower levels, lies in the fact that they could use common " head-ends " prepared centrally. This may become important in areas where the government has an interest in bringing its policies to bear among widely dispersed contractors, for example in the defence or space areas.

Network techniques are promising for special aspects of normative forecasting, particularly €or the evaluation of different systems concepts. The use **of** operational models seems to be of less significance in normative than in exploratory forecasting; it will probably be applied mainly to the problem of selection from among complex alternative developments.

The potential of systems analysis has so far remained almost untapped for the purposes of technological forecasting. Systems analysis is applied by the pioneers in the field—RAND Corporation, System Development Corporation, General Electric's TEMPO Center, all in California—whose tasks frequently include, or are related to, problems of technological forecasting. Systems analysis is a general approach that has to be adapted to each new job—there is no rigorously set routine which can be easily transferred to other users.

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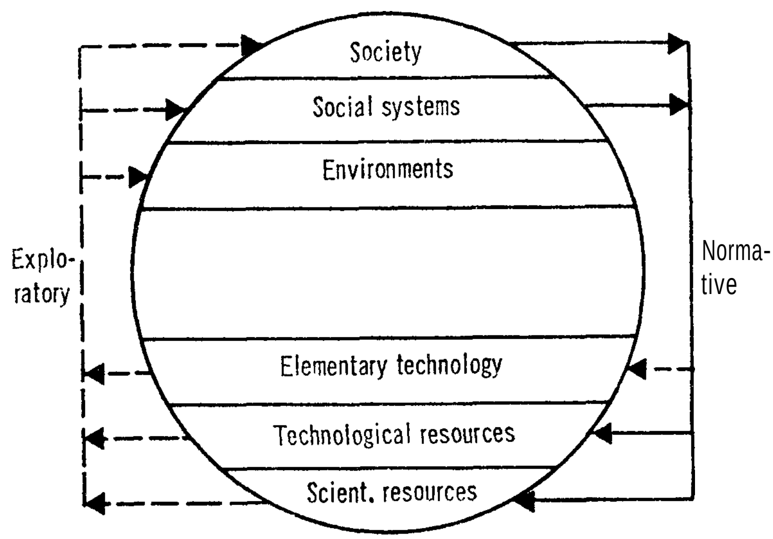
1. We are not concerned here with the varying definitions assigned to these terms, Sometimes " operations research " is taken as the heading for all three areas.

Feedback ***techniques*** may ultimately be constructed out of the elements of exploratory and normative forecasting. or will be based on newly developed elements. In principle, **it** would not seem feasible on the basis of today's techniques to combine them to form a fully-integrated feedback system covering all levels and directions of technology transfer. What do seem feasible today, however, are multi-level feedback systems on the basis of a " man-technique dialogue, " and partial feedback systems covering only two or three levels or certain directions of technology transfer.

Feedback systems are a natural consequence of the same conditions that have brought normative forecasting to the forefront. **It** may be assumed that considerable effort will be devoted to their development and perfection once decision-making techniques have been adopted in areas of broad national and social concern.

" By-puss " techniques, with the exception of intuitive thinking, have not generally been explored up to the present time (although a few qualitative techniques, such as historical analogy, seek to establish direct forecasting relationships between non-adjacent levels). Their feasibility must still be regarded is uncertain. The basic aim of " by-pass " techniques is to make it possible to start from one technology transfer level and obtain



" random access " to any other level. An urgent need for such techniques seems to exist primarily in the normative direction. In integrated normative forecasts that range from the highest to the lowest levels of technology transfer, there is **an** inevitable—and apparently substantial—loss of information. (This would be a problem amenable to exploration **by** information theory.) In addition, certain significant aspects and values seem to escape ordering by hierachic principles.

It would be of the greatest significance if reliable techniques could be developed that permitted, for example, the derivation of the necessary tasks for fundamental research and fundamental technological development directly from social goals, national objectives, high-level missions, etc. (In a way, **this** is implicitly attempted on an intuitive basis by the COSPUP reports - see Chapter **1.4.).** Such " by-pass " procedures would be even of much greater importance if alternative sets of anticipated goals—not **only** the **goals** valid at present— were taken into account in future schemes (see section 11.5. 1.). Intuitive thinking on the basis of the " Delphi ·· technique (see section II. 2. 2.) already seems to be yielding a few preliminary results in this direction by formulating future desirata in the form of functional technological capability.

A *table* of *the individual techniques* and elements of techniques which are reviewed in the following chapters is provided below and may give a broad idea of their applicability and their principal orientation. The graphic indications are necessarily imprecise and are open to discussion. Techniques extending over many levels seem to be relatively rare. Exploratory techniques are crowded into the lower (technological) levels, while normative techniques are firmly anchored in the upper (impact) levels but penetrate courageously into the technological levels.

It will be recalled that the significance of the eight levels of technology transfer was given in Chapter **I.** 1. of this report :

I = Scientific resources
II = Technological resources
III = Elementary technology
IV = Functional technological systems
V = Applications
VI = Environments
VII = Social systems
VIII = Society

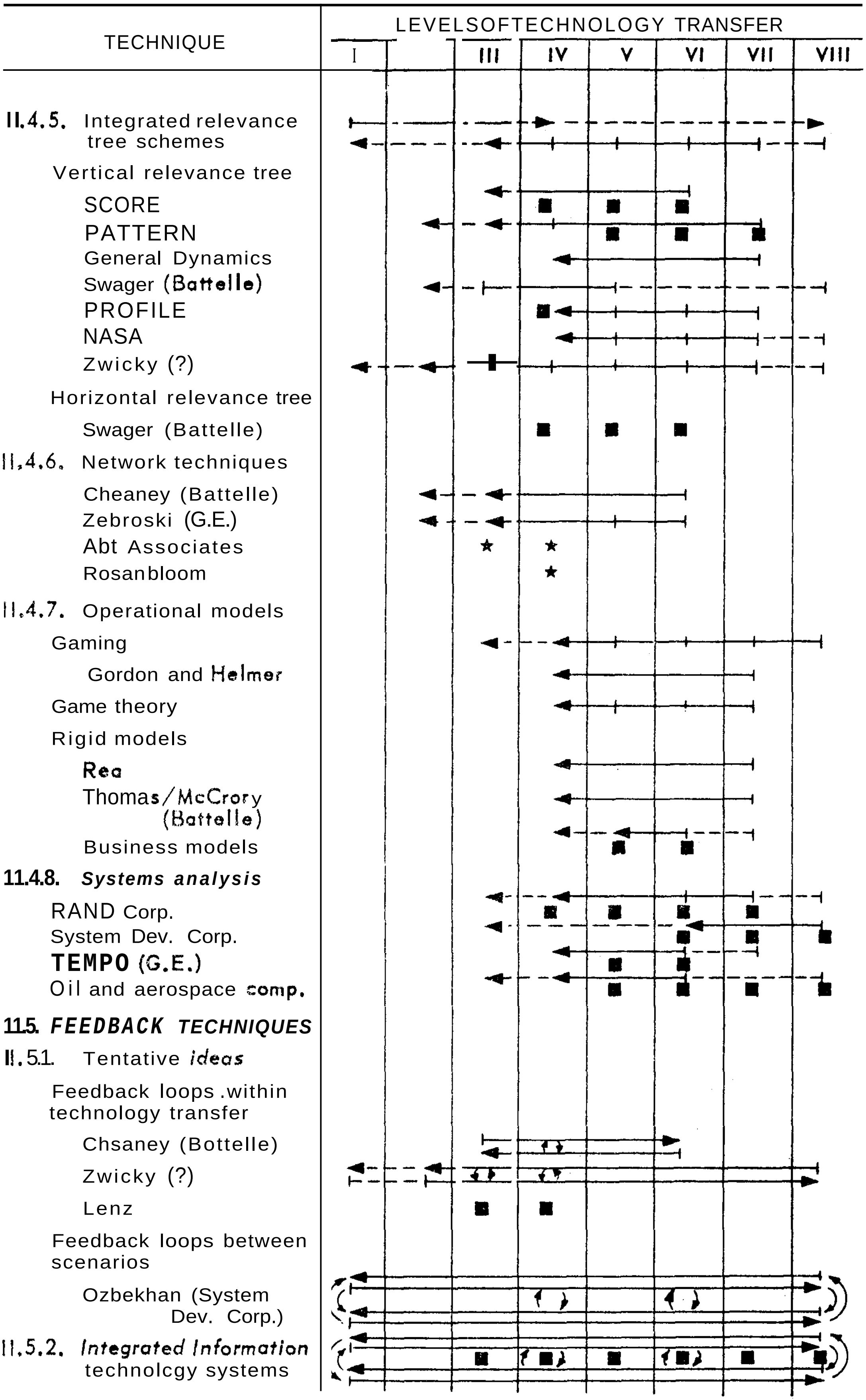
The following graphic signs are used in the table below :

* (*)	Levei of (isolated) application (with brackets : doubtful or less formal)
■	Substantial combination with horizontal factors
---+——+——►	Direction and penetration of transform method (vertical marks : individual evaluation for that level possible; dotted line : uncertain)
◄—·—- — -┤	Strong stimulation for (human) feedback

TECHNIQUE (with section number showing where it is discussed in this report)	LEVELS OF TECHNOLOGY TRANSFER I	II	III	IV	V	VI	VII	pi-
11.2. *INTUITIVE THINKING*								
11.2.2. Brainstorming								
Straight brainstorming		(*)	*	*	*	*	(*)	(*)
" Buzz group " technique			*	(*)				
" Oper. creativity "		*	*				*	*
11.2.3. " Delphi " technique				(*)				
11.2.4. Utopia and *science* fiction								*
11.3. *EXPLORAT. FORECAST*								
11.3.2. Extrapolation of time-series, anal. models								
Adams			*					
Isenson		■	●					

TECHNIQUE	I	II	III	IV	V	VI	VII	VIII
	LEVELS OF TECHNOLOGY TRANSFER							
Hartman		■	■					
Lenz (biol. growth analogy)		■	■					
Holton	⊢	— ★	→ ★					
Putnam		■	■					
Ridenour				⊢	→ ★			
11.3.3. Extrapolation of time-series, phenomenological								
Single trends	← ⊢ - -	- - ⊢	★	(★) →				
Precursive events		⊢	★	★	→ ★			
Envelope curves	←	- - -	★	→ ★				
11.3.4. Learning curves		⊢	—	→ ★				
11.3.5. Contextual mapping	← ★	★	★ *	★	★	*	*	(★)
Trend as process				★		*		
Trend as evolution				★	★			
11.3.6. Morphological research	← ⊢	★	★	★	★	★	→ ★	
11.3.7. Scenario-writing and iteration through synopsis								
Scenario			⊢ - -	⊢	■	■	■	→ ■
Iteration			⊢ - -	⊢	■	■	■	→
11.3.8. Historical analogy				⊢	—	—	—	→
11.3.9. Elements of probabilistic forecasting			⊢	■	→ ■			
Mansfield					■			
Lancoud and Trachsel				⊢	→ ■			
Propagation of variance			⊢	→				
Bayesian statistics		⊢ - -	- ⊢	⊢	→	→		
Monte Carlo					■			
Parametric sensitivity				★	■	■		
11.3.10. Economic analysis				⊢	→ ■			
Undisc. return on inv.: Olsen, Pacifico, Teal, Sobelman								
Discounted cash flow "Batch-wise" DCF: Disman, Hoskold				⊢	→ ■			
Continuous DCF: SCAIR (G.E.C.), Cramer & Smith, Dean & Sengupta								
Risk assessment: Bönke					■			
Kotler					■			

TECHNIQUE	LEVELS OF TECHNOLOGY 'RANSFER I	II	III	IV	V	VI	VII	VIII
11.3.1 1. Operational models								
Gaming								
Rigid models								
Rea				■				
Churthrnan					■			
Lent			■	■				
Abt Associates								
Battelle					■	■		
Business models					■	■		
11.3.1.2. Aggregated level								
Statistical models						■	■	
Input/output analysis						■	■	
Chains of industries						★		
Diffusion of technolog:						■		
Mansfield						■		
11.4. NORMATIVE FORECAS'								
11.4.1. Horizontal decision matrices	■	■	■	■	■			
Resources deployment			■	■				
Programme cube				■				
French res./res. matri:	■	■						
11.4.2. Vertical decision matrices								
French Res./ind. matri								
Research/ programme matrix								
Stanford Research Institute			■	■	■			
Walter (North Americar Aviation)								
11.4.3. Simple techniques, operations research approach								
Econ. analysis/OR								
Linear programming								
Asher								
Freeman								
Dynamic programming								
Hess								
Rosen & Sonder								
11.4.4. Simple techniques decision theory approach								
Check lists				■	■	■		
Hetrick and Kimball								
De l'Estoile								
Mottley & Newton								
Gargiulo								
Ansoff (ec. an./dec. th				■	■	■		
Pound (relevance tree)								
Beckwith								
U.S. Navy								


TECHNIQUE
LEVELS OF TECHNOLOGY TRANSFER
I
III
IV
V
VI
VII
VIII
11.4.5. Integrated relevance tree schemes
Vertical relevance tree
SCORE
PATTERN
General Dynamics
Swager (Battelle)
PROFILE
NASA
Zwicky (?)
Horizontal relevance tree
Swager (Battelle)
11.4.6. Network techniques
Cheaney (Battelle)
Zebroski (G.E.)
Abt Associates
Rosanbloom
11.4.7. Operational models
Gaming
Gordon and Helmer
Game theory
Rigid models
Rea
Thomas/McCrory (Battelle)
Business models
11.4.8. Systems analysis
RAND Corp.
System Dev. Corp.
TEMPO (G.E.)
Oil and aerospace comp.
11.5. FEEDBACK TECHNIQUES
11.5.1. Tentative ideas
Feedback loops within technology transfer
Chsaney (Bottelle)
Zwicky (?)
Lenz
Feedback loops between scenarios
Ozbekhan (System Dev. Corp.)
11.5.2. Integrated Information technolcgy systems

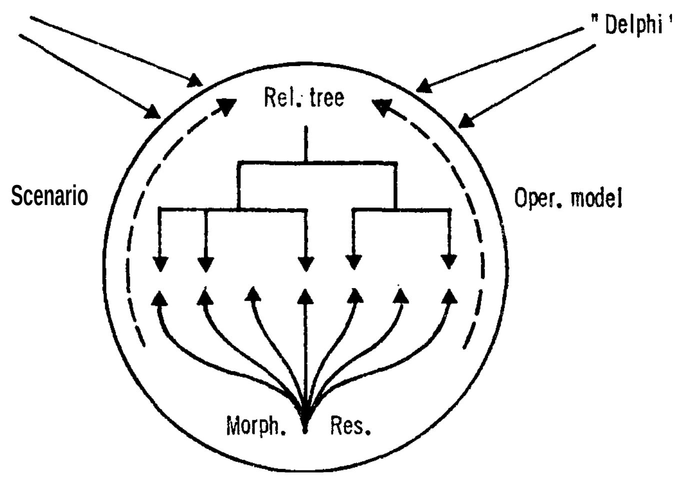
This surprisingly large number of techniques, or even of groups of techniques using the same approach, should not cause too much confusion. There are relatively few which really constitute " breakthroughs " in their area. Apart from the older art of trend extrapolation and its more recent refinements through S-curve and envelope curve extrapolation, there have been only three really important developments:

the " Delphi " technique for the improvement of intuitive thinking;
the " morphological approach " to exploratory forecasting;
the relevance tree principle as a basis for a number of normative forecasting techniques.

Future " breakthroughs " may be achieved in the areas of gaming and operational computer models, systems analysis, and feedback systems; important ideas have already been conceived in these fields.

An *optimum* complete large scale *forecasting **scheme*** would employ. on the basis of techniques in **an** operational state in 1966, a combination of the following techniques:

1. The " Delphi " technique for the unbiased selection of social and other high-level goals, possibly aided by scenario-writing or operational models in the economic, political, military and social areas.

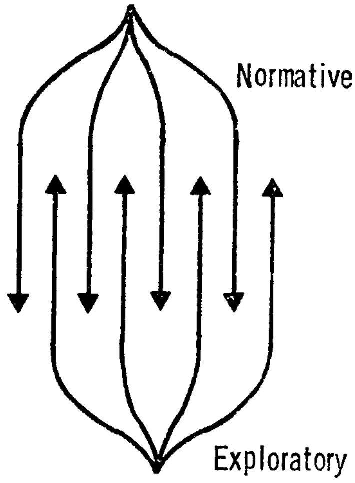


2. " Morphological research, " aided by trend extrapolation, for an unbiased exploration of possible and feasible technological opportunities.
3. **A** relevance three scheme, such as PATTERN, for the clearly structured introduction of the normative basis to make the proper selection.

Honeywell's actual forecasting scheme centred around **PATTERN** looks similar, but employs only trend extrapolation and scenario-writing.

In **an** optimum forecasting scheme embracing a limited number of alternatives (for example on the higher levels) total systems analysis would replace the relevance tree.

Different purposes will, of course, favour different optimum concepts of such a combination. Whereas, in the example above, exploratory and normative transforms meet near the " equator " and are matched there without penetrating deeply into each other's hemispheres, one may desire deeper inter-linking of the two opposite transforms. The problem in that case would become over-determined, which may not be undesirable in highly uncertain problem areas. Feedback may also be facilitated by such deeper inter-linking.



Attention may also be drawn to the importance of " bonding " between levels, or between different techniques in the same combination. Economic analysis provides an excellent means for performing certain " bonding " tasks, for example between the systems and the use level, and may assume even greater importance if economic (monetary) units can be introduced for the quantification of forecasting problems in a wider context. The first attempts to quantify social goals in terms of dollars may pave the way to a more universal " language " for the formulation of forecasting problems, which, moreover, would seem to be a pre-requisite for integrated computer techniques and for their future inclusion in large information technology systems.

Probabilistic forecasting—the evaluation of input information (data and relationships) which is introduced in the form of probability distributions so as to produce probability distributions as the output information—is being attempted, but is in a very early experimental stage. The development of probabilistic forecasting is clearly one of the crucial problems faced in the development of forecasting techniques.

Cross support on different levels, for example the usefulness of a specific material for various components, of a component or sub-system for various primary systems, etc., has so far remained in a rather unsatisfactory state. A few techniques take it into account in an additive way or by a modification of the score, and PATTERN has kept a place open in its system for future refined evaluation. The present emphasis on " communalities " in the US defence research and production programme may be expected to encourage developments along this line.

Although feedback models are not yet operational, a few techniques are particularly stimulating for feedback. This is the case, confirmed by reported experience, of trend extrapolation, contextual mapping and " morphological research, " all of them leading to a situation in which fundamental research and exploratory development are asked to provide answers to urgent questions that may trigger basic thinking or even research programmes. Problems of the greatest importance have been recognised and solved in this sequence. which came into being with technological forecast-

ing. This function of technological forecasting would seem to merit particular attention in future developments.

If the technological forecasting problem is structured by ***typical questions*** asked, the following pattern of applicable techniques emerges on the basis of today's state of the art:

QUESTION	APPLICABLE TECHNIQUE	STATE OF THE ART
1. Scientific breakthroughs.	?	
2. Technological breakthroughs.	Trend (envelope curve) extrapolation?	Uncertain.
	Morphological research.	Useful, partly proved.
	Relevance tree.	Feasible.
3. Areas of fundamenta research and expla ratory developmen to be favoured.	Trend (envelope curve) evaluation.	Proven, but limited.
	Contextual mapping.	Feasible.
	Morphological research.	Very useful, partly proved.
	Economic analysis. Horizontal decision matrix. Vertical decision matrix. Simple operations research. Simple decision theory.	Useful within limits.
	Relevance tree.	Very useful, proved.
	Normative operational models	Uncertain.
	Systems analysis.	Potentially very useful, proved.
4. Nature of technological innovation.	Brainstorming.	Doubtful.
	" Delphi " technique.	Useful within limits.
	Morphological research.	Very useful, proved.
5. Technological performance (technica parameters, functional capability, etc.).	Trend extrapolation (analytical).	Unsatisfactory.
	Trend extrapolation (phenomenological).	Useful, proved.
	Contextual mapping.	Feasible.
	Morphological research.	Useful in combination with trend extrapolation, etc.
	Systems analysis.	Feasible?
6. Development time.	" Delphi " technique.	Tested, some doubts.
	Trend extrapolation analytical).	Unsatisfactory.
	Trend extrapolation (phenomenological).	Useful, proved.
	Learning curves.	Tested, needs much further evidence.
	Network techniques.	Feasible.
7. Development costs.	Learning curves.	Unproved.
	Network techniques.	Feasible?
8. Return on investmen	Economic analysis.	Very useful, especially diecounted cash flow.
9. Production costs.	Learning curves.	Tested, needs much further evidence.

QUESTION	APPLICABLE TECHNIQUE	STATE OF THE ART
10. Maintenance costs.	?	
11. Horizontal impac (especially marke impact).	Economic analysis.	Useful in combination with other techniques.
	Operational models (gaming)	Promising, unproved.
	Operational models (rigid models).	Useful, proved for established business areas, unproved for general technological acceptance.
	Systems analysis.	Useful, proved.
12. Vertical impact.	Scenario-writing.	Promising, being tested.
	Iteration through synopsis.	Useful, partly tested.
	Historical analogy.	Uncertain, partly tested.
	Operational models (gaming).	Very promising, being tested.
	Operational models (rigid models).	Promising, unproved.
	Systems analysis.	Useful, proved.
13. Lower level goal (tasks, missions, etc.).	Brainstorming.	Doubtful.
	" Delphi " technique.	Useful withim limits.
	Scenario-writing.	Feasible.
	Horizontal decision matrix.	Useful, partly proved.
	Vertical decision matrix.	Useful, being tested.
	Relevance tree.	Very useful, proved.
	Systems analysis.	Potentially very useful, partly proved.
14. High level goals (national, social, etc.).	Brainstorming.	Very doubtful.
	" Delphi " technique.	Very promising, partly tested.
	Utopia, science fiction.	Potentially partly useful, unproved.
	Scenario-writing.	Useful, proved.
	Operational models (gaming).	Potentially useful.
	Operational models (rigid models).	Potentially useful in auxiliary function.

This is an impressive list, especially since it reflects systematic development over little more than five or six years. Some of the best operations research and systems analysis experts may feel tempted to contribute new and more sophisticated techniques for coping more adequately with the questions which technological forecasting seeks to answer.

ZZ.I.3. UTILISATION OF TECHNIQUES

The use of techniques is by no means a measure for determining the quality of technological forecasting. Two of the three big American institutes offering technological forecasts—the Stanford Research Institute and Arthur D. Little, both producing continuous series of technological forecast reports—generally do not employ elaborate techniques; the third, the Battelle Memorial Institute, joined the pioneers in the development of technological forecasting techniques only fairly recently.

The users of forecasting techniques are virtually unanimous in agreeing that at the present stage the primary gain from this exercise is the greatly improved insight into the nature and inter-relationships of influencing factors and into the sensitivity of solutions to their variation. The possibility, within a consistent pattern, of evaluation discrete alternative solutions probably ranks as the second most valued gain.

A well-organised company may, paradoxically, find less incentive to using techniques if it has attained a degree of insight which it cannot itself substantially improve. A sophisticated American electronics company abandoned the use of a number of quantitative (simple) techniques[1] when, by virtue of a thorough, fully-integrated organisation of the planning side, it really " got on top " of the technological innovation process. " Projections distracted from planning. "

The " insight " argument is also a factor in a certain hesitation by top management people to approve the use of more elaborate techniques. In modern future-oriented companies—represented by the better-than-average American industrial company in an innovating branch—management attitude seems to favour the moderate use of techniques but to limit them to simple and transparent types. The widespread use of simple two- and three-dimensional matrix techniques reflects this attitude. Sometimes, simple and elaborate techniques are used side by side, not so much to supplement each other, but to suit different inclinations at different management levels. Honeywell **(US),** the company which generated and applies the most elaborate relevance tree technique, PATTERN, also uses simple matrices that are reportedly found " more convincing " by top management people, while middle-level management places a great deal of confidence in PATTERN—which attains the maximum degree of transparency to be expected of an elaborate model.

Another important factor which is assessed quite differently in different companies, is the economic value of more elaborate forecasting techniques or, more precisely, the " return on investment. " Elaborate techniques cause expenses that are not negligible even for big companies. In section **11.4.5.** an estimate is given for PATTERN, which cost approximately $250,000 to set up at the outset for use in Honeywell's military and space activities, and which may involve somewhere between $50,000 and $100,000 per year in updating and operation expenses. An even more stringent requirement is the use of high-quality technical and operations research people whom a company may hesitate to assign to an experiment the outcome **of** which is uncertain. Moreover, considerable time—possibly several years—may be needed to adapt a complex technique to the characteristics of a company. Continuous confidence, perhaps even enthusiasm, are required if the company is successfully to weather such a period of adjustment. Technological forecasting, at least in its more sophisticated forms, is comparable with the problem area of scientific and technical information in this respect: in both cases, it is difficult to assess future benifits in quantitative terms, or to prove past benefits. Nevertheless. confidence in techniques is generally growing wherever they are applied, and results are considered encouraging.

A factor which constitutes a more delicate problem may be found in a management attitude that tends to regard the simulation of one's own

1. **A few numerical techniques are still in use as strictly auxiliary means.**

decision-making process as superfluous. This argument is also raised by Ayres *(lit. ref.* 89) with respect to US military administrations.

Finally, some of the proposed methods seem to be insufficiently close to reality, or to constitute ad-hoc procedures suitable to a narrow sector or a particular company only. Brandenburg *(lit. ref. 97)* and Baker and Pound *(lit. ref. 91)* in their critical review of a number of simple " ranking procedures " based on economic analysis, operations research and decision theory approaches, point out a number of short-comings of this type. Multi-dimensional considerations such as " project success " are often introduced as single indices equal in weight to a number of other factors.

Baker and Pound also tried to assess the number of US companies and government laboratories, out of a total of roughly 50, in which these " ranking procedures " were known, tested or applied. The result, for 1964, indicates very low utilisation. Ranking procedures based on an operations research or decision theory approach were generally tested or applied only in the originating companies or laboratories, and testing—though reportedly successful—sometimes did not lead to practical application. Most companies were not aware of procedures developed elsewhere. One may conclude that it is too early to expect a broader diffusion of experimental approaches which generally do not merit wider recognition. In 1964 the enthusiastic " pioneer " and the " self-made man " who solves urgent problems through his own efforts in a simple manner were the rule. The year 1966, with interest in technological forecasting growing rapidly in many companies and laboratories in the United States, and with successes such as PATTERN becoming widely known, may already mark a transitional period leading to the beginning of " cross-fertilization. "

Kiefer *(lit. ref. 146),* in a review of the US chemical industry in 1963, names five companies using check lists (plus one company which was considering them and one that had abandoned their use), 11 companies using discounted cash flow methods to assess the expected " return on investment " for research and development projects in an advanced stage (four of these companies employed formulas which also included other factors, such as probability of success, etc.), one company (Monsanto) which used economic analysis in combination with other more refined techniques, and one company (Hercules Powder) that ran business models on an analog computer for each project.

On the basis of the present investigation, which concentrated on industrial branches of an innovating character (primarily the electrotechnical, chemical and petrochemical, petroleum, pharmaceutical, and aerospace industries) and on military technological planning, the following general picture emerges as of 1966 (unless otherwise indicated, reference is to the US scene):

TYPE OF TECHNIQUE	UTILISATION
" Delphi " technique	In a few European companies and in NATO in a version which includes systematic preparation. Tests planned by TRW Systems (US).

TYPE OF TECHNIQUE	UTILISATION
Trend extrapolation on phenomenological basis	Extensive use, including refined S-curve and envelope curve extrapolation, in military environments in both the US and Europe, in industry mainly in the US; most systematic use is for the preparation of input information to PATTERN scheme (Honeywell), necessitating hundreds and thousands of individual evaluations.
Contextual mapping ....,.	Limited application in a few places, growing importance.
Morphological research.	According to its author, 30 industrial applications already, the most thorough application being to jet propulsion systems at Aerojet ; also applied to basic astronomy.
Scenario-writing	Applications only where higher-level goals are to be explored, for example at Honeywell for the preparation of their PATTERN scheme, and at the big oil companies, in Europe as well as in the US.
Iteration through synopsis	Systematic application by Unilever (Brech) in the United Kingdom. Less systematic applications apparently numerous, including the big oil companies in Europe.
Economic analysis	Practically all companies with large research and development programmes. Discounted cash flow methods are used by approximately 20 to 25 per cent of the companies visited and are generally applied to well-defmed projects in the advanced development stage. The Swedish Wallenberg group (ASEA, Ericsson, etc.) applies it rigorously for project selection. Ranking procedures based on refinements of DCF are used in several places, for example SCAIR in GEC (United Kingdom).
Exploratory operational models—gaming	Possibly occasional application of business games; under consideration by Canadian Paper and Pulp Research Institute, growing general interest.
Exploratory operational models—rigid computer models	Integrated business models are also used for forecasting (Xerox Corp., US) but are very rare; ad-hoc models are used occasionally; applications in the military technological area (?).
Horizontal decision matrices	Wide use, especially research/resources matrices ; some rigorous application for decision-making (Boeing).
Vertical decision matrices.	Some applications, especially of the research development programme type; ambitious three-dimensional matrix to link space developments to social end-uses applied by North American Aviation.
Simple decision techniques based on an operations research approach.	In spite of the interest of professional operations research people, only few applications so far; generally combined with economic analysis (maximisation of total expected net value); possibly a "growth field."
Simple decision techniques based on a decision theory approach.. ..	Numerous applications of check lists with and without rating, but apparently decreasing in number; some numerical formulae in military environments for ranking (France) or partial problems (US Navy), few in industry.

TYPE OF TECHNIQUE	UTILISATION
Integrated multi-level relevance tree schemes	Six known applications of PATTERN, (Honeywell, military/space and medical, NASA, US Air Force); at least three applications of other techniques (including NASA); under development at the Battelle Memorial Institute; under consideration by US Navy; arousing great interest-enthusiasm as well as scepticism — and the wish to design similar techniques in a simpler way so as to reduce the substantial effort involving setting them up; operations of a "pioneering" character possibly giving rise to applications in wider technological and governmental decision-making arcas.
Network techniques	Application, for example, by General Electric Atomic Power Dept., under consideration at the Battelle Memorial Institute.
Normative operational models—rigid computer models	A few applications for new consumer products (BBDO's "Demon" and the 3M Company's "New Products" models in the US); a model in preparation for use by the US Air Force; the Battelle Memorial Institute is considering applications.
Systems analysis..	Pioneered and applied to tasks involving technological forecasting by the RAND Corp., System Development Corp., and General Electric's TEMPO; also in industrial environments such as General Electric Atomic Power Dept. or North American Aviation; can probably be applied usefully only where sophisticated management environments exist.

B. THE AGGREGATED LEVEL

"Delphi" technique	Application to population forecast tested (doubtful).
Exploratory aggregated level techniques	Applications of statistical models (Battelle Memorial Institute, CECA) input/output analysis (Quantum Science Corporation, RAND/US Air Force, attempted for US economy by Harvard Economic Project), chains of industries (France's BIPE), horizontal diffusion models on empirical basis; forecasts of energy consumption, number of telephone subscribers and telephone traffic are beginning to incorporate technological change in the models used.
Horizontal decision matrices	French national research/research matrix, in experimental stage.
Vertical decision matrices.	French national research/industry matrix, being tested.

C. ENVIRONMENTS OF "SOCIAL TECHNOLOGY"

"Delphi" technique	First tests have been made (RAND Corporation), others in progress (US Air Force), great interest aroused.
Contextual mapping	Being considered for application.
Morphological research	According to its author, applications are being considered for city planning and education.

TYPE OF TECHNIQUE	UTILISATION
Scenario-writing	Pioneered by the RAND Corporation, System Development Corporation, and particularly the Hudson Institute (Kahn, Brennan); applied to the "Year 2000 Program" of the American Academy of Arts and Sciences and other broad programmes with a socio-economico-political context.
Historical analogy...............	Systematic testing by the American Academy of Arts and Sciences ("The Railroad and the Space Program"); large-scale use doubtful.
Exploratory operational models—gaming	Considered as an important tool by all leaders in "social technology," but apparently not yet applied to problems involving technological forecasting.
Exploratory operational models—rigid computer models	Proposed by Abt Associates to OECD, considered important by leaders in the field, but apparently not yet applied.
Normative operational models—gaming	Gordon and Helmer's "Game of the Future," being tested in 1966.
Systems analysis	Applications by the RAND Corp. (cities and vehicles of the future, etc.), System Development Corp. (education, etc.), General Electric's TEMPO (cities of the future).
Feedback models	Development phase, pioneered by System Development Corporation (US).

II.1.4. OUTLOOK FOR THE NEAR FUTURE

A few modest "forecasts on forecasting" may be ventured with respect to the further development of techniques. In a true normative spirit. they are all based on clearly recognisable requirements:

In the immediate future, interest will focus on the improved integration of techniques over many levels of technology transfer, either by the combination of available elements and partial techniques or by the designing of new techniques;

Better "bonding" of vertical forecasts with horizontal forecasts will be attempted on various levels (not only on the impact level), for both exploratory and normative techniques; particular attention may be directed to the horizontal integration of normative sets of goals, missions, etc.—in other words, non-technological goals and missions will influence technological forecasting on a more systematic and comprehensive basis; consistent sets of social goals may include variables for different countries, etc.;

Techniques will use dynamic formulations (not "snapshots"); this will be the case, *inter alia,* for assessing impact and stipulating goals and missions (which up to now have largely represented views of the present);

Techniques will increasingly adopt a total systems approach;

Feedback techniques will become the predominant problem a few years hence:

Feedback control techniques, i.e. techniques for regulating feedback by adaptations of the entire forecasting function, will follow;

Computer uses will increase, first in military and government technological environments, then in industry as well;

Cross support will receive much more attention in relation to future forecasting techniques, with developments pointing in the direction of " module thinking ";

The use of intuitive thinking will become respectable and will be greatly improved, especially in the area of social goals; techniques for improving and evaluating consensus will be generally developed further;

Exploratory techniques minimising prejudice and bias will be cultivated:

Better understanding of historical inertia and other factors influencing technological progress will give rise to techniques for improved time-dependent estimation and extrapolation;

Efficient normative " by-pass " techniques may be developed that would make it possible to determine some of the worthwhile tasks for fundamental research directly on the basis of higher-level criteria;

Technological forecasting will become an integrated function in future comprehensive information technology systems (see a discussion of this point in section 11.5.2).

As to the evolution of technique utilisation, one might attempt an analysis over time of the " precursive events " to be found in sophisticated management techniques and in computer uses for management tasks in the public domain as well as in industry. The trend shown by such a study would certainly be characterised by a rapid rise.

Technological forecasting today is a child of less than ten years old. Only a small fraction of the total number of potential users has so far had an opportunity, or felt an incentive, to decide on the level of sophistication on which to tackle it. The coming years will constitute the decisive period of adolescence that will form the character of the future mature adult...

Chapter 11.2

THE APPLICATION OF INTUITIVE THINKING AND TECHNIQUES FOR ITS IMPROVEMENT[1]

The improvement of intuition is a highly technical matter.

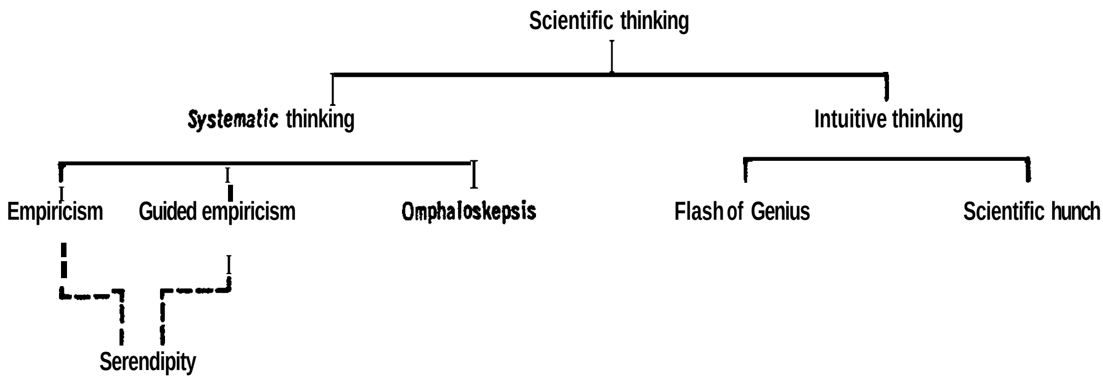
Marshall McLUHAN.

The creative imagination I am talking of works on two levels. The first is the level of social engineering, the second is the level of vision. In my view both have lagged behind technology, especially in the highly advanced Western countries, and both constitute dangers.

Dennis GABOR.

11.2.1. CREATIVE THINKING AND FORECASTING

Green's typology (*lit.* ref. 7) provides a useful starting point:

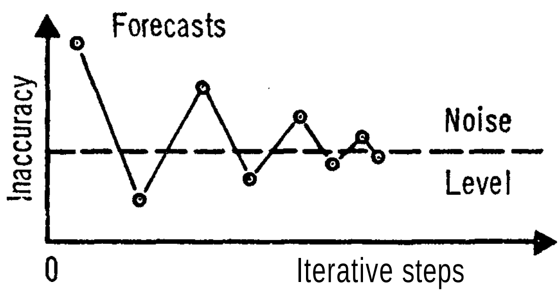


In this scheme, systematic thinking is “ the deliberate act of the conscious mind, ” and intuitive thinking “ the gracious gift of the sub-conscious in return for the previous labours of the conscious mind. ” The term “ omphaloskepsis ” denotes “ deep meditation, in Oriental fashion, while gazing at the navel. » (Green remarks that “ the Occidental style of gazing at feet on a desk is capable of producing a similar effect. ”) Serendipity, coined by Horace Walpole, was suggested by the story about the three princes of Serendip (the ancient name for Ceylon) who had “ the happy faculty of discovering something valuable by accident while searching for something else. ” American research laboratories often claim, in emphasising their open-minded management policy, that serendipity is encouraged by a number of subtle means.

It is an obvious fact that high hopes have been placed in the past, and are still being placed, in intuitive thinking as a means of achieving exploratory technological forecasting. This represents a tendency which basically seems to point in the wrong direction. Informed judgement, implying the use of systematic thinking, will generally be superior to intuitive methods where the effects of causal relationships are projected into the future. Intuitive forecasts are not far removed from the kind of expectation that is inherent in decision-making which takes place in the absence of any explicit forecast: they forego whatever possibility may be available of using input information in a systematic and comprehensive way.

Intuitive thinking may be placed on a slightly better footing through the development of a certain sophistication in the selection of experts, possibly—as Gordon and Helmer ***(lit. ref. 269)*** suggest—by using schemes for a self-appraisal of competence, corrections by feedback procedures, etc.

An interesting approach to the improvement of intuitive expert forecasts and the reduction of the " noise level " implicit in intuitive forecasting has been developed by Abt Associates and made part of their comprehensive operational models, including models for technological forecasting ***(lit. ref. 83).*** In this approach, incremental forecasting of short-term changes by experts is iterated by applying the appropriate quantitative



corrective bias to the next round of predictions. " In this way, the expert predictions will gradually approach a stable path, which will not normally be absolutely accurate, but which will be inaccurate to a constant degree. This level of inaccuracy can be defined as the' noise level ' for any particular predicted change. Within the range thus defined, there will be no bias for preferring one prediction over another, but outside the range (which may well become narrower as time goes on, compensating €or increasing possibilities) predictions can usefully be compared and evaluated. "

Thomas and McCrory ***(lit. ref. 181)*** **of** the Battelle Memorial Institute developed a method for synthesising expert opinion and testing the sensitivity to deviation by an individual expert; this method has not yet been published.

Helmer ***(lit. ref. 134)*** remarks that there are two kinds of experts, generalists and specialists, and that both kinds should be used for intuitive forecasts. The ways in which experts can be deployed are classified by Helmer into a symmetric pattern (several experts on the same problem) and an asymmetric pattern (different experts on different aspects of a problem). The development of a rationale for the use **of** experts is one of the important tasks in the area of social technology.

In studying supposedly intuitive forecasts of future technologies one finds in general, that they represent rather cluttered pieces of systematic thinking, uncritical extrapolations of the present state-of-the-art, and recapitulations of other forecasts. The " World in 1984 " series of " The New Scientist " (*lit. ref. 261*), which elicited contributions from many of the leading minds in a wide variety of technological areas, demonstrates the limited usefulness of intuitive thinking for exploratory purposes: the substantial contributions reflected a more systematic attitude, or an approach from the normative side.

For very-long-range exploratory forecasting, meaning time-frames of 50 years and more, intuitive thinking is, of course, less limited than systematic thinking. On the other hand, at that range it may be nearly tantamount to a " serious " version of science fiction (respecting laws of nature, etc.).

Most of the very-long-range forecasts involving the effects of revolutionary future technologies—such as Muller's view, in 1910, (*lit. ref. 326*) of the possibility of influencing the genetic characteristics of man, and of applying eugenics—apparently have a strong normative basis: " The making of such inventions will be favoured when we have a system in which their value will be duly appreciated " (*lit. ref. 326, pp. 134/135*). This normative basis is most clearly visible where technological projections are guided by considerations of available resources, as in the energy field. This can be seen, specifically, in the case of nuclear energy, where the necessity for breeder reactor development has been derived from considerations of available fissile and fertile materials resources already in an early development stage (see, for example, *lit. ref. 347*).

One may believe that the more sophisticated techniques described below—especially the " Delphi " technique—ought to be applied primarily to an improvement of our view of future goals and needs. The rapidly increasing importance of normative forecasting, which is dealt with frequently in this report, will have the effect of placing great emphasis on such techniques of intuitive thinking.

The idea proposed to the French " Centre de Prospective " of applying " Delphi " or similar techniques to the problem of ascertaining to what extent, and in what respect, sets of desirable future goals vary as among groups of different origin by country, continent, race, etc., will—if carried out—constitute the first large-scale attempt to provide a basis for normative forecasting through intuitive thinking.

A working hypothesis of far-reaching consequence may be ventured: The relationship between anticipated intuitive goals and history can be conceived in terms of an analogy with the fundamental biological law " Ontology recapitulates philogeny " (which, simply expressed, means that development from embryo to full-grown animal passes through the same stages as those which have marked the development of the species). A central " idea, " acting at a given future moment and determining the set of desirable goals for that moment, also—spread out over time— guides the historical development towards that set of goals. F. L. Polak (*lit. ref.77a*) attempted to prove the historical truth of this hypothesis and warns that the normative and beneficial future-shaping activity would come to a stop if we do not review the goals for a future society.

Very little is known about the interaction of intuitive recognition and .history, apart from the discovery (by C.G. Jung and his school) of " archetypes " and their determination of an anthropomorphic view of the world.

If, as McLuhan *(lit. ref. 374)* assumes, the " archetypes " are changed themselves by history, this would probably set a natural limitation to the anticipative use of intuitive thinking.

11.2.2. BRAINSTORMING IN DIFFERENT VERSIONS

Brainstorming is certainly not an original concept of our century. But it was recognised and widely used throughout the **1950's** as a systematic creativity training technique. All techniques aimed at discovering new ideas and achieving **a** consensus by a number of people on the basis of intuitive thinking derived from the concept of brainstorming. The following summary of different versions of brainstorming is condensed from Hinrichs' survey *(lit. ref. 137).*

Straight *brainstorming* (" connoisseurs " use the term only for this version) can be carried out by individuals or by groups. It is based on the hypothesis that a large number of ideas will include at least a few good ones; this has, however, not yet been conclusively proved. Von Fange *(lit. ref. 118)* gives the following basic rules for brainstorming sessions:

1. State the problem in basic terms, with only one focal point;
2. Do not find fault with, or stop to explore, any idea;
3. Reach for any kind of idea, even if its relevance may seem remote at the time;
4. Provide the support and encouragement which are so necessary to liberate participants from inhibiting attitudes.

Sporadic research in the field has also led to certain encouraging conclusions: brainstorming experience can increase the score of the participants *(lit. ref. 160). Or,* more " good " ideas are produced under the conditions stipulated in the third rule above than if only " good " ideas were sought *(lit. ref. 161).*

Whereas straight brainstorming aims primarily at a harvest of new ideas, the " *buzz group " technique* seeks group consensus among approximately six people.

The " *operational creativity " approach (lit. ref. 127)* introduces the refinement that only the group leader knows the exact nature of the problem and structures the discussion so as to arrive at a solution—only one is sought.

Stimulating " supervision " is strictly a training technique. The task, for example, may be to describe life on an imaginary planet. The conditions of this planet are developed by the group, and the individual trainees then try to think of the most logical solutions in specific areas.

Little has been published about the effectiveness of these approaches, apart from certain uncritical and enthusiastic accounts (see, for example, *lit. ref. 107,* which also gives a number of illustrative practical examples). In general, however, brainstorming seems to have been reduced in the **1960's** from a primary source of ideas, and a shortcut to solutions, to an auxiliary function in analysis and decision-making. It is significant that the big advertising firm BBDO (Batten, Barton, Durstine, and Osborn, in Buffalo, **N.Y.),** one of the main promotors of brainstorming as a universal technique in the **1950's,** has subsequently developed the " Demon " model based on operations research and decision theory techniques ***(see*** chapter **11.4.7.).**

Brainstorming today is used successfully as one element in a larger framework that comprises analytical functions before and after the " brainstorming sessions "—if this designation can still be applied to committee meetings or " cross-fertilisation " meetings. Committees or " brain trusts " without supporting analytical staff (where the committee members do not do the detailed analysis themselves) have become increasingly obsolete. Some modifications can be found today in European more than in American industry, and especially in France.

An interesting version of brainstorming, practised at the Lockheed Aircraft Company, is described in ***lit. ref. 102:*** Marketing, research, financial, and engineering people are asked to assume the role of decision-making managers in a customer firm and, from this standpoint, to evaluate the decisions of Lockheed which are under consideration.

Meetings of highly qualified experts may still permit successful brainstorming. Future-oriented meetings of the National Security Industrial Association in the **US** have reportedly led to some remarkable brainstorming.

In military forecasting, a certain role is still reserved to brainstorming sessions. NATO, in its " Long-Term Scientific Studies " programme, holds two-week sessions of approximately 50 people whose task it is to tear to pieces a prepared working paper and to transform it into an " agreed report "; since only 25 to 30 per cent of the findings of such a working paper reportedly remain intact, there is obviously an important brainstorming component. The " operational creativity " approach, outlined above, is used for the purposes of French military technical forecasting and planning. Groups of outside experts are asked to think of possible solutions for specific scientific or technological problems, while the military requirements or the envisaged functional system are kept secret for a number or reasons.

II.2.3. THE " DELPHI " TECHNIQUE

Since the publication of a " Report on a Long-Range Forecasting Study " by the RAND Corporation in **1964** *(lit.* ***ref. 296,*** also discussed in ***lit. ref.*** *134a),* the " Delphi " technique, developed by Helmer and colleagues, has become widely publicised. Described in a simplified manner, it can be regarded as a succession of iterative brainstorming rounds in which an attempt is made to avoid the interference of psychological factors that tend to reduce the value of brainstorming sessions.

The aim of " Delphi " is to develop " a carefully designed programme of sequential individual interrogations (best conducted by questionnaires) interspersed with information and opinion feedback derived by computed consensus from the earlier parts of the programme. " It is believed that as a result of contacting the panel by letter, factors such as specious persuasion or the bandwagon effect produced by the majority opinion are reduced. However, these disturbing factors certainly can not be ruled out altogether, since the iterative process confronts the participants with the majority opinion in the second and successive rounds. The suggestion that drastic " dissenters " from the majority opinion be asked to state their reasons may result in increasing the bandwagon effect instead of reducing it as intended.

A short description of the RAND Forecasting Study mentioned above may serve to demonstrate a practical version of the technique. Six broad areas were selected—scientific breakthroughs, population growth, automation, space progress, probability and prevention of war, and future weapon systems. Six panels, one for each area, were formed from a group of 82 people, about half of whom where from the **RAND** Corporation; **6** Europeans participated. The procedure for the first panel (scientific breakthroughs) will serve as an example of the methods used:

***First** round:* The participants were asked, by letter, to name inventions and scientific breakthroughs which appear both urgently needed and realisable within the next 50 years. **A** list of 49 items resulted.

Second round: The participants were asked, again by letter, to situate the 50-50 probability of realisation of each of the 49 items in one of a number of time periods into which the next 50 years had been divided (or " in more than 50 years, " or " never "). These probability estimates were then combined and represented in quartiles and medians, the significance of which can best be demonstrated by an example: If, for the item " accurate meteorological forecasts, " the median date is 1975, and the two quartiles are at 1972 and 1988, this means that one quarter of the participants have estimated the " break-even " date (for which a 50 per cent probability of realisation exists) before 1972, half have situated it before 1975 and one quarter believet that the " break-even " probability of realisation would exist only after 1988. For 10 out of the 49 items a reasonable consensus resulted.

***Third** round:* The letters announced to the participants the substantial consensus for the 10 items and invited " dissenters " to state their reasons. At the same time, 17 items out of the 39 for which no significant consensus had been achieved were presented anew, with an invitation to the participants to state the reasons for widely dissenting estimates of the: time of realisation. In general, a narrower range of time estimates resulted.

Fourth round: The same procedure was followed as for the third round. The range of time estimates was narrowed down further. 31 items were included in the final list of those for which reasonable consensus had been obtained.

The **RAND** report ***(lit.** ref. **269)*** also includes **a** detailed study of the results. This yields certain quantitative indications that may become useful in the further development of the " Delphi " technique. For example, the following conclusions can be drawn:

The quartile range of a forecast (i.e. the precision of the consensus. after iteration) is, in first approximation, equal to the expected distance in the future, expressed by the median. If the median is x years in the future from the time the forecast is made, the lower quartile will be roughly located at $2/3\ x$, and the upper quartile at $5/3\ x$ (giving x years for the quartile range). For example, if the median of a forecast made in 1964 is estimated at 2000, the quartiles are estimated at 1988 and 2024.

The quartile range (as can be expected) decreases with successive steps of iteration. The average ration between the final and the initial quartile range is 5/8.

The assumption of " crash programmes, " i.e. of a high-priority research policy directed to the developments in question, is sharply reflected in the resulting time estimates. In the area of future weapon systems, for which alternative estimates under " crash " and " non-crash " conditions were asked for, the resulting time spans, as expressed by the estimated medians, were on the average reduced by half on the assumption of a " crash " programme. Under these conditions, all but two items in the future weapon systems area could possibly be developed by 1975!

The effect of an established long-range plan, such as that of NASA in the field of space progress, is reflected in the precision of the consensus. Forecasts by the space progress panel for items with medians up to 15 years in the future show quartile ranges between 1 and 7 years only (instead of 15 years, as would be expected according to the general rule above).

A comparison of the estimates of " break-even " dates (50 per cent probability of realisation) and of dates for which the probability is believed to be 90 per cent shows a very close correlation, indicating perhaps a hidden " psychological coupling " of these two estimates. The ratio of the medians is

$$M(0.9)/M(0.5) = 9/5 = 1.8$$

and the corresponding ratios for the lower quartiles 1.6 and for the upper quartiles 2.0.

Possible improvements recognised by the authors of the RAND report concern the selection of experts, schemes for a self-appraisal of competence, improved feedback mechanisms, statistical models of the question-and-answer operation of a panel. A certain degree of mechanised management seems desirable to speed up the procedure, which in turn appears to be essential to the value of the results.

The " Delphi " technique is being further developed and tested at the RAND Corporation, in the US Air Force—where a big forecasting study along " Delphi " lines was started in the beginning of 1966—and at the TRW Systems aerospace company in Redondo Beach, California. A partial application of the " Delphi " technique is also envisaged for Gordon and Helmer's " Game of the Future " (see section 11.3.10).

In examining questions put to the panels, one notices that the RAND Forecasting Study, in asking for items both urgently necessary and realisable within 50 years, does ask implicitly for an opinion on high-level goals. However. these goals remain rather ill-defined, and it does not become clear from the answers precisely what the participant had in mind. The item " hereditary control at the molecular level. by chemical means, " for example, may imply a wide spectrum of goals, as does " reliable weather forecasts. " At the same time, items may range from specific technologies (" stimulated emission—' lasers '—in the X-ray and gamma ray region of the spectrum, " or " controlled thermo-nuclear energy ") through more or less specific applications (" automatic libraries, effecting search and reproduction ") to economic developments (" factor of 10 increase in capital investment in computers used for automatic process control "), or to manpower developments (" automation of office work and services resulting in the displacement of 25 per cent of the current manpower "), or even to broad social developments (" education becomes a respectable leisure pastime ").

At the same time, the attention of the participants is drawn primarily to the time factor, and the attempts to improve the consensus concentrate almost exclusively **on** it. Thus, the participants are implicitly asked to project both public and private interest in the potential innovations. Where this is assumed to be pre-determined to some extent, as in the case of the space programme, or the assumed " crash " programmes for weapon developments, the influence on the time estimates is considerable.

The **US** Air Force test of the " Delphi " technique puts chiefly questions of a political and historical nature to the participants, very often questions which cannot be answered on a rational basis, e.g. " reunification of Germany. " It poses only a few questions of a technical character (" a family of weapons more dangerous than nuclear weapons ") or with social implications (" the emergence of language as a major international issue "). Here again, the aim is to achieve a certain consensus on the time factor.

In the light of the remarks made in section II.2.1. above, it may be hoped that the " Delphi " technique will be applied in future to the most important task of setting up goals on higher levels: social goals, national goals, corporate goals, major military goals, etc. It is obvious that, for this task, the " Delphi " technique will have to be adapted, through the use of the iterative process, in order to improve the consensus on the goals themselves—not on the time factor involved in their realisation (which will be affected by feedback anyway if a consensus on the nature and priority of goals has a practical effect.)

II.2.4. UTOPIA AND SCIENCE FICTION

Pure science fiction, meaning science fiction without a noticeable component of " informed judgement " on progress, still enjoys a considerable public reputation for very-long-range forecasting. However, while it was possible for imaginative writers in the 19th and the first decades of the **20th** century to catch up somehow with broad scientific progress and to place their stories on a reasonable basis which did not conflict very seriously with natural laws and technical non-impossibilities, these elements of " serious " science fiction have become less and less accessible to writers who are not professionals in science or technology. There is no Jules Verne in our day—nor is there a science fiction writer who could portray character so well.

A brilliant critique of 20th century science fiction has been made by Gabor ***(lit. ref 363)***, pointing out the basic trend of sentimental out-of-this-world optimism prevailing in the West up to 1930, and still in full flourish in Russia today (where it even penetrates into supposedly serious forecasts —see ***lit. ref. 285)***. As a source for the recognition of social goals and of mankind's great aspirations, this type of science fiction is of minor value only. Nor does the dreary " space opera " genre which abounds today contribute anything in this direction.

The valuable contributions in more recent science fiction have been made by writers capable of applying logical thought and scientific understanding. To some degree, this type of science fiction, which came into being with Huxley's famous " Brave New World " ***(lit. ref. 387)***, approximates scenario writing, except for the literary form which it assumes. Huxley, in Gabor's words, has arrived at a " self-consistent logical construction " by taking " in one hand all the science and psychology of the late twenties, in the other all the social trends of the last happy years before the great depression, and constructed from these a model world in which all the problems were solved—but at a price! " *(lit. ref. **363**)*. Huxley's book, by portraying the end result of a development guided by the naive exploitation of scientific opportunities, emphasised the necessity of carefully chosen social goals—which, however, have not yet been provided by science fiction since the time Huxley published his book in **1931.** Science fiction written by scientists often takes the form of warnings against abuse of their science (see *lit. **ref. 385)***.

Another type of logical " scenario, " in poetic form, has been attempted by the great physicist Szilard in " The Voice of the Dolphins " This is an account of world events as seen in retrospect by a future historian, starting with the present.

Summing up the situation, which is not marked at present by the positive contribution from science fiction that is conceivable, Gabor states that " the sceptics and the pessimists have taken man into account as a whole; the optimists only as a producer and consumer of goods. The means of destruction have developed ***pari passu*** with the technology of production, while creative imagination has not kept pace with either. " *(lit. **ref. 363)***. The new optimism introduced by Elisabeth Mann-Borgese ***(lit. ref. 388)*** is still a rather unique phenomenon.

11.2.5. NEW ELEMENTS FOR THE IMPROVEMENT OF INTUITIVE THINKING

A research programme being conducted at the Centre for Culture and Technology at the University of Toronto is concerned with the exploration of elements in intuitive thinking which so far have been neglected or have not been perceived at all. Preliminary findings will be included in some of McLuhan's forthcoming books *(lit. ref's. **72, 73, 74** and **75**)*.

Two aspects of this research seem to be of particular importance:

a) The concept of a " sensory profile " of man and the changes it undergoes in its interaction with technological and social change. Knowledge of the laws of this interaction could conceivably become a forecasting tool of considerable operational value.

b) The notion that human " archetypes " are processes, not invariables (as C.G. Jung conceived them) and are in continuous motion.

The programme also deals with, inter alia, the relation of poets and painters to history—they see the present (not the future!), whereas ordinary people see the past, so that an empirical basis for historical trends would exist in the present.

Thus, McLuhan has not been content with merely making the statement quoted at the head of this chapter—"The improvement of intuition is a highly technical matter "—but has set about to explore the technical elements involved. **A** review of the present state of techniques for the application of intuitive thinking, as outlined in this chapter, seems to indicate a definite need to learn to know these elements and how to handle them for the purpose of forecasting.

Chapter 11.3

TECHNIQUES OF EXPLORATORY TECHNOLOGICAL FORECASTING

The dominance of the machine presupposes a society in the last stages of increasing entropy, where probability is negligible and where the statistical differences among individuals are nil. Fortunately we have not yet reached such a state.

Norbert WIENER.

11.3.1. THE DATA INPUT

Exploratory technological forecasting, usually starting from an assured empirical—or reasonably good theoretical—basis, is in the favourable position of being able to use measurable data in most practical cases. This is a definite advantage over normative forecasting.

For technological forecasting in a narrow sense—extending up to the elementary technology level only—Isenson *(lit. ref. 141)* tried to group the technical data input into three sets of data:

Functional capabilities, independent of any specific technology. For example, if the field of interest is communication, appropriate data sets might be " frequency spectrum exploitable " or " number of intelligence bits per unit of time and per unit of distance between the communicators, " for which the totality of available specific technologies is considered;

Technical parameters enabling the functional capabilities to be accomplished, in this case involving specific technologies. For example, in the communications field, this might be " bandwidth capability of microwave links ";

Scientific and technical findings for which the relationship to functional capabilities has not yet been established: in general, data that accrue outside the application of technology to the achievement of functional capability,

As Isenson remarks, all three data sets, representing past history, lend themselves to extrapolation over time.

The data input to technological forecasting in the sense given to it in this study will, of course, be much more comprehensive and will include relevant material from non-technical fields, such as a wide variety of economic, political, and social data.

The storage and retrieval of these data as well as of any other input material is a straightforward problem of information science which has been solved in the past few years even in response to fairly sophisticated demands. It will suffice to recall here only the two important new opportunities which have been opened up by the application of computers:

a) refined retrieval with deep-indexing up to about 20 or 25 key-words per item normally, but unlimited in theory, and

b) selective dissemination of information (SDI) by matching pre-established " personal profiles " periodically against new input.

One could readily apply these techniques not only to any research task but also to specific forecasting jobs. *All* that would be needed is a number of key-words or indices describing the potential interest of a given information item for forecasting—and the organisation of input so as to comprise material of value to forecasting.

The computerised reporting system and the attached data bank used by Samson Science/Quantum Science Corporation (US) as a source for inputs to their technological forecasting may constitute the first full-scale application.

Some people in the field are already thinking further ahead and propose data banks and retrieval systems within the framework of future information technology. Their ideas will be outlined in section II.5.2. on " Technological Forecasting and the Evolution of Information Technology. "

II.3.2. EXTRAPOLATION OF TIME-SERIES: ATTEMPTS TO FORMULATE SIMPLE ANALYTICAL MODELS

In our dynamic world, many quantitative characteristics exhibit an exponential or nearly exponential growth over time, with a subsequent flattening when a limit or a saturation value is approached[1]. In a logarithmic plot over linear time, exponential growth appears as a straight line and thus offers a particularly tempting invitation to extrapolation.

The extrapolation of time-series constitutes perhaps the principal quantitative technique which is available to technological forecasting in the pre-innovation stages. In general, the characteristics which have been and are extrapolated with reasonable success belong to Isenson's three classes of technical data, outlined in section 11.3.1. above; they belong to the levels of technology and functional technological systems. The step from the scientific and technological resources level to these higher levels is only partly a logical one—its logical content is represented primarily by the anticipatory recognition of a natural or practical limit (if it is recognised at all). The slope of the curve is usually forecast on the basis of a naive belief, at least over short or medium time range, that the growth law of the past will also determine the future growth, either in an identical way (continued exponential growth) or with slight modifications if saturation phenomena become visible.

A discussion of the time factor as an implicit element in the structure of each level of forecasting has been given in Chapter 1.3. The explicit introduction of time in the extrapolation of secular trends, in turn, is based on an implicit judgment of factors which act horizontally on the level of technology or functional technological systems. The simple models which are presented here try to link the shape of technological growth curves to

1. **The resulting S-shaped curves are sometimes referred to as " logistic curves. " This term will not be used here in order to avoid confusion with older, and more legitimate meanings of the word " logistic ".**

such horizontally acting factors in the hope that the generalisations made will yield a useful tool for quantitative trend extrapolation.

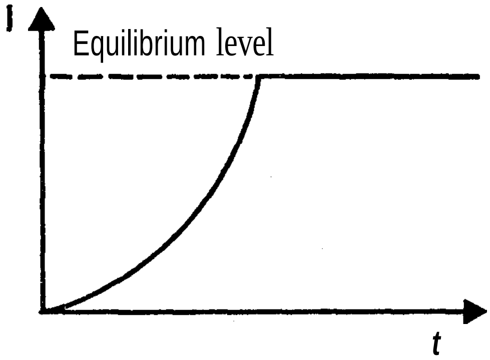
Lenz *(lit.* ref. ***151)*** cites an early attempt by Henry *Adams* in 1907 to compare the acceleration of progress with the effect produced by a new mass introduced into a system of forces previously in equilibrium. The new mass is induced to accelerate its motion, for example under **the** influence of gravitational forces. The accumulated information would be seen as analagous to the distance the new mass has travelled, the rate of information gain as analagous to the speed, and the second derivative of information over time as analagous to an acceleration (assumed constant). Then the following equations hold:

$$\frac{d^2I}{dI^2} = g = \text{const.} \qquad (1)$$

$$\frac{dI}{dt} = g \cdot t \qquad (2)$$

$$I = \int_0^T g\,t\,dt = \frac{g}{2} T^2 \qquad (3)$$

I = Accumulated information (state of knowledge)
t = Time
T = **Time for** which I is evaluated
g = Acceleration constant, per square of time unit.



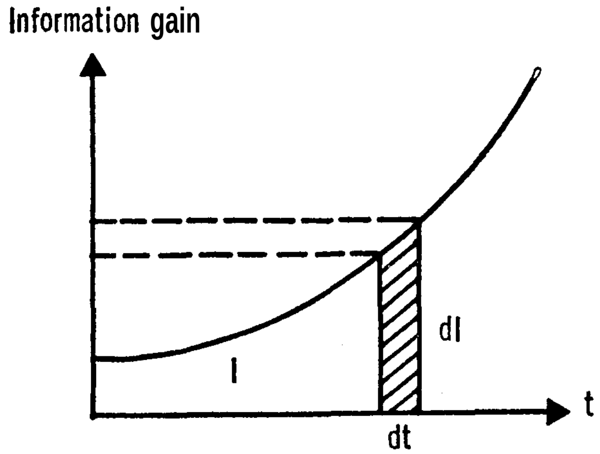
Analogy with a stone falling down to earth would give a parabolic curve abruptly hitting an equilibrium level. However, more complex analogies to two- and multi-body problems could be conceived.

Isenson's Model: Isenson *(lit. ref. 142)*[1] assumes dependence of the incremental information gain over time on two factors only, the number of investigators and a recognised upper growth limit. A third factor, which he calls the " inter-scientist communication factor, " is assumed to depend entirely on the number of investigators. Without recognised limit and communication factors, the information gain can be simply expressed as:

$$\frac{dI}{dt} = qN(t) = qN_o e^{ct} \qquad (4)$$

1. The outline here follows Isenson's text but proposes a different mathematical formulation.

I	Information (state of knowledge)
t	Time
q	Average productivity factor per investigator and time unit
$N(t)$	Number of investigators actively engaged at time t
N_0	Number of investigators actively engaged at time $t = 0$
e	Basis of the natural logarithmic system1
c	Coefficient (slope of curve in logarithmic plot)



The exponential increase of N corresponds to the general historical trend for the total number of scientists in the world, which over a long period of time has doubled approximately every 15 years, as de Solla Price *(lit.* ref. 6) shows. The simple productivity factor implies the finding, also discussed by de Solla Price, that the number of scientific papers is proportional to the number of scientists. Numerical values, according to de Solla Price (and assuming an average productive life of 35 years for a scientist) would be approximately: $q = 0.1$ papers per year per investigator for the broad average: $q = 0.8$ for the top 10 per cent; $q = 2.0$ for the top 2 per cent. It may be noted, however, that the production rate for significant papers already shows signs of deviating from an exponential rise with a resultant flattening[2].

Integration of equation (4) yields the state of knowledge, which is implicitly assumed to be proportional to the value of a functional technological capability or any other representative numerical characteristic:

$$I = qN_0 \int_0^T e^{ct} dt = \frac{qN_0}{c} (e^{cT} - 1) \qquad (5)$$

T Time span of evaluation

It also rises exponentially.

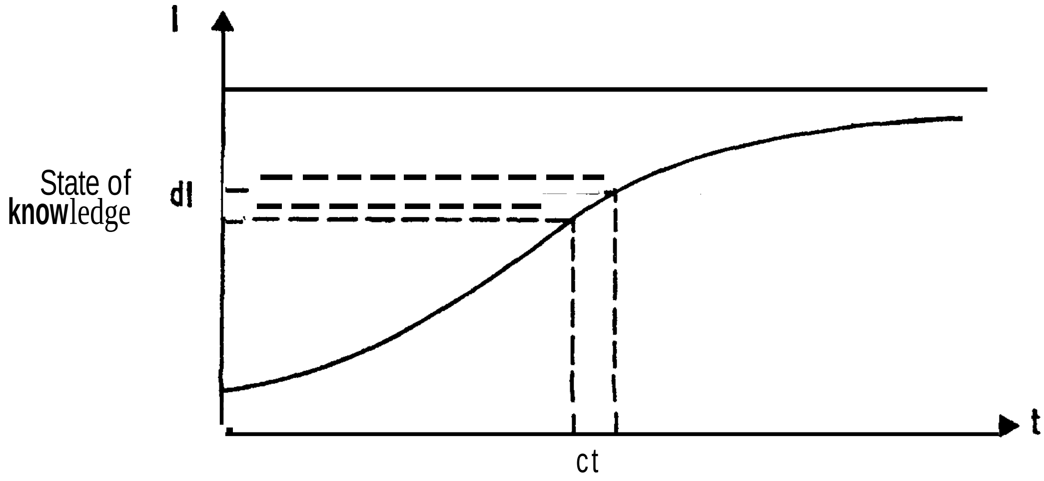
1. $e = 2.71828....$ In a logarithmic plot the difference between the generally used decadic system (log) and the natural system *(ln)* is only one of scaling: $\ln x = 2.30 ... \log x$, but differentiation and integration processes involve the natural logarithmic system and its base e.

2. The March 1966 issue of " Scientific Research " notes that in 1961 there were 658,000 significant documents generated in the world's technical literature. In 1965, the figure had risen to 900,500 and by 1970, it is expected to reach 1,143,000.

For the approach to an upper limit L, Isenson introduces a correction factor $(1 - I/L)$, so that equation (4) now also becomes dependent on the level of I, and brings it closer to Hartman's model described below:

$$\frac{dI}{dt} = qN_o \, . \, e^{ct} \frac{L - I}{L} \tag{6}$$

which leads to an S-shaped curve for the state of knowledge:



$$I = L \left(1 - e^{-\frac{qN_0}{cL} e^{ct}}\right) \tag{7}$$

Isenson's " inter-scientist communication factor " is based on the assumption that each link between N investigators—the maximum number of links being ½N(N — 1)—gives rise to a contribution equally productive to that which an isolated investigator can make. (This certainly will not hold for many practical cases.) Equation (4) then becomes:

$$\frac{dI}{dt} = q\,[N + \tfrac{1}{2}N\,(N - 1)] = \tfrac{1}{2}qN_o e^{ct}\,(N_o e^{ct} + 1) \tag{8}$$

or, when $N \gg 1$, which is normal:

$$\frac{dI}{dt} = \tfrac{1}{2}qN^2 = \tfrac{1}{2}qN_o{}^2 e^{2ct} \tag{9}$$

with the integration between $t = 0$ and $t = T$:

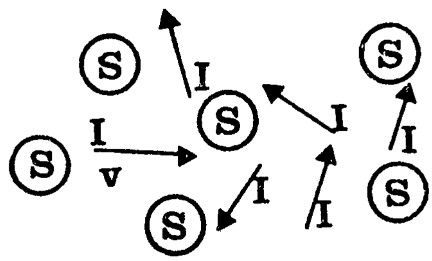
$$I = \frac{qN_o{}^2}{4c}\,(e^{2cT} - 1) \tag{10}$$

Information gain and state of knowledge again rise in exponential form, but with the double exponent.

The only explanation which this model seems able to furnish is that of the general rise of total scientific and technical knowledge, a value which is no longer measurable by single indices but which may be roughly proportional to the number of scientists at work in the world. The laws which govern typical team work today—often carried out with a constant number of people during the critical period—are obviously not represented by Isenson's model.

Hurtman's *model:* Hartman (Zit. ref. 133) derives his model from a simple analogy with reaction processes in a gas. The information gain, in this model, depends on the amount of information already available—thus ;basically differing from Isenson's model, and conform, in this respect, more closely with our general thinking on the production of scientific and technological results.

Hartman imagines a "gas," the molecules of which are scientists and pieces of information, both occurring at a given volume density (N scientists per cubic metre, etc.). The scientist "molecules" **S** do not move significantly, whereas the information "molecules" I move with assumed constant velocity v in random direction. A useful reaction (i.e. the generation of new information) is supposed to occur when the scientist "molecules" S have a "reaction cross section" σ on being hit by the information "molecules."



The incremental information gain (the generation of new information "molecules" per volume unit) over time is then (if no limit is yet approached):

$$\frac{dI}{dt} = kvN\sigma I\,(t) \tag{11}$$

k = Proportionality constant.
v = Speed of information "molecules."
N = Number of scientists (volume density of scientist "molecules").
σ = Reaction cross section (target area) of scientists for the generation of new information through collision between the two types of "molecules."
I (t) = Amount of information at time t (volume density of information "molecules").

Taking N as constant one may arrive at a reasonable model for **small** or medium-scale team work at early stages (when each "collision" between a scientist and a piece of information can be expected to give rise to the production of new information). Integration between t = 0 and t = T yields an exponential increase of information:

$$I = I_0\,(e^{bT} - 1) \tag{12}$$

I_0 = Amount of information at time t = 0.
$b = kvN\sigma$ = const.

If N, too, is taken to rise exponentially: $N = N_0 e^{ct}$, as in Isenson's model, one may come close to arriving at a model for **a** new breakthrough field, where the number of investigators increases exponentially while " collisions " between scientists and available information will still trigger the production of new information—a situation which, however, will not prevail very long. Equation (11) then becomes:

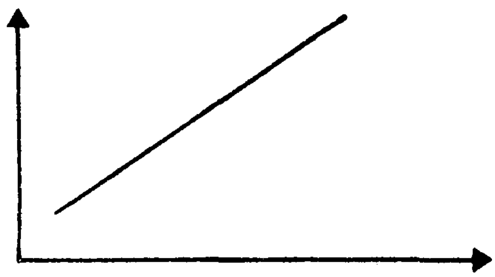
$$\frac{dI}{dt} = kvN_0\sigma e^{ct}I\,(t) \tag{13}$$

Integration yields a double-exponential growth curve

$$ln\,(lnI) = ct + \text{const.} \tag{14}$$

or, in explicit terms

$$I = I_o\left(e^{\frac{kvN_o\sigma}{c}e^{c\tau}} - 1\right) \tag{15}$$



Such a growth characteristic. represented by a straight line in a double-logarithmic plot, can indeed be encountered in several fields. Isenson *(lit. ref. 142)* gives the example of the growth of numbers of papers published on maser/laser technology which closely follows a double-exponential curve —and of commercial computer speed, which increases even faster than a double-exponential rise.

For the approach to a limit L, Hartman introduces the same correction factor as Isenson, so that equation (11) becomes

$$\frac{dI}{dt} = (kvN\sigma)\,I\,\frac{L - I}{L} = bI\,\frac{L - I}{L} \tag{16}$$

which again results in an S-shaped curve for the information gain:

$$I = \frac{L}{1 + \left(\frac{L}{I_o} - 1\right)e^{-b\tau}} \tag{17}$$

The same curve follows from the biological growth analogy, equation (19), and the properties of the curve are discussed under this heading below.

In criticising Hartman's model, the basic assumption $dI/dt \sim I$ (the information gain is proportional to the amount of existing information) holds only where: *a*) ideal communication between all investigators and all pieces of information can be assumed, and b) where every new opportunity presented by this communication can in fact be exploited. Both assumptions certainly do not hold for overall science and technology growth (where communication is not ideal and where—in the present situation—

far more opportunities for the production of new information exist than can be followed up).

Hartman's model may, however, be a useful approach to research and development in a specific field, or within a small or medium-sized team. It may, therefore, also become a useful element in the extrapolation of secular trends of scientific or technological properties or performance factors that are investigated in such a way. This will probably apply less to functional capabilities than to Isenson's second and third technical data sets (see section 11.3.1. above).

This model also has the advantage of flexibility with respect to the accommodation of possible refinements (introduction of time dependencies or statistical distributions for the factors taken as constant in the simple model, etc.) and of always enabling it to be viewed in terms of a clear analogy with physical processes—even including the delicacies of kinetic gas theory—that can easily be translated into significant meanings for our problem.

Hartman himself comments on a possible refinement as follows: if the reaction cross-section for the generation of new information through collision between scientists and information is broken up into two probability factors

$$\sigma = p_c p_I \tag{18}$$

p_c = Probability of a collision.
p_I = Probability that the collision will result in the generation of new information.

one can take p_I as a measure of the efficiency of R & D management. If, for example, under the conditions assumed for equation (13)—that $dI/dt \sim I$ and that N increases—the investigated parameter or capability still exhibits only exponential growth, this would mean that $N.p_I$ = constant, and since N is assumed to increase, p_I must decrease; i.e., R & D management in the specific project is becoming less efficient. At the same time, one may also take the velocity v as a measure of efficient and rapid communication that increases with better management. The question arises, then, whether σ and v are independent variables, or whether $\sigma . v$ = constant (as for certain nuclear reactions) would fit reality better (rapid communication results in decreasing absorption probability).

The task of long-range technological forecasting would therefore partly consist of forecasting all these horizontally acting factors. Problems of R & D management, such as the question of whether to perform a certain type of research in a number of small groups (v and possibly p_I higher) or in an organisational framework of larger dimensions, can also be elucidated by an operative model of this type.

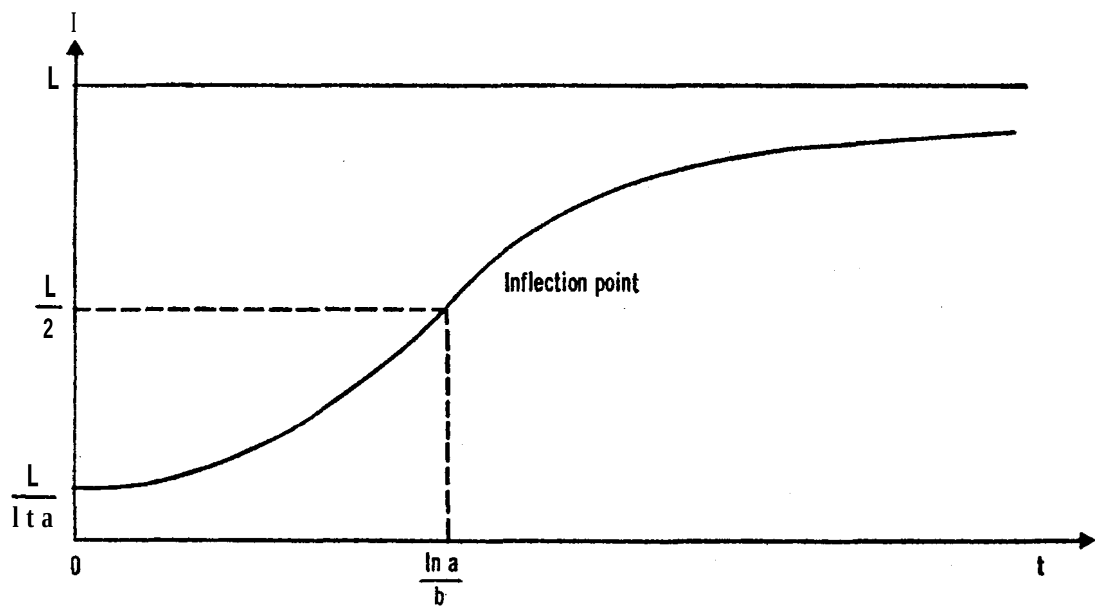
Analogy to biological population growth under constraint (Lenz's model): Lenz ***(lit. ref. 151)*** proposes the use of this analogy for technological forecasting, while de Solla Price ***(lit. ref.*** 6) considers it within the larger framework of all growth phenomena in science, including the number of scientists or papers, etc. The great attraction which this analogy has is explained by the fact that it yields a perfectly symmetrical S-shaped curve naturally, without further assumptions; or, rather, assumptions concerning constraints already govern the biological model. The biological processes which Lenz has in mind refer back to investigations conducted by R. Pearl in 1924/25: the rate of increase of fruit flies within a bottle; the rate of increase of yeast cells in a given environment; the rate of cell increase in white rats. De Solla Price examines the growth of length of a beanstalk over time. " Autocatalytic " chemical processes are suggested by Ayres (lit. *ref.* 89).

Each of Pearl's examples follows the same simple mathematical law, which, applied to the generation of new information, would read:

$$I = \frac{L}{1 + ae^{-bt}} \tag{19}$$

I = Accumulated information (state of knowledge) at time t.
L = Upper limit of information (due to constraints).
t = Time.
a = Constant, dimensionless.
b = Constant, per time unit.

Equation (19) is identical to equation **(17)** derived from Hartman's model.

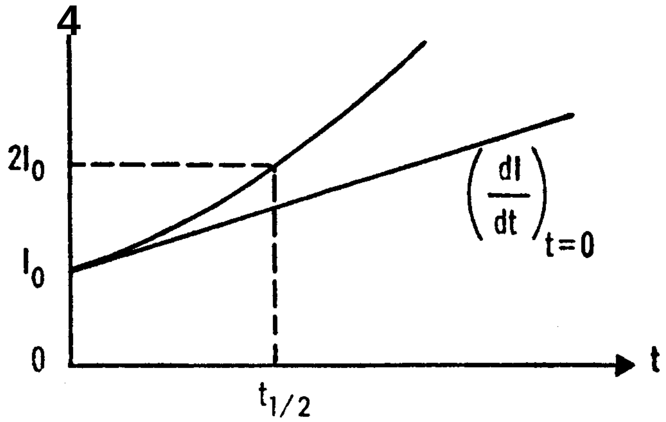


This simple mathematical formulation would, indeed, be an ideal tool for quantitative trend forecasts—if it **can** be proved to hold for practical **cases.** The resulting curve is symmetrical in relation to an inflection point, and **between** the limits $I = 0$ (at $t = -\infty$) and $I = L$ (at $t = +\infty$). By setting the second derivative $d^2I/dt^2 = 0$ it can readily be shown that the inflection points occurs at $t = (\ln a)/b$ and that the accumulated information at that point is always half the ultimate limit: $I = L/2$.

The constant a **fixes** the position of the curve in the time dimension (a difference in a means shifting the curve to the right or to the left). The constant b fixes the slope of the **curve.**

The value of I at a given time in the past or at present is **known** empirically. If the upper limit **L can** be determined through basic considerations, the constant a can be fixed: $a = L/I_0 - 1$, with I_0 denoting I at time $t = 0$. The constant b can be determined either from the known or estimated tangent dI/dt at the time $t = 0$:

$$b = \frac{(1+a)^2}{aL}\left(\frac{dI}{dt}\right)_{t=0} \tag{20}$$



or from the known or estimated doubling time $t_{1/2}$:

$$b = \frac{1}{t_{1/2}} \ln \frac{2a}{a-1} \tag{21}$$

Equation (21) holds only as long as the inflection has not yet been reached (because at that point the value of I is already L/2; it cannot double after the inflection point). If the inflection point is already covered by the empirical or estimated portion of the curve, b can be simply determined from the time t_i at which inflection occurs;

$$b = \frac{\ln a}{t_i} \tag{22}$$

Thus, with the knowledge of an ultimate limit, the complete curve can be extrapolated on the basis of a very short time-series. The critical point is, of course, to know which scientific, technical, and functional parameters, if any, can be expected to follow this simple law precisely.

In principle, this analogy offers numerous possibilities for refinement through adaption of horizontally acting internal and external factors mfluencing the gain of information. Many of these factors can be Seen as directly analogous to factors in the biological model. Lenz *(lit. ref. 151)* himself offers imaginative lists of such detailed analogies for cell growth and for bisexual reproduction:

BIOLOGICAL GROWTH	TECHNICAL IMPROVEMENT
Cell division	Inventive process.
Second generation cell	" New " idea or invention.
Cell division period............	Time required for initial invention to initiate " new " invention.

BIOLOGICAL GROWTH	TECHNICAL IMPROVEMENT
Nutrient media..	Economic support for invention.
Cell lifetime..	Useful life of invention.
Cell death, normal..	Obsolescence of invention
Cell mass..	Technical area or machine class.
Volume l i t of cell mass..	Limits of economic demand for invention in a given technical area
Size of cell mass	Total of existing, non-obsolescent inventions in technical area.
Strength of cell mass	Performance capability.

2. BISEXUAL REPRODUCTION ANALOGY

Male parent, or parent cell..	Existing invention or discovery.
Female parent..	Inventor.
Opportunity of fertilisation	Communication of knowledge.
Conception.	Origination of idea.
Embryo	Evidence of growth of idea.
Embryonic growth..	Development of idea.
Gestation period.	Period required for invention.
Birth	Disclosure of invention.
Nutrition	Economic support.
Maturation period	Reduction to practice.
Maturity	Operational use of invention.
Lifetime	Period from disclosure to obsolescence.
Death, normal	Obsolescence.
Total male population	Total inventions disclosed minus obsolete inventions.
Total work force..	Total operational inventions.
Total strength of work force	Performance capability.

In summarising the possible applications of these detailed analogies to analytical forecasting, Lenz points out that:

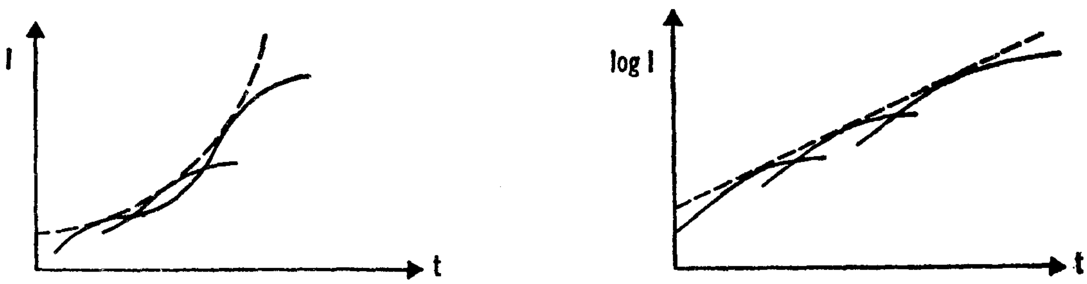
" the analogy of cell division to technological improvement may be used for prediction in the followings ways:

1. By identification of the average period required for ideas to be generated from prior inventions, and use of this time period as the basis for predicting the doubling of technical progress over each such period;
2. By relating economic growth of invention to the rate of increase of invention, to show that exponential increase in invention is not likely without exponential increase in the economic support;
3. By indicating the lower rate of progress caused by the obsolescence of invention; and
4. By projecting the growth curve to ' maturity ', with a constantly diminishing rate of increase in progress, where the limits of demand for invention in a given field can be reasonably determined. "

the bisexual reproduction analogy can be usefully applied in the following way: " If performance capability is a function of the total number of operational inventions, which is a function of numbers of inventors and economic support for development, then growth in performance capability can be related directly to economic support and numbers of inventors. The forecaster can predict values of economic support and numbers of inventors, and derive from this information a prediction of the rate of technical progress. "

The obvious advantage over Isenson's and Hartman's models lies mostly in the possibility of introducing economic support in an explicit way.

Holton's Model: Holton (quoted by *lit. ref.* 89) looks at a " *tree of* knowledge " from which specific new scientific and technological development lines branch off; each new branch, in turn, is likely to give rise to additional branches. Since the number of existing branching points at a given time is then proportional to the number of fields under investigation at that time, the accumulated amount of known or applied information—if each new field is assumed to " contain " roughly the same amount of information to be explored—rises exponentially (by analogy with Hartman's model and its basic assumption $dI/dt \sim I$). However, since the individual information growth in each field follows an S-shaped curve due to the depletion of ideas left for exploration, the overall exponential increase takes place by " escalation ":



" Escalation " is, as a matter of fact, the characteristic form of growth for many important functional capabilities (see also the discussion in the following section II.3.4.). Holton's chiefly qualitative model, however, does not seem to provide analogies which could become useful on the operational level.

Putnam's model for the technological growth process ***(lit. ref. 168)*** is based on such factors as man effort, group size, individual interplay, and concept cross-fertilisation, and includes a mathematical model for the breakthrough process. It seems to be more ambitious than the published models discussed here.

Ridenour's model for the utilisation of technology (quoted by Ayres, *lit. ref.* 89) assumes that the rate of public acceptance of a new product or service is proportional to the number of people who are familiar with it through exposure, so that the incremental increase of this number is proportional to the number of people having already accepted: $dN/dt \sim N$, with the resulting exponential increase of N. To account for the approaching of the limit L of people who can be expected to accept (to buy a certain product, etc.), Ridenour introduces the same correction factor as Hartman, equation (16):

$$\frac{dN}{dt} = bN\,\frac{L - N}{L} \tag{23}$$

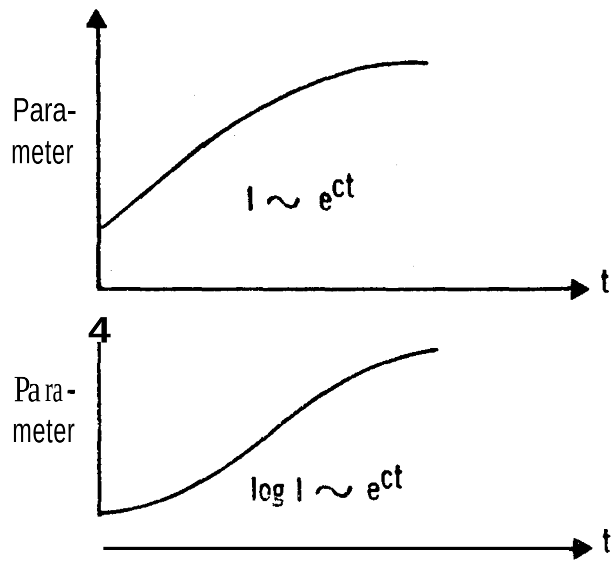
with the integration

$$N = \frac{L}{1 + \left(\frac{L}{N_0} - 1\right) e^{-bT}} \qquad (24)$$

This is the Same S-shaped curve as that which can be derived from Hartman's model, equation (17) and Lenz's model, equation (19). It should be noted, however, that this fact represents not so much a consensus of different models (only Lenz's analogy to growth under constraint leads inevitably to such a characteristic) as a limitation of correction factors which can be expressed and handled mathematically in a simple way. Ridenour's model is significant for the growth of technological capability only insofar as this growth can be assumed to be essentially determined by market demand.

An examination of the models outlined in this section leads to the conclusion that no model has so far succeeded in taking into account more than a limited number of influencing factors by assuming relationships that are generally unproved or not known in detail. and that mathematical formulations do not yet include even all of these recognised factors.

No explanation has yet been given of why growth trends in scientific or technical parameters or in functional capabilities should be directly proportional to the growth of accumulated knowledge. It may well be plausible that certain parameters are, rather, proportional to the logarithm of the accumulated knowledge. In this case, the typical form of curve would be a) a straight line if knowledge increases exponentially, and b) an exponential curve if knowledge increases in a double-exponential way (the sketches include the flattening due to the approach of an upper limit).



The principal usefulness of such simple analytical models may thus be seen to lie in their making visible the influence of external, horizontally acting factors which are responsible for the intricate relationship **between** scientific and technical progress and time.

11.3.3. EXTRAPOLATION OF TIME-SERIES ON A PHENOMENOLOGICAL BASIS

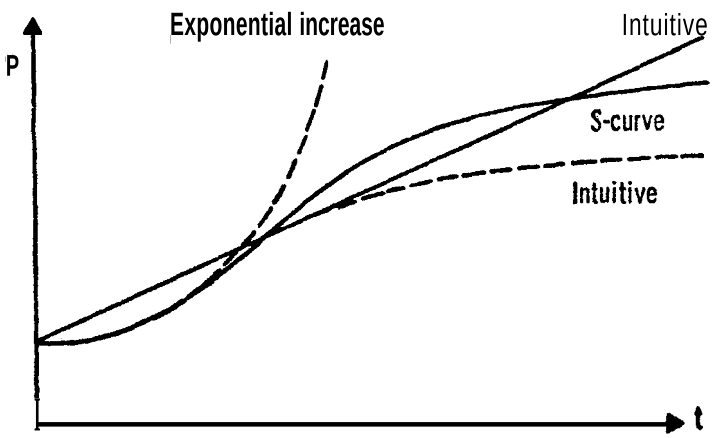
Strictly speaking, the simple extrapolation of secular trends does contain one analytical element—the intuitive expectation that the combined effect of internal and external factors which produced a trend over a past period will remain the same during a future period (" deterministic technique " in business forecasting), or that it will undergo an estimated gradual smooth change (" symptomatic technique "). It is frequently suggested that the extrapolated period should not exceed the period of recorded past experience. This is a very artificial criterion, however; no one, on a reliable basis, could extrapolate the number of scientists over the next 300 years, although an exponential increase, with approximately 15 years doubling time, has been observed over the past 300 years (lit. ref. 6). For many parameters and capabilities of concern to the modern technical world, the period of available past experience does not exceed 50 or 60 years—a reasonable period for long-range forecasting into the future. On the other hand, the 20-year history of nuclear energy should not prevent us from assessing its role and impact for a period ranging possibly up to 100 years.

The significance of an explicit time factor in technological forecasting has been discussed in some detail in Chapter 1.3. The reservations which were formulated there—and which are summarised in the quotation chosen to head that chapter, " History is a very poor guide; we have improved " (Brooks)—will probably render naive trend extrapolation less useful than it has been so far.

General Electric's TEMPO Center expects that trend extrapolation will become " unproductive " because everything will depend on the interaction of many trends.

An important observation is that the smoothest trend curves are achieved for the pace setters, i.e. for the best available technologies, not for average values. This implies that the factors influencing horizontal diffusion of technology complicate the picture so as to distort a smooth curve in some instances. A basic rule for trend evaluation obviously is to select parameters that are affected in a consistent way by the influencing factors —and to limit horizontally acting factors as much as possible.

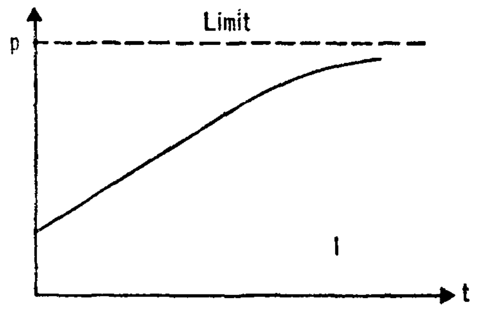
General experience has shown that the intuitive forecasting by experts of scientific and technical parameters or functional capabilities tends to result in linear projections. The first and perhaps most important value

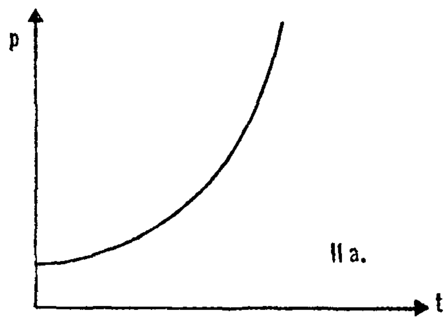


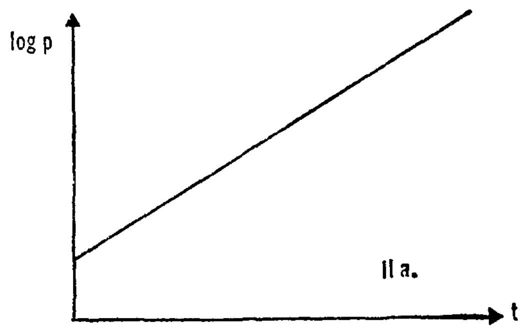
of trend extrapolation may therefore be seen in a correction of intuitive forecasting by giving greater weight to factors which have dominated in the past case history. In general, intuitive expert forecasting will tend to be over-optimistic for the near future and too pessimistic for the more distant future. If intuitive forecasting does not recognise a limit—which is often the case with implicit limits that are not readily discerned—it may again become too optimistic. However, intuitive forecasting often adopts a " feeling " of accumulating difficulties and limitations beyond the time-frame for which concrete research and development programmes can be formulated, so that the intuitive forecast curve will level off—not, however, at the level of an analytically recognised limitation, as would be desirable, but at a level which seems to be influenced by the personality of the expert and usually reflects bias on the pessimistic side.

Trend curves may be divided roughly into four classes which are illustrated by the accompanying sketches:

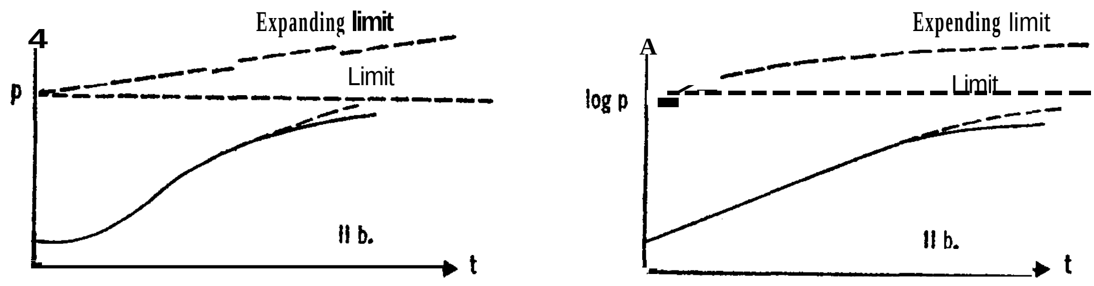
Class *I* (linear increase with flattening): the efficiency of thermal power plants exhibits these characteristics, for example. Also the mechanisation of human work (expressed in terms of the decrease in annual working hours per man) has been linear over the past 75 years.







Class *II.a.* (Exponential increase with no flattening in the considered time-range): these characteristics are exhibited by a number of functional capabilities, for example maximum combat aircraft speed, or maximum transport aircraft speed (up to the planned operational availability of the Mach 2.2 " Concorde ", the Mach 2.7 SST and the advanced Mach 3.0 SST, all currently under development). The almost precisely exponential increase of energy conversion efficiency (lumen per watt) in illumination technology from the paraffin candle to the gallium arsenide diode *(lit.* ref. ***184,*** quoting a General Electric. Co. source) seems to suggest that a functional capability can follow a class II.a. trend until it abruptly hits a limit —the gallium arsenide diode is already close to efficiency 1.



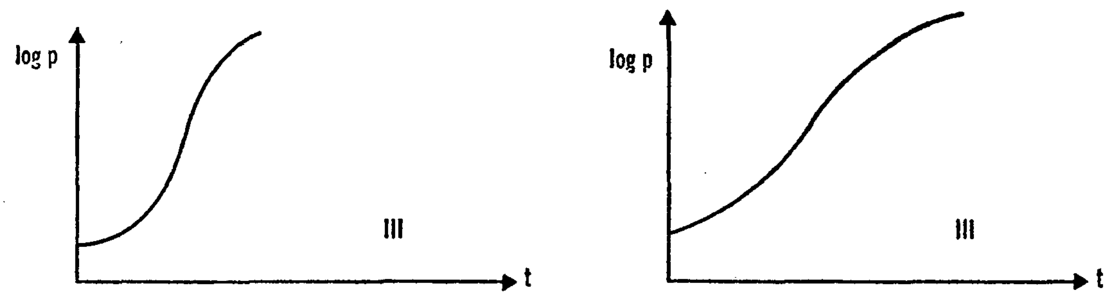
Class II.b. (S-shaped curve, possibly with initial exponential or nearly exponential increase): this is the normal characteristic of specific maturing technologies.

Apart from the logistic growth according to equation (19), one may also find S-shaped growth curves which can be better fitted to Gompertz' law which describes growth phenomena in some areas of economics, for example, income growth. Its mathematical expression is:

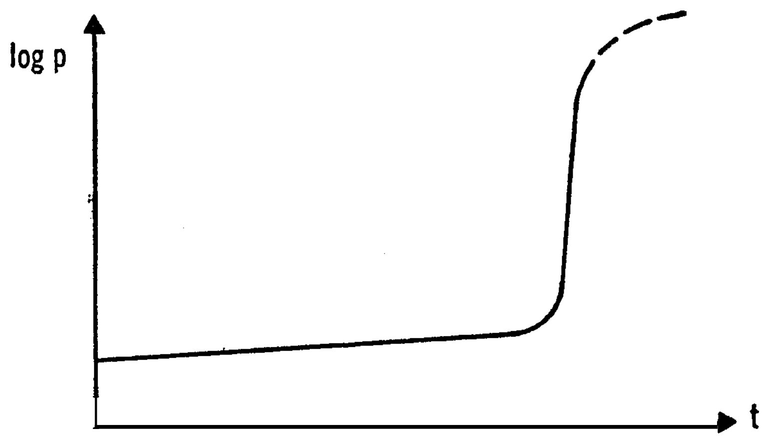
$$p = Le^{-be^{-ket}} \tag{25}$$

L = Limit (in the same units as the parameter p).
b, k = Constants.
t = Time.

In contrast to equation (19), Gompertz' equation (25) represents a non-symmetrical S-curve, with a value of $p = L/e$ at the inflection point at $t = (ln\ b)/k$. However, like equation (19), this S-curve also approaches the extreme values zero and L at t minus and plus infinity; at $t = 0$ the curve has the value $p = L/e^b$.



Class III (double exponential or even steeper increase, with subsequent flattening): these characteristics hold for some functional capabilities in areas of concentrated research and development; according to ***lit. ref. 89,*** examples are maximum speed attained by man and operating energy in particle accelerators. It is interesting to note that, according to ***lit. ref. 142,*** operating speed of commercial computers would belong to this class, whereas, according to *lit. ref. 89,* the ratio of computer capacity to add time would, up to the present, be characterised by an exponential growth of class II.a. (This ratio may be regarded as a " figure of merit " of overall computer development progress, whereas operating speed singles out one of the important parameters only).



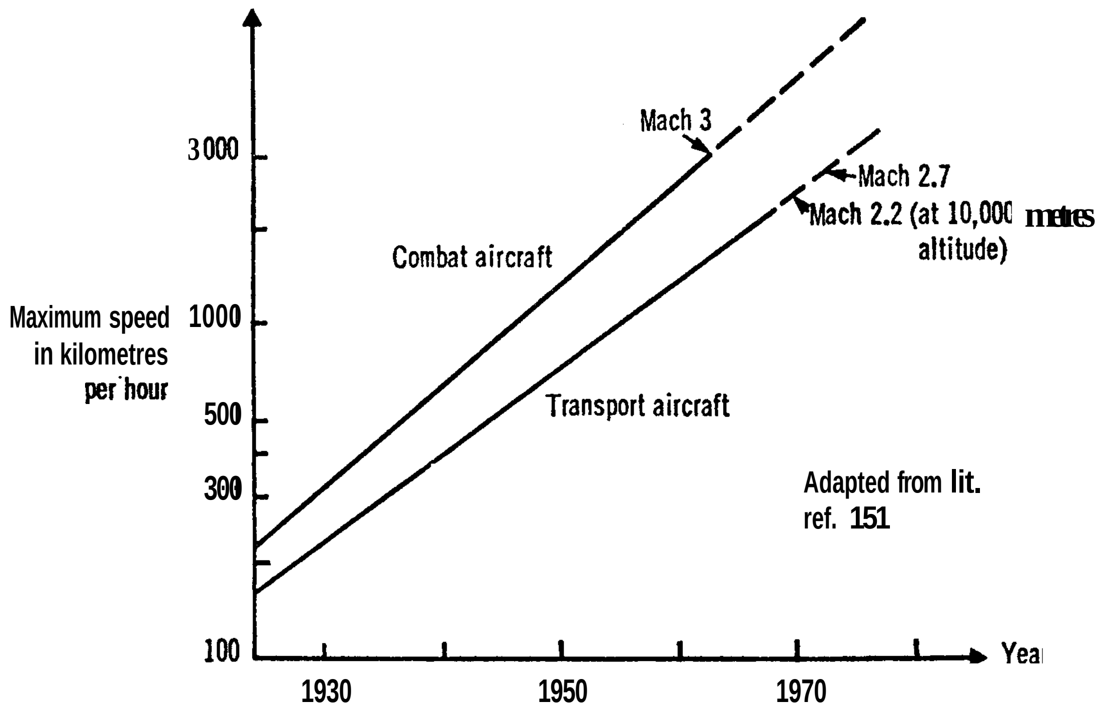
Class IV (slow exponential increase followed by sudden, much more rapid increase, with eventual flattening): this type of curve applies, according to *lit. ref. 89,* to the maximum explosive power available for delivery at a distance, The very steep rise is, of course, mainly due to the advent of nuclear fission and fusion weapons, but had already begun in World War II with the conventional 10 ton " blockbuster. " The flattening of the curve is caused by the effective limit of utility at approximately 100 megatons rather than by technical limitations.

Trend evaluation and extrapolation on a simply phenomenological basis has become a widely used auxiliary technique, especially where emphasis is put on normative forecasting, as in defence research. It provides a first answer to the question of whether a specific goal (a specific advance) has a reasonable chance of being attained by the same mechanism of innovation which produced past progress. At the same time, trend extrapolation strengthens the mechanism of " self-fulfilling prophecy ·· by increasing confidence in the reasonable attainability of a goal which otherwise could not be analytically assessed.

Little or no use is yet being made of a possible extrapolation of trends which would depict the impact of technological improvement (for example, the increase of functional capabilities) in a quantifiable way. In general, the " social ·· impact, on the analogy of the Weber-Fechner law which holds for human sensual perception, would be expected to be roughly proportional to the logarithm of a technological capability. However, this field —important as it appears to be for future exploratory technological forecasting over the full range from fundamental science to social impact— is still in a very early stage of investigation.

Two refinements of secular trend extrapolation can be applied with considerable advantage in suitable cases: forecasting by analysis of precursive events, and forecasting by envelope curve extrapolation. They will be discussed in the following paragraphs.

Forecasting by analysis of precursive events uses the correlation of progress trends between two developments, one of which is leading the other. A striking and unconventional example is presented by Zebroski *(lit. ref. 351)* who predicts the growth of future fast reactor application as logically dependent on the plutonium production from the current generation of thermal reactors. Lenz *(lit. ref. 151)* gives an interesting and plausible example by comparing the maximum speed of combat aircraft and transport aircraft:



It is obvious that these two developments are logically related to each other in the way depicted; the research and development effort applied to combat aircraft eventually also bears fruit in the transport sector. That the time lag increases—the slope of the combat aircraft speed trend corresponds to a doubling time of 10 years, and that of the transport aircraft speed trend to one of 12 years—is an interesting observation which can probably be explained only by the combined effect of various factors.

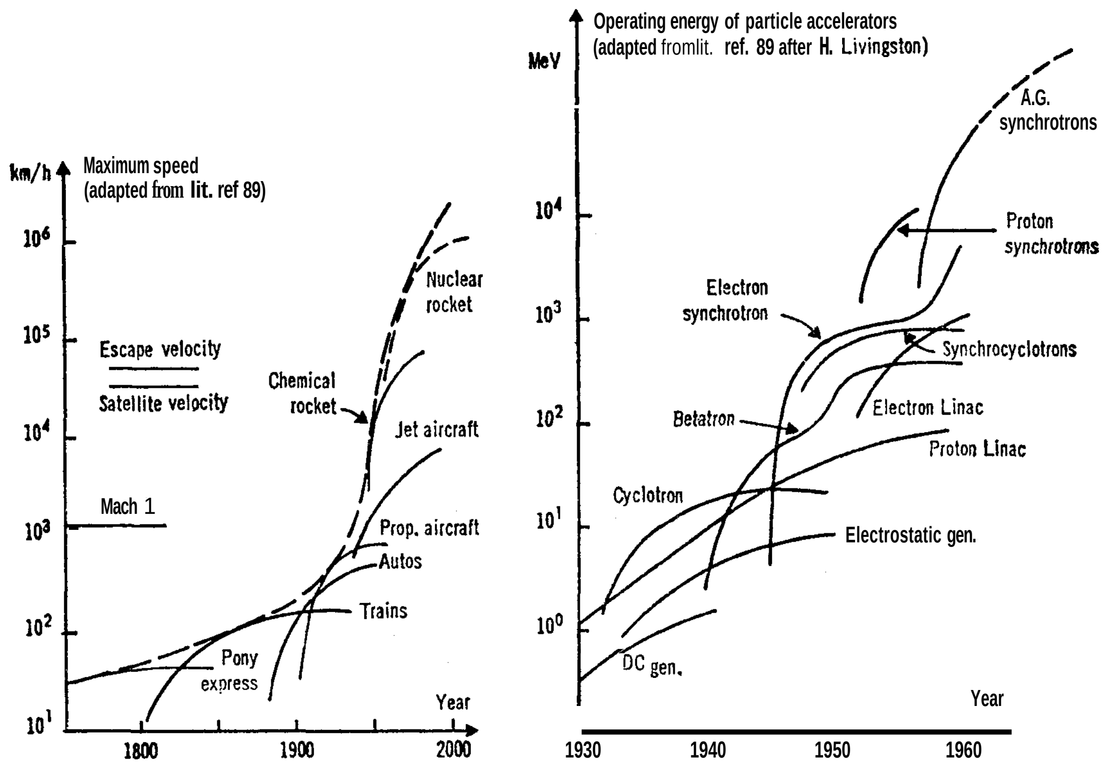
Certainly, such a simple correlation of two trends is valuable for forecasting only insofar as the leader-follower relationship between the two developments is maintained. For the example given above, the situation is now changing. Whereas the Mach 3 bomber has not gone into production in the US (though prototypes have been manufactured which continue the trend curve fairly accurately), and hypersonic planes for the early 1970's will probably depend much more on strategic decisions than on technical feasibility (for which the necessary elements would seem to be ready), civilian transport aircraft development, for the first time, is now receiving substantial support from governments (the planned operational availability of the supersonic transport aircraft under development fits the trend curve extremely well). How this will affect the two trend curves and the correlation between them must be a matter for speculation.

An important implicit factor in the aircraft speed exampla is the lead time of one trend over the other in a causal relationship. Because of this, the correlation of secular trends is legitimate. If two parameters, however, are intrinsically related to each other without involving the time factor, their correlation by means of secular trends is artificial and obscures the real causal relationship. Lenz's example of the parallel trends of tensile strength of materials, and of maximum span of bridges, would belong here.

In general, more parameters are intrinsically related to each other than may be obvious at first sight. For example, aircraft weight, and thus (for the same speed) aircraft power, are a function of the complexity of components, such as electronic systems. The utility of parametric trend co-relations which do not include an explicit time dependence will be discussed in the next section 11.3.5.

The unjustified assumption of a leader-follower relationship can lead to totally wrong conclusions. An example of this was provided by an early US-AEC forecast for civilian nuclear power ***(lit. ref. 331)*** which assumed that nuclear power will on the average always be at least twice as costly as conventional power, and estimated a margin of 10 to 20 per cent of total energy consumption within which nuclear power could play a role under these condition.

Envelope curve extrapolation: Functional capabilities that can be achieved by various different techniques, or parameters of a general nature, represent a " system " of a higher order, characterised by a succession of innovations at either a constant or changing rate. Two frequently cited examples, themselves representing two different device levels (the speed example is given in more general categories) will serve to demonstrate this:



Ayres ***(lit. ref. 89),*** who has treated envelope techniques in the greatest depth, states the problem as follows:

" How, then, can one predict the future of a complicated ' system ', one of whose characteristics is a constant (or changing) rate of innovation? Where is there a model of the system whose performance can be analysed? The oversimplified answer is, clearly, that the past performance of the system is fairly likely to be a good model for its future performance, i.e. the system simulates itself. We should expect this to be true on general grounds, as long as, and to the extent that, the system is not radically changed by some exogeneous factor... Thus, when we extrapolate envelope curves beyond the current state-of-the-art, we automatically assume a continuation of the rate of invention (and perhaps its rate of change) which has characterised the system in the past. This may, of course, fail to take into account the effects of rare and extraordinary breakthroughs, but the consequence of a continuous process of ' ordinary ' innovation would presumably be taken into account. Disaggregative analysis, on the other hand, has no way of anticipating even the more ordinary kinds of innovation (if the system configuration is changed thereby), since one predicts the limiting performance of a given class of inventions by using envelope curve extrapolation only at the component level. »

For the choice of suitable parameters, Ayres suggests that one determines beforehand whether the predominant constraints are intrinsic or extrinsic, and that progress be expressed accordingly in " intensive " or " extensive " parameters. In general, " intensive " parameters may be expected to become more predominant for the progress characteristics of a system the closer they approach inherent limits. Ayres' examples of " intensive " parameters include:

Ratios of input to output, eventually approaching unity: energy conversion efficiency, information transmission through a specific channel, etc.;

Functional capabilities, eventually approaching absolute (natural) limits: speed, low pressure, low (in certain cases also high) temperature, etc.;

Functional capabilities, eventually approaching practical or tolerance limits: traffic flow per lane, acceleration of passenger transport devices, etc.

" Extensive " parameters would include population, production, GNP, etc.

One would of course expect envelope curves to take the form of a " big S " riding on the " small " S-curves for the individual techniques. Experience—see, for example, the speed and accelerator energy curves given above—seems to indicate that envelope curves are even S-shaped in a logarithmic plot; i.e. the represented parameter initially increases faster than exponentially.

The examples given for suitable " intensive " parameters show that upper limits may often be recognised more easily for envelope curves than for individual techniques; they may readily be recognised as:

Absolute (natural) limits: velocity of light, absolute zero temperature, zero pressure, unity efficiency, temperatures at which molecular bonds break up, etc;

Limits due to characteristics of the earth or to human capabilities: maximum velocity in atmosphere, minimum time to circumnavigate the globe, human tolerance for acceleration, human noise tolerance, etc;

Derived limits: Carnot efficiency between given temperature levels, etc.

Likewise, the " external " factors, such as population and GNP, determine upper limits.

Ayres remarks that " the more disaggregative (component-oriented) the analysis, the more it is likely to be intrinsically biased toward the conservative side... In fact, it is almost normal for the maximum progress projected on the basis of analysis of components to be, in effect, the lower limit on actual progress, because it assumes no new innovations come along to change the technology. "

Upper limits of the same class as those which can be readily stated for envelope curves can rarely be given for individual techniques on the same grounds. The maximum speed and altitude of aircraft (air-breathing vehicles), limited by the escape velocity and height of the atmosphere, are exceptions here.

In many practical cases larger systems represented by envelope curves show more stable progress than their individual components (technologies) and, in the long run, are often not visibly affected by extraordinary events such as depressions or wars (whereas elements contributing to such systems exhibit marked effects, such as a decrease in the number of new scientists or an increase in military development programmes).

Ayres *(lit. ref. 89)* offers plausible reasons for this higher stability:

" Apart from feedback mechanisms, one reason for the comparative stability of extensive macrovariables seems to be that the ' law of large numbers' is operating. This law, which is a weak form of the fundamental central-limit theorem of statistics, says that an additive ' macrovariable' (i.e. sum over many components) is likely to deviate relatively (percentage-wise) less from its mean or centroid than any of its component ' microvariables', provided that the latter are all roughly equal in size and vary independently of one another within similar ranges.—Suppose an additive microvariable is defined as $P = \underset{i}{\&}.$ Then the standard deviation of P is given by

$$\sigma_p^2 = \sum_i \sigma_i^2 \qquad \sigma_p = \sqrt{\sum_i \sigma_i^2} \tag{26}$$

If N of the σ_i are all of roughly equal magnitude (the others being negligible) and $\bar{x}$ is the mean value of the non-negligible variables, then is $P \approx N\bar{x}$

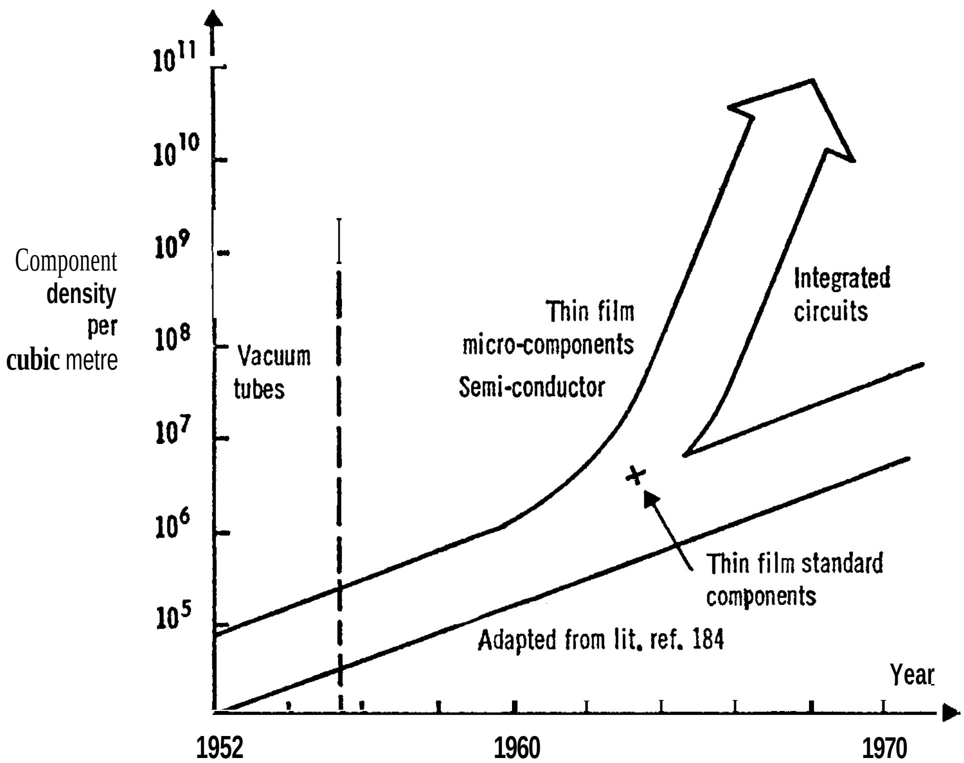
and

$$\frac{\sigma_p}{P} \approx \frac{\bar{\sigma}}{\sqrt{N}\,\bar{x}} \tag{27}$$

" The rate at which aggregate variables fluctuate is somehow a function of the reaction time (or ' relaxation time ') of the interconnected system to a perturbation. This determines the speed with which a disturbance (analogous to a ripple in water) will be propagated throughout the ensemble. "

However, certain case histories, such as that of the speed plot given above—where the bend in the envelope curve is obviously influenced by military aircraft and missile development (with civilian technology being speeded up through a causal follower relationship)—may be better interpreted by assuming the introduction of extraordinary driving forces. The system progress then would tend to stabilise, for some time, at a different pace. It can be confidently assumed that the present movement in the direction of more conscious planning, the increasing number of possibilities for pushing developments towards clearly recognised goals, and—last but not least—a future feedback effect from technological forecasting, will increasingly influence progress curves of large functional systems. The same may prove true with respect to the intervals between successive technologies (in envelope curves rising faster than exponentially, a steady decrease of intervals can be observed, i.e. " cycle times " for successive technologies become reduced).

Since a new specific technique is, in general, introduced by a technological breakthrough, one may distinguish different " classes " of breakthrough in accordance with the effect on the envelope curve. The example given above for the explosive power available shows the effect of a " super-breakthrough " marked by the advent of nuclear weapons. This is not surprising in view of the basic change from chemical to nuclear energy and the scientific breakthrough involved. However, " super-breakthrough " characteristics can sometimes also be observed with developments which, viewed from the outside, appear as the logical extension of known techniques. Integrated circuit technology, for example, has the effect of speeding up progress in certain directions much faster than did the succession of its predecessor techniques:



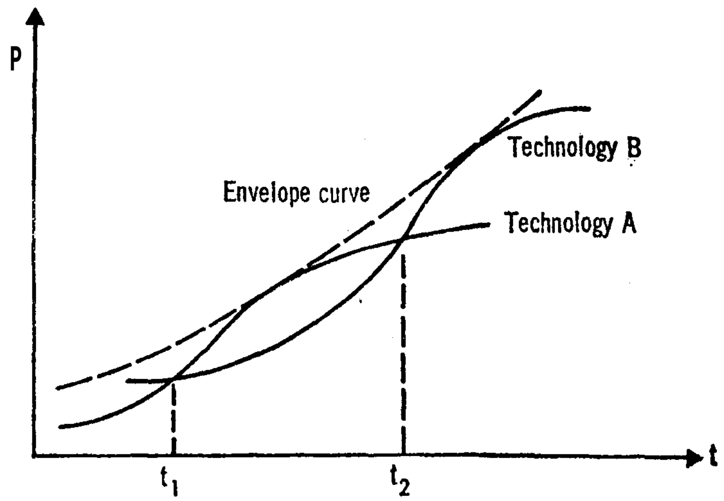
Little is known, so far, in the area of a phenomenology of scientific and technological breakthroughs.

For the practical purposes of technological forecasting, one may conclude, with Ayres, that the risks of non-specific forecasting (parameters of functional capabilities instead of specific techniques) can be " traded off " against the advantages of the envelope technique:

this technique introduces no inherent bias into the forecast;
the ultimate limit can often be recognised directly and explicitly;
the technique benefits from a greater stability in the progress characteristics.

Although envelope techniques have apparently been used in recent military technological forecasting, e.g. in the US and the UK, and in NATO, few examples are yet known of long-range forecasting ventured on this basis over time spans that would correspond to more than two successive leading technologies. However, forecasters are gradually becoming accustomed to envelope techniques, and sufficient confidence may be gained to inspire the use of the conclusions drawn from them.

An even more important practical use of envelope techniques may result from the possibility they provide of conjecturing, with a fair degree of confidence, the advent—and, in broad terms, the effect—of technological breakthroughs. A deeper scrutiny of technologies in an early stage of developnient may then lead to an early recognition of the new " growth " technology:

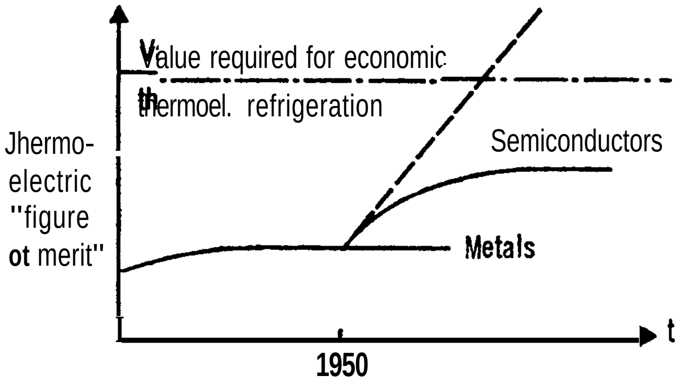


The graphic example illustrates the possible advantages as well as the possible pitfalls: a company exploiting technology A can gain considerable advantage by recognising and developing technology B well in advance, long before technology A starts to level off. On the other hand, direct comparison of trends A and B at time t_1 or shortly afterwards would lead to the wrong long-range conclusions if not seen in the context of the envelope graph. It was precisely this type of neglect which caused a number of big companies to reject the Xerox technology when offered to them in an early stage of its development; for Gevaert-Agfa (Belgium). this experience has been a major element in the consideration being given today to the establishment of a systematic technological forecasting function.

The conscious evaluation of S-curves corresponding to individual technologies within the framework of envelope thinking is regarded as a valuable (if auxiliary) means of improving the allocation of resources. It is most systematically applied in military administrations. In the (former) British Ministry of Aviation the characteristic S-shaped curve of improving technology was know as the "Cawood S," a reference to the basic attitude cultivated and refined by the Chief Scientist. For the preparation of Honeywell's PATTERN scheme (see section II.4.5.) trend extrapolation in general, and individual and envelope S-curve extrapolation in particular, are systematically used for a five- to 15-year forecast of hundreds or thousands of technical parameters and functional capabilities.

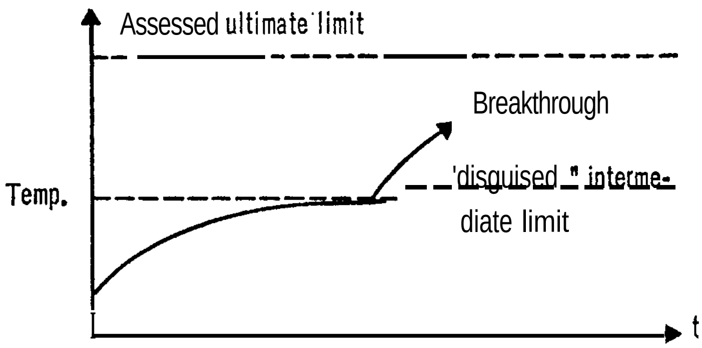
At the same time, the conscious or unconscious adoption of the principle of successive technologies in the same functional area can point to the necessity of analysing the nature of progress, or can lead to the recognition of implicit limits which require a new breakthrough. Two practical examples of far-reaching consequence may illustrate these points:

When, in 1950, measurements of the thermoelectric " figure of merit "[1] of available materials started to show a rise, hopes were aroused that the threshold required for the economic application of



thermoelectric refrigeration would soon be crossed. On the basis of this hope, Westinghouse went ahead with a fairly large-scale development programme. General Motors, setting up an *ad hoc* group to investigate the nature of the sudden rise and ascertaining that it was due solely to the availability of an new class of materials, i.e. semiconductors, succeeded in forecasting, on theoretical grounds, a natural limit for semiconductors which would still be below the economic threshold. The decision made by General Motors to abandon the development project turned out to be the correct one.

In US defence research, the attained temperature resistance of materials in an oxydising atmosphere—a functional capability whose improvement was pushed with all available means because of its paramount importance for missile and other defence developments—recently tended to level off far below the assessed natural



limit; a hitherto unknown " disguised " intermediate limit made itself felt. A major effort, involving top experts, was undertaken by IDA (Institute for Defence Analyses) and succeeded in determining the nature of the intermediate limit (related to the oxygen transport mechanism in the material); the required breakthrough was subsequently achieved.

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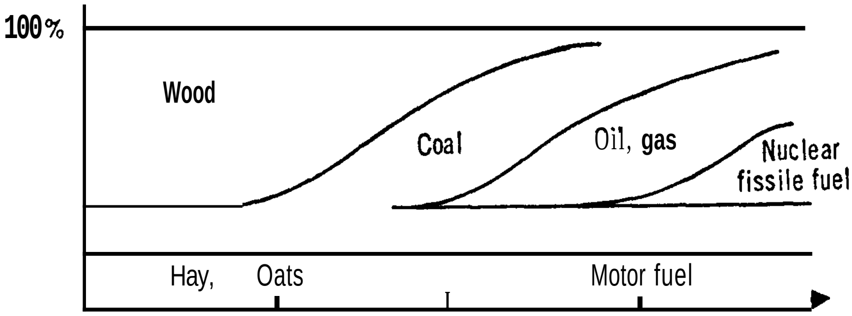
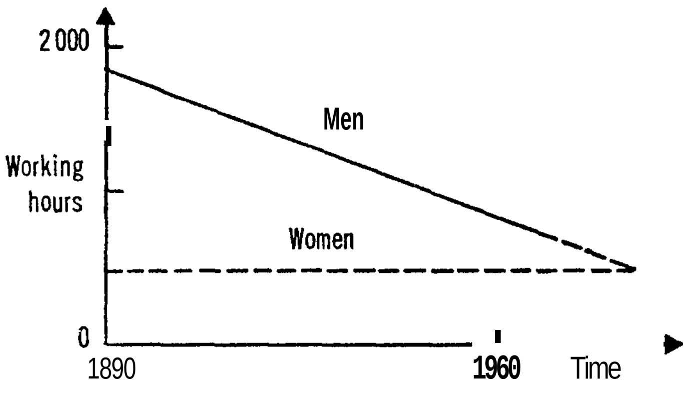
1. The thermoelectric " figure of merit " combines thermal conductivity, electrical conductivity and thermo-power (differential thermo-voltage) of thermoelectric materials.

These two examples also seem to imply that the pattern encountered so far—that of new technologies preparing themselves " silently " before the limiting factors in the old technologies become felt, so that the rising pressure of incentives " forces " embryonic new technologies into existence —no longer holds in a general way. One of the most important tasks of technological forecasting in a framework of well-oriented technical planning will undoubtedly be the recognition of intermediate limits and the clear formulation of breakthrough requirements.

Another possible avenue to representing time-series—and touching on other implicit inertiae which serve to smooth them—is the extrapolation of ***relative trends*** within a broad entity, such as the total consumption of fuels. This approach is successfully followed by General Electric's TEMPO Center in Santa Barbara, California. A regular SO-year cycle emerges, with smooth relative S-curves, in the above example.



A variation of the relative trend method is an approach which might be labelled " anthropomorphic thinking " and is also practised by TEMPO. Paid working hours per year, computed as a life-time average, are taken to constitute a representative trend with respect to mechanisation and future full automation[1]. The correlation yields a remarkably straight descending line for men (on a US basis), and no variation for women (who



for the most part work without pay at home). Still another example of a ;relative trend approach, again provided by TEMPO, is the breaking up of the automation trend by professional classes; the exponential trends can

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1. **TEMPO's forecast for 1984 foresees school attendance up to the age of 25 and a working life extending to the age of 50, with a 40-hour week but with six months annual vacation!**

then be expressed in terms of individual " half-lives " for the replacement of professional categories: accountants 10 years, pilots 15 years, engineers 20 years.

Mathematical trend-fitting techniques have been developed with the use of well-known statistical techniques (see, for example, *lit.* ref. *140*), and are widely employed in business forecasting. Trend-fitting can be simplified by determining first to which class a given trend belongs: linear increase, exponential increase, S-curve.

The most common method of trend prediction makes use of classical regression technique: If two parameters x and y (one of which may be time) are to be related to each other, one postulates a mean relationship, for example $y = bx$, and minimises the total error for a number k of observed pairs (x_i, y_i) by the least squares method:

$$\text{Total squared error} = \sum_{i=1}^{k} (y_i - bx_i)^2 \tag{28}$$

By setting the first derivative zero, one gets the minimum; solving for b yields:

$$b = \frac{\sum_{i=1}^{k} x_i y_i}{\sum_{i=1}^{k} x_i^2} \tag{29}$$

The relationship, i.e. the value of b, will be modified by each new observation (x,y).

" Exponential smoothing " is sometimes useful for business trend evaluation and may be preferable also for technical parameter trends in certain cases.

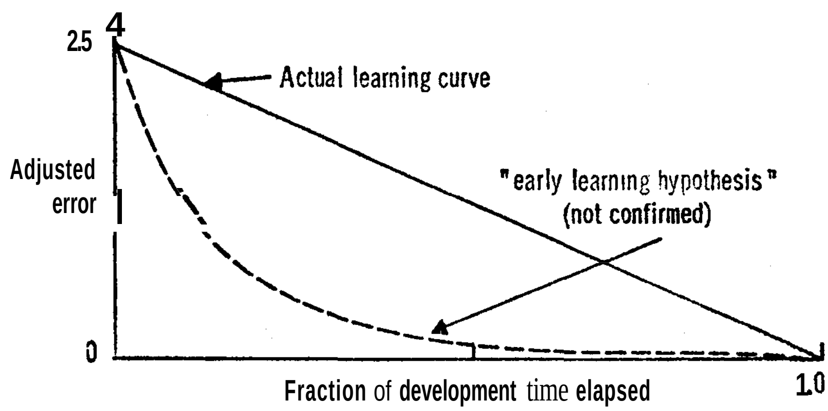
11.3.4. LEARNING CURVES

At the beginning of the preceding section, II.3.3., a " personal equation " was mentioned which is frequently encountered in intuitive forecasting of technical performance over time. Such forecasting is marked as a rule by an initial over-optimism and a subsequent over-pessimism. " Learning curves " are potentially useful in correcting for the " personal equation. "

A number of investigations carried out at the RAND Corporation in Santa Monica, California, attempted to correlate development cost, development time, and production cost estimates, which were revised at various stages of development. The aim was to test an " early learning hypothesis. " These investigations concerned weapon system developments in the late 1950's and early 1960's. The results, therefore, indicate relationships for developments with the following characteristics: systems engineering of complex systems: military developments in which the attainment of estimated technical performance (functional capability) was, at that time, considered the primary goal, justifying substantial readjustments of development time and costs, and also of production costs; the existence of a " psychological " interest in initial under-estimations of cost and time factors on the part of contract bidders. It may be considered as doubtful whether the resulting correlations would hold in the same way for typical technical developments in the civilian sector. They are presented here only to demonstrate a feasible approach to the problem, which may be modified for broad technological areas.

Klein (lit. ref. 244) presents a correlation of 35 estimates of availability ***(development time*** plus testing, etc.), made at various stages of development of eight US missile programmes. A linear " learning " characteristic for the error was obtained (after adjustment for certain irrevelant influences):

$$\text{Error} = \frac{(\text{actual time to go}) - (\text{estimated time to go})}{\text{actual time to go}}$$



For ***development costs*** on the basis of estimates for the same eight missile programmes, the " early learning hypothesis " could not be proved.

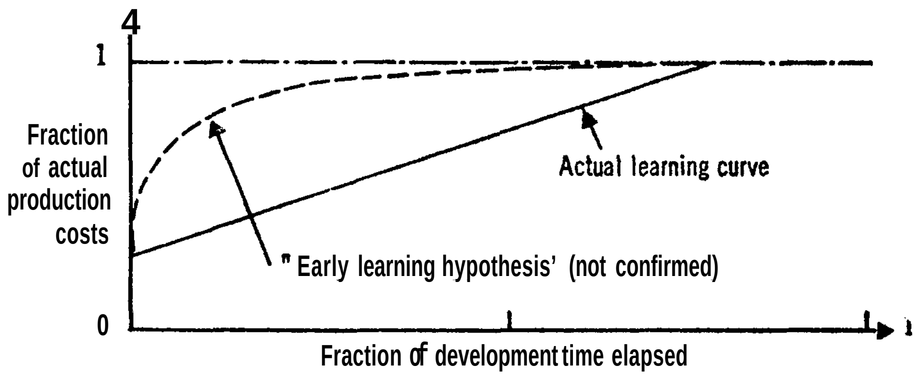
Mention may be made of the drastic " learning curve " exhibited by the development cost estimates for the British/French supersonic aircraft " Concorde " up to 1969 (without taking into account rising costs and devaluation of money):

1962 estimate	$ 400-460 million
1963 "	$ 740 million
1964 "	$ 1,000 million
1966 "	$ 1,360 million

i.e., so far the estimated costs have more than tripled.

Summers (lit. ref. 250) investigated estimates of ***production costs*** made at various development stages of 22 different US weapon systems. Approximately 100 estimates were available, of which 67 were evaluated. It was necessary to adjust the comparisons to the actual production volume since estimates were often based on high production volume estimates which were then changed because of strategic and other considerations. For example, the ratio of actual to estimated production costs for air-breathing guided missiles would be as high as 58 if one compared the 1947 estimate based on the production of 100,000 articles (missiles without supporting system) with the actual production costs for only 150 articles in 1958; after quantity adjustment and price level correction (1947/1958), the adjusted ratio of actual to estimated production costs is **only** 5.

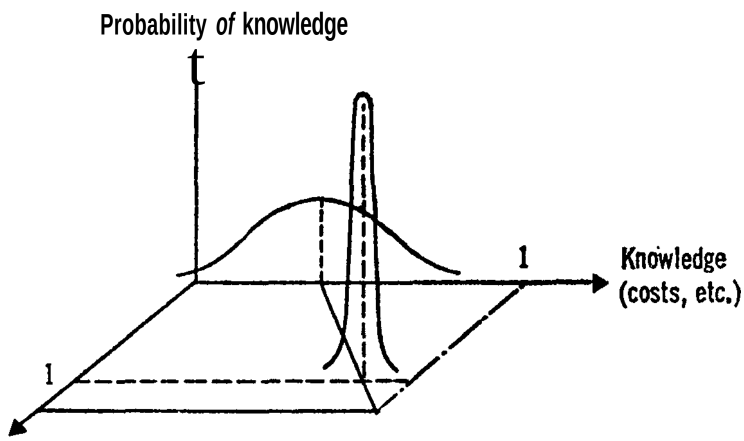
In Summers' investigation production costs turned out to be higher than estimates in 80 per cent of the cases. The general relationship, in most (but not all) cases, again is linear:



Accurate cost estimates were generally achieved as soon as the technical elements of the system were accurately known. For unconventional designs, even at the end of the development time, good estimates could not be made.

In general, the ratio F between actual cost and estimated cost can be expressed as a function $F = F(t, A, ...)$, where t is the elapsed fraction of development time, and A a measure of technological advance. Six to eight more parameters may be involved and are at present being investigated.

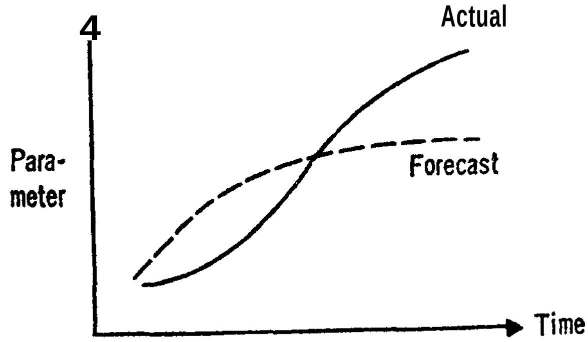
Learning curves may also be represented with probability distributions for each estimate. The distributions would then become narrower with increasing accuracy as progress is made with development time.



In the reported examples, the " early learning hypothesis " of the RAND Corporation could not be proved as conclusively as hoped. However, further tests will certainly be worthwhile and might become a means of measuring the success of technological forecasting.

Increasing sophistication in technological forecasting—an art which is still in a very early stage of development—may be expected to improve not only the initial estimates at $t = 0$, but possibly also the learning characteristics. The " early learning hypothesis " may then become true in broad areas and may, in turn, further improve technological forecasting through a feedback.

A variation of learning curve techniques is suggested by *Pardee* of the **RAND** Corporation *(lit.* ref. ***166)*** with his " variance analysis." The development of a parameter over time (if it can be followed in that way) is periodically compared with the forecast; the variance thus determined. and assumed reasons and contemplated action, are put on to a form which tells a dynamic story once the later development stages have been reached.

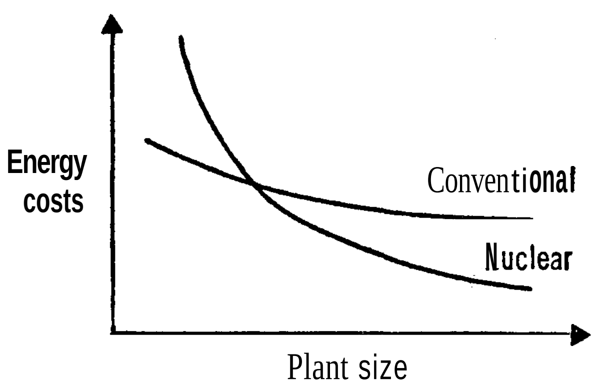


II.3.5. TIME-INDEPENDENT CONTEXTUAL MAPPING

Contextual mapping is a broad concept, comprising both qualitative and quantitative versions, and is applicable to virtually all technology transfer levels including higher impact levels. Quantitative contextual mapping is of particular value for the development levels.

Whereas time-dependent trend extrapolation attempts explicit forecasting, inter-relationships between parameters can be explored on a much more general level if they do not have to fit into an explicit time-frame. Nevertheless, they may represent extrapolations of reality by correlating parameter values beyond present capability, or estimated for future technologies.

Of special importance are forecasts of the effects of scaling. Drastic differences in early forecasts of the impact of civilian nuclear energy can be traced back to differences in the expected effects of scaling up the size



of nuclear as well as conventional power plants. In particular, the lack of such a forecast—and the assumption of equal scaling effects in both types of power plants—led to wrong conclusions.

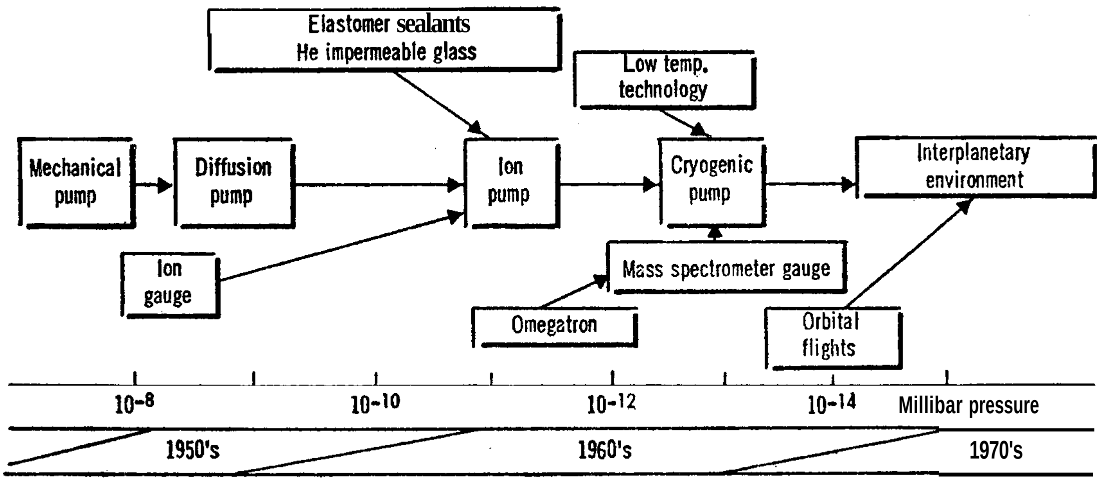
There are obviously many technical parameters which can be related to each other beyond the area already attained, whether through extrapolation or through logical analysis of causal relationships. The possibility of combining parameters in such a way that dimensionless groups are compared may have considerable potentiality but has thus far hardly been studied[1].

Contextual mapping in this sense was already being systematically employed by the RAND Corporation in the late 1940's. Parametric studies and so-called " rubber " engines and air frames were used to determine the " best " strategic bomber (see *lit. ref. 231*).

At the same time, technical and economic parameters can be related to each other in many ways. Value analysis can be applied to the development of new products and, even more effectively, to the improvement of known technologies. The easily derived break-even point for the costs of an improvement in a system—for example, the higher price that can be paid per kilowatt for an improvement of one per cent in the efficiency of a power plant—can guide the direction and level of effort in development projects. Production and market figures may be related in like manner.

Cetron et al. *(lit. ref. 184)* describe two variations of this technique:

a) Expressing a ***trend as process*** in the acquisition and application of knowledge. Cetron remarks that the example given here of high vacuum technology " could be elaborated to great detail



without loss of its communication value, especially if groups of blocks are colour coded (for example: inputs, devices, outputs, applications, etc.) and if the process arrows are coded for various meanings (for example: A begat B, A merged into B, etc.). The logic implied by blocks related by arrows so coded could be conjectured inputs and impacts of potential future technologies. "

The fact that inventions often occur in functional equivalent groups, already pointed out by Gilfillan *(lit. ref.* 70) enhances the value of this approach.

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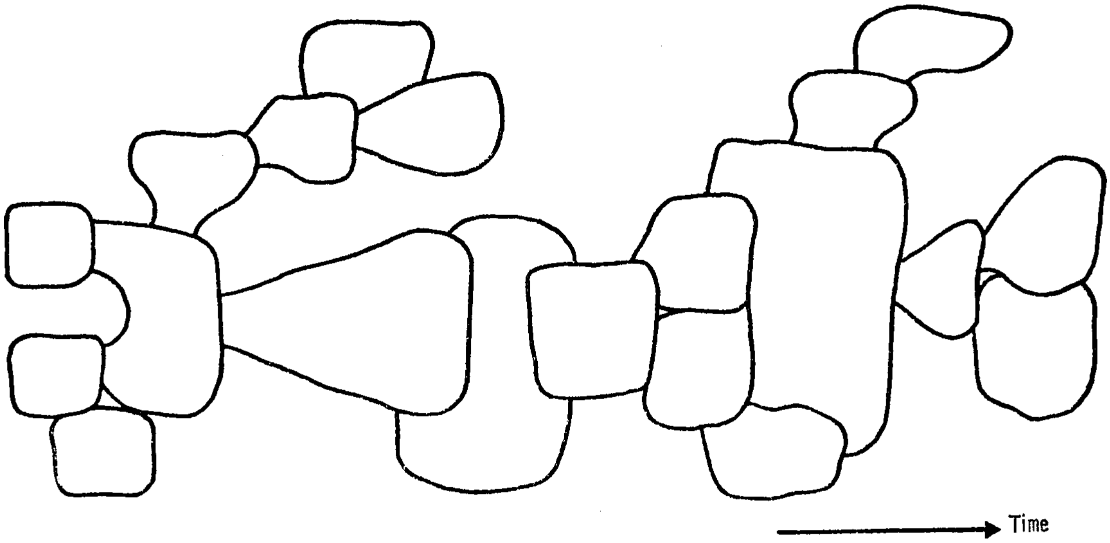
1. Dimensionless parameter groups constitute an important, simple means of describing complex physical realities in thermodynamic engineering.

b) Expressing *a* trend *as* evolution in the configuration of a system, such as large military technical systems that are in continuous evolution and absorb and discard a large number of specific technologies (Cetron's example of such a system is the ground environment of air defense).



Directions of systems growth which were abandoned or are expected to flourish only temporarily are depicted as buds which stop reproducing. The size and interfaces of buds can be used to indicate the strength and sources of growth increments.

Parameter-depending trends as well as those depicted as processes or evolutions can, of course, be put into a broad-time-frame. Their important feature, however, is the explicit recognition of causal relationships apart from the effect of time, and the simple possibility of conditional forecasting. Future developments which depend on the simultaneous progress of a number of parameters or capabilities, or on certain environmental (economic or other) conditions, can be forecast explicitly—for a given set of conditions—where it would be difficult to forecast with any reasonable probability time-dependent progress or all the parameters involved.

It becomes clear that time-independent contextual mapping is of greatest importance where exploratory forecasting is employed to prepare a basis of potentials which will be matched against priorities derived by normative forecasting. If emphasis is placed on normative forecasting so as to endow it with the power of supporting the development of chosen potential, the task of exploratory forecasting will shift from the prediction of the future to the mapping of possibilities, relationships, and conditions.

Technological forecasting for the *US* Air Force, from the Von Karman report " Toward New Horizons " (1946) through the different major efforts up to " Project Forecast " (1963), have systematically used contextual mapping by observing combinations of current and possible future technologies in expected future environments. This approach became a most valuable tool in defining new missions and conceiving future complex weapon systems.

Contextual mapping played a decisive role in the proper timing of the commencement of integrated circuit development at Fairchild, in Mountain

View, California. Fairchild deliberately did not join the early attempts (for example, project " Tinkertoy " in the early 1950's), but waited until a clearly recognised set of factors showed signs of approaching feasibility -especially planar techniques, the concept of isolating by p-n junctions, experience in mass production yield. A strong programme, started in 1960, quickly made Fairchild one of the two world leaders in this highly important development.

Contextual mapping is also practised by the big oil companies for their very-long-range forecasts (up to the year 2000 A.D.) to assess the competitive position of the different types of fuel. Esso *Research (US)* also applies this technique to forecasts concerning fuel cells, nuclear energy, etc.

North American Aviution's Los Angeles Division makes extensive use of a " Configuration Analysis Program " on a computer which evaluates trends and envelope curves for all aircraft ever built. The computer itself does not forecast, but correlates past history with a bias that is fed in. Careful analysis of the better-than-average cases off the main trend sometimes leads to important basic ideas. The sudden recognition of compressive lift for example, made the Mach-3 bomber **B-70** possible. The programme is also of considerable value for the development of the VTOL (vertical take-off and landing aircraft).

For the Long Range Planning Service of the Stanford Research Institute in Menlo Park, California, contextual mapping is not only a standard technique for examining complex situations, but is also used in the reports as a means of representing the results of longer-range forecasts.

This aspect of exploratory forecasting seems to have been applied very successfully. In the absence of systematic large-scale normative forecasting in areas other than advanced technical development, contextual mapping has not yet received the full attention which it deserves; it is considered of potential value within the framework of social technology.

II.3.6. THE MORPHOLOGICAL APPROACH TO A SYSTEMATIC EXPLORATION OF TECHNOLOGICAL POSSIBILITIES

Trend extrapolation and contextual mapping generate new, though more or less inaccurate, information about specific functional capabilities or parameters or simple parameter combinations. They do not yield any information about the nature of functional technological systems, and there is no indication of how comprehensively future possibilities are grasped by a number of intuitively chosen trend extrapolations. Intuitive thinking, of course, can attempt to fill gaps and to imagine how parameter and capability trends may combine in functional systems—but unstructured intuitive thinking, again, is bound to miss a certain fraction of imaginable possibilities and feasibilities.

The increasingly important function of normative forecasting **will** be very seriously hampered if there is no systematic exploratory technique to survey all opportunities at the technological levels—primarily at the level of functional technological systems, but also at the lower levels of technologies, technological resources, and even scientific resources. Normative forecasting selects from items prepared by exploratory forecasting. It should be noted, moreover, that the techniques outlined in the following sections of this chapter on exploratory forecasting represent merely structuring devices and depend on the input from the " information-generating " techniques.

It is astonishing, in view of the above, that the only technique yet developed for systematic exploration has not received very wide attention so far. As a matter of fact, it was one of the first techniques proposed far technological forecasting in general, and for some time could be considered precocious in the context of the prevalent attitude to technological planning. It is time to repair this neglect.

The ***morphological method*** was developed by Zwicky, a well-known Swiss astronomer working at the Mount Wilson and Mount Palomar Observatories, in California, as long ago as **1942** when he was temporarily engaged in early rocket research and development at the Aerojet Engineering Corporation at Azusa, California. In **1961,** a Society for Morphological Research was formed in Pasadena, California, with Zwicky as its president. It appears that Zwicky's stubborn " campaign " for his method, has somewhat obscured his message. Everybody knows of Zwicky, but very few have acquainted themselves with his method.

To quote Zwicky *(lit.* ref. *190)*:

" There are, in particular, three types of generic problems which the morphological analysis attempts to solve. These are:

How much information about a certain limited set of phenomena can be obtained with the help of a given class of devices? Or, stated differently, what devices are necessary to obtain all of the information about a given set of phenomena?

What is the sequence of all effects issuing from a certain cause?

Deduce all of the devices of a given class, or all of the methods of a given class or, generally speaking, all of the solutions of a given definite problem. "

An answer to the second type of question is found in the relevance (or hereditary) tree, which will be discussed in its normative aspects in section **II.4.S.**

The third type of problem is the crucial one for exploratory forecasting and will be discussed here in greater detail. The solution is provided by the morphological method, as understood in a narrower sense, and this has been summarised by Zwicky ***(lit.*** ref. ***190)*** as follows:

" This method ... is concerned with the totality of all of the solutions of a given problem. The method proceeds as follows:

1. An exact statement is made of the problem which is to be salved. For instance, we may wish to study the morphological character of all modes of motion, or of all possible propulsive power plants, telescopes, pumps, communication, detection devices, and so on. If one specific device, method, or system is asked for, the new method immediately generalizes the inquiry to all possible devices, methods, or systems which provide the answer to a more generalised request.

   It will be found that the task of formulating the initial statement or definition of the problem on hand is far more exacting than most investigators not acquainted with the new method are inclined to think. In fact, one is hard put to find in the existing literature satisfactory definitions even of well-known devices like pumps, stationary power plants, telescopes, and so on. The exact definition of apparently simple devices like injectors will be found to be a most difficult task and I doubt whether the combined common sense and sophisticated knowledge of any group of men would suffice to produce such a definition.

2. The exact statement of the problem to be solved, or the precise definition of the class of devices to be studied, will reveal automatically the important characteristic parameters on which the solution of the problem depends. For instance, in the case of telescopes, some of these parameters are the location of the telescope (medium in which it is embedded), the nature of the aperture A, the recording device R, the nature of the changes to which the light is subjected from A to R, the motion of the telescope, the sequence of operations, etc. The second step thus involves the study of all of these significant parameters.

3. Each parameter p_i will be found to possess a number of k_i different independent irreducible values $p_i^1, p_i^2 \ldots p_i^k$.

   For instance, the parameter "motion" of a telescope may have the independent values p^1, p^2, p^3 = translation in three directions; p^4, p^5, p^6 = rotatory motion; p^7, $p^8 \ldots p^{12}$ = oscillation in the first six motions, etc. These matrices are written in the following scheme:

$$
\begin{array}{l}
[p_1^1,\ p_1^2,\ \ldots\ p_1^{k1}] \\
[p_2^1,\ p_2^2,\ \ldots\ p_2^{k2}] \\
\cdots\cdots\cdots\cdots\cdots\cdots \\
\cdots\cdots\cdots\cdots\cdots\cdots \\
[p_n^1,\ p_n^2,\ \ldots\ p_n^{kn}]
\end{array}
$$

   If one element is encircled in each matrix and all the circles are connected, every resulting chain of circles represents one possible solution of the original problem. The above scheme of matrices, if used to construct an n-dimensional space, leads to a *morphological box*. The analysis is complete if either one or no solution will be found in every drawer of the box.

   It is exceedingly essential that *up to this point no questions be asked as to what value one or the other solution may have*. Such premature curiosity almost always defeats the unbiased application of the morphological method. However, once all of the solutions are found, one must know their relation to any given set of adopted performance values.

4. The determination of the performance values of all of the derived solutions represents the fourth major step in the morphological analysis.

   Lest one wishes to get lost in an enormous confusion of details, the performance evaluation must be carried out on a universal, although necessarily simplified basis. This is not always an easy task.

5. The final step involves the choice of particularly desirable special solutions and their realisation.

The conviction that all solutions can be realised is inherent in morphological thought. It may, of course, happen that some among the many solutions are of a relatively trivial nature.

It can be seen that the morphological method is simply " an orderly way of looking at things " and so achieving " a systematic perspective over all the possible solutions of a given large-scale problem. " It provides a framework for thinking in basic principles and parameters which is growing in importance, even if practised in a disordered or *ad hoc* fashion.

An example (also lit. ref. *190)* may illustrate the practical application of the matrix discussed under point 3) above. It concerns the totality of all jet engines which are composed of simple elements and activated by chemical energy, reflecting knowledge in 1951:

$[p_1^1, p_1^2]$	= intrinsic or extrinsic chemically active mass
$[p_2^1, p_2^2]$	= internal or external thrust generation
$[p_3^1, p_3^2, p_3^3]$	= intrinsic, extrinsic, and zero thrust augmentation
$[p_4^1, p_4^2]$	= internal, external thrust augmentation
$[p_5^1, p_5^2]$	= positive and negative jets
$[p_6^1, p_6^2, p_6^3, p_6^4]$	= nature of the conversion of the chemical energy into mechanical energy
$[p_7^1, p_7^2, p_7^3, p_7^4]$	= vacuum, air, water, earth
$[p_8^1, p_8^2, p_8^3, p_8^4]$	= translatory, rotatory, oscillatory, and no motion
$[p_9^1, p_9^2, p_9^3]$	= **gaseous,** liquid, solid state of propellant
$[p_{10}^1, p_{10}^2]$	= continuous and intermittent operation
$[p_{11}^1, p_{11}^2]$	= self-igniting and not self-igniting propellants

Zwicky remarks that " this, if no internal contradictions were present, would make possible

$$\prod_{i=1}^{n} k_i = 2 \times 2 \times 3 \times 2 \times 2 \times 4 \times 4 \times 4 \times 3 \times 2 \times 2 = 36{,}864$$

pure-medium jet engines containing single simple **elements** only and being activated by chemical energy. However, there **are some internal** restrictions which, as the reader will find out, cut **the above number to 25,344** possible simple engines. " A first evaluation, in **1943,** on the basis of fewer parameters, arrived at only **576** possibilities, which, however, correctly included the then secret German pulse-jet powered aerial bomb V-1 and the **V-2** rocket.

One may recall, in this context, that the fatal failure of Lindemann, Churchill's scientific advisor, to recognise the potential of the V-2 even when he was shown photographs (" It will not fly ") is plausibly explained by his exclusive preoccupation with solid propellants, stubbornly rejecting the idea of liquid propellants.

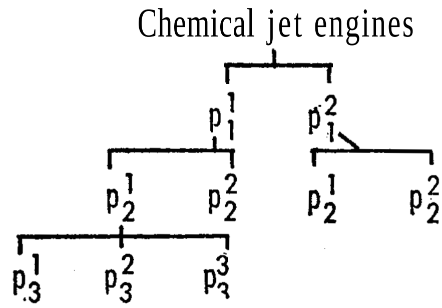
The example marked in the matrix above by circling specific parameters is the interplanetary aeroduct or ramjet. Zwicky remarks that " the principal point of interest is the presence of the element p_1^2 in the above matrix. This means that we derive our chemical energy entirely from the surrounding medium and that our jet engine is one which operates although is does not carry any propellants with it at all. " One way to achieve this characteristic is to make use of the sun's energy which is stored in the upper atmosphere in the form of excited and ionised atoms and molecules and newly formed molecules. The inclusion of a jet which conceivably might use this stored energy would stimulate research in two directions: high atmosphere research, to find out about the nature and number of the excited particles (this is already well under way); research in the possibilities of de-exciting the particles and using the energy gained in aeroducts, aeropulses, and other devices for the generation of propulsive power. Zwicky believes that such gradual and continuous acceleration might ultimately prove to be superior to the use of nuclear propulsion for space-ships leaving the earth.

It will be noted that the matrix includes possibilities that may appear to lie far in the future. For example, the elements p_7^3 and p_7^4 would be characteristic of varieties of hydrojets and terrajets (for example, with propellants reacting with water or earth). One may discard these possibilities for a forecast restricted to a given time-frame, or in general, after a thorough evaluation, but one should not do so a priori.

Zwicky calls the full matrix an n-dimensional " morphological box " (also " manifold " and " filing cabinet "). **A** partial representation in two dimensions only, for example with the two parameter sets [p_1^1, p_1^2] and [p_8^1. p_8^2, p_8^3, $_8^4$], **takes** the form of a two-dimensional rectangular matrix, which Zwicky calls a " morphological chart. " Such morphological charts are also widely used outside the context of the method. For example, one could observe a " rush " for patents which would fit into hitherto unpatented fields of a coolant/moderator chart **of** nuclear reactors. **A** number of companies evidently use this approach to " block " possible future inventions (or to share their profits) by trying to patent, in a somewhat abstract way, combinations of basic parameters.

With respect to the representation of specific possibilities by parameter chains in the matrix, there are not many alternatives. One could, in principle, represent all possibilities by a relevance tree, analogous to the relevance tree which has become the basis of multiple-level integrated normative forecasting (see section 11.4.5.). The bottom row would then list all possibilities. However, such a representation would probably somewhat obscure the problem here; the *n* parameters normally do not stand for a hierarchic dependence, characterising systems, sub-systems, components, etc., but are, in the general case, of equal significance. To make the " morphological **box** " visible as a " chest of drawers " with individual

" compartments " is possible only for a combination **of** three parameter sets, but it gives the general idea.



McCrory *(lit. ref. 105),* at the Battelle Memorial Institute adopts a somewhat modified three-dimensional " morphological box, " but applies it only to hierarchic relationships of systems, sub-systems, etc. For his problem, a relevance tree may be the better form of representation.

Zwicky distinguishes between *dimensionless, phenomenological,* and *dimensional absolute* morphology. These terms refer to the parameters or parameter groups studied. In the preceding section, **II.3.5.**, the potential value of studying suitable dimensionless parameter groups was already underlined. The significance of parameters expressed in absolute terms, and in relation to absolute limits, was discussed briefly in section **11.3.4.**

The morphological method, structuring thinking in such a way that " new " information (concerning combinations that would slip through non-systematic imaginative thinking) is generated, is not restricted to any level of technology transfer, or to technological forecasting in general. Zwicky observes that " the greatest successes of the morphological method may be expected in the field of human relations, where the prejudices have been most rampant and the activities in many cases tragically disastrous... its application there is most urgent, because of the often appalling incapability or unwillingness of scientists and engineers to deal systematically, constructively and uncompromisingly with these human problems. " For our problem of technological forecasting, the application of morphological thinking to the impact levels of technology transfer, or to large-scale social systems and to society itself, appears feasible and potentially fruitful. In elucidating the elements of human perception, one may even cross McLuhan's stream of thought (see section **11.2.5.).**

For fully integrated technological forecasting, exploratory morphological thinking will have to be matched by normative thinking, or, **as** Zwicky calls it, " the avowed purposes of man. " He promises to develop an original method in that area, too, to be presented in a forthcoming book on the " Morphology of Truth, " and based on considerations derived from the theory of marks. However, the value of exploratory morphological thinking is not bound up with any particular normative approach. The normative schemes based on relevance trees (see section **11.4.5.)** are perfectly suitable for integration with a morphological exploratory approach.

The practical application of the morphological method is conceivable over a wide spectrum ranging from a mere conscious or unconscious attitude to the careful construction of parameter matrices and their evaluation. The basic attitude can certainly be found in many forms of technological planning.

General Electric's TEMPO Center in Santa Barbara, California, seems to take essentially a " morphological " approach in its systematic attempt to examine the detailed characteristics of rockets, warhead developments, etc., and to investigate feasible combinations. A computer model is employed to study interactions and yield " emerging " feasible systems configurations.

The Stanford Research Institute in Menlo Park, California, applies morphological research to the investigation of feasible combinations for future transport systems.

The full-scale application, as it has been practised by Zwicky in rocket and jet fuel development, apparently has had considerable success and was decisive in producing an unbiased approach in the early stages. It has also been successful in forecasting progress in these fields—and it puts Zwicky far ahead of any other space age forecaster when he derives the possibilities of making the moon habitable (with on-site water and oxygen production) or when he penetrates into the realm of " planetary engineering " (including the possibility of changing planetary orbits to make them habitable by man).

II.3.7. SCENARIO-WRITING AND ITERATION THROUGH SYNOPSIS

The term " scenario-writing " denotes a technique which attempts to set up a logical sequence of events in order to show how, starting from the present (or any other given) situation, a future state might evolve step by step. The purpose is not to predict the future. By analogy with the techniques described in section II.3.5., scenario-writing may be regarded as en extension of contextual mapping to the formation of a synoptic view of as many developments as can be grasped and as may appear relevant to an experimental simulation of a possible reality. Scenario-writing is usually performed in an explicit time-frame; this feature seems to be significant for the application to political problems. For the purposes of technological forecasting, however, time apparently would not always have to be introduced explicitly.

Scenario-writing has so far been applied primarily to the exploration of potential military or diplomatic crises. One of the leaders in the field, *Herman* Kahn, is currently applying the scenario technique to the much broader context of the Hudson Institute study " On Alternative World Futures: Issues and Themes " *(Zit.* ref. *272),* which will use technological forecasts to form a synoptic view embracing cultural, social, political, economic, and technological patterns of possible futures. To be precise. scenario-writing in this case does not propose to contribute substantially to technological forecasting itself; ready-made forecasts are used which may remain more or less unchanged in the " melting pot " of the scenarios, while the other patterns are allowed more fluidity. This does not mean, however, that this technique will not in the future be adapted to technological forecasting itself, once enough contextual mapping has become available to play with a large variety of alternatives.

In the introductory chapter to this study, Kahn emphasises that " the scenario is particularly suited to dealing with several aspects of a problem more or less simultaneously. By the use of a relatively extensive scenario, the analyst may be able to get a ' feel ' for events and for the branching points dependent upon critical choices. These branches can then be explored more or less systematically." Two points in Kahn's discussion of the advantages seem to be of particular interest to technological forecasting:

Scenarios are one of the most effective tools in lessening "carry-over" thinking; scenarios force one "to plunge into the unfamiliar and rapidly changing world of the present and of the future by dramatising and illustrating the possibilities they focus on."

Scenarios "force the analyst to deal with details and dynamics which he might easily avoid treating if he restricted himself to abstract considerations. Typically, no particular set of the many possible sets of details and dynamics seems specially worth treating, so none are treated, even though a detailed investigation of even a few arbitrarily chosen cases can be most helpful."

Kahn himself warns of the dangers that may arise from the use of scenarios to guide and facilitate further thinking and analysis. Specifically, the initial conjectures might erroneously be assumed to be sufficiently correct to lead to scenarios with some content of "reality." However, as Kahn remarks, "a specific estimate, conjecture, or context, even if it is later shown to have serious defects, is often better than a deliberate blank which tends to stop thought and research."

An interesting version of scenario-writing, combined with cost/effectiveness analysis has been given by Ayres (*lit.* ref. 288) in the food production area. Essentially it attempts a critical evaluation of the fundamental alternatives (such as non-photosynthetic energy sources) on economic grounds and in broad contexts—resulting in the rejection of some much-discussed, technically feasible solutions. This approach merits particular attention in the area of "social engineering."

Scenario-writing is applied by several of the big oil companies which are deeply interested in future economic, political, and social environments. It is also employed by Honeywell (US) to determine and assess higher-level goals and missions for their PATTERN scheme (*see* section II.4.5.).

A variation of sccnaro-writing—but having the aim of simulating "reality"—is ***iteration through synopsis*** which has been used by Brech for his "Britain 1984" study (*lit.* ref. *256*). His method, broadly described in another publication (*lit.* ref. *99*), consists of writing scenarios in six different fields (demography. phsychology, sociology, technology, politics. and the economy) and subsequently combining them by iteration; the individual scenarios, especially the economic one, could be partially derived by more rigid techniques such as econometric or statistical analysis. In the "Britain 1984" study the psychological and sociological factors were discussed separately as a result of the difficulties they raised for a synoptic view embracing more exact fields.

Similar iterative techniques are applied by the big oil companies. The thought process of an individual who is seeking to arrive at a decision concerning a development programme without using explicit technological forecasting is also often described as the intuitive development of separate "scenarios" with subsequent iteration through synopsis.

II.3.8. QUALITATIVE HISTORICAL ANALOGY

Historical analogy has always played a certain conscious or unconscious role in forecasting which aims no higher than at the, next or next but one level; e.g. forecasting of the market impact of a given product.

A programme recently carried out under the auspices of the American Academy of Arts and Sciences, which resulted in the book " The Railroad and the Space Program—An Exploration in Historical Analogy " (*lit.* ref. *373*), sought to test the feasibility of using historical analogy in a systematic way for multi-level forecasting—in this case starting from the level of technology or functional technological systems and aiming all the way up to the level of society. It is unfortunate that an integral approach, exploring each aspect of the problem in depth, proved too difficult for this systematic attempt. The result, as it appears in the book, is a series of seven papers dealing with the political, technological, economic, social and intellectual aspects of the introduction of railroads in the 19th century. They are written by experts on the 19th century, who are not in a position to venture any statements or comparisons with respect to the space programme (apart from two insignificant exceptions), and are preceded by an introductory chapter in which the editor, Bruce Mazlish, tries to draw all the conclusions along the lines of historical analogy.

In outlining some of the theoretical aspects of this technique, for the anticipation of the impact of " social inventions, " to use Gilfillan's terminology (*lit.* ref. *70*), Mazlish emphasises two major problems: a) the success depends on fair sampling (he believes that the 20th century is the " Space Age " by virtue of the same criteria which determine that the 19th was the " Railroad Age "); and b) a historically conditioned awareness must be allowed for. He formulates five generalisations which he recommends for further testing and refinement:

" All social inventions are part and parcel of a complex— and have complex results. Thus, they must be studied in multivariate fashion " (which, he adds, has not yet been done sufficiently with the railroad/space example).

No social invention can have an overwhelming and uniquely determining economic impact, and this is so partly because no completely new innovation is possible in reference to any set of economic objectives.

All social inventions will aid some areas and developments, but will blight others.

All social inventions develop in stages, and have different effects during different parts of their development. (According to the editor, the railroad/space study ran into difficulties with stage analysis).

All social inventions take place in terms of a national 'style' which strongly affects both their emergence and their impact. "

The results of the railroad/space study are not as yet particularly impressive. However, some of the questions asked and problems investigated contribute to the forecasting of the impact of " social inventions " elements which tend to be neglected in other forecasting approaches: e.g., political elements (influence of lobbying, etc.), social elements (status and power systems, etc.), philosophic impact, and impact on imagination and on what McLuhan calls the " sensory profile " of man.

Historical analogy has been applied in the past mainly in the realm of cultural criticism (in a rigid form by Spengler, later in a more flexible way by Toynbee). As a supplementary technique to forecasting the effects of " social inventions, " this new branch of social study may improve our anticipatory insight.

11.3.9. ELEMENTS OF PROBABILISTIC EXPLORATORY FORECASTING

Probability is defined only for conceptual processes. This means that probabilistic forecasting can be applied only where the possible outcomes can be defined beforehand. Technological forecasting implies the forecasting of a technology transfer process governed by probabilistic laws; such a process is called a stochastic process.

In the simplest cases, a stochastic process can be conceived of as a chain of events with transition probabilities that are not affected by what happened at the earlier stages; starting with and initial probability the whole process is then defined. For such a process, called a Markov process or a Markov chain, all transition probabilities could be determined or estimated before multi-stage forecasting starts.

Technology transfer processes, which are the subject of technological forecasting, can rarely be conceived of as Markov processes. For example, if the level of effort is changed in accordance with the outcomes of individual stages, the transition probabilities may be affected. Nevertheless, the assumption of a Markov process usually underlies attempts at probabilistic technological forecasting; it can be accepted as a first approximation.

If one inspects a single chain of events E_i which are linked by transition probabilities $p_{i,\, i+1}$ that express probability only in terms of a " yes/no " alternative

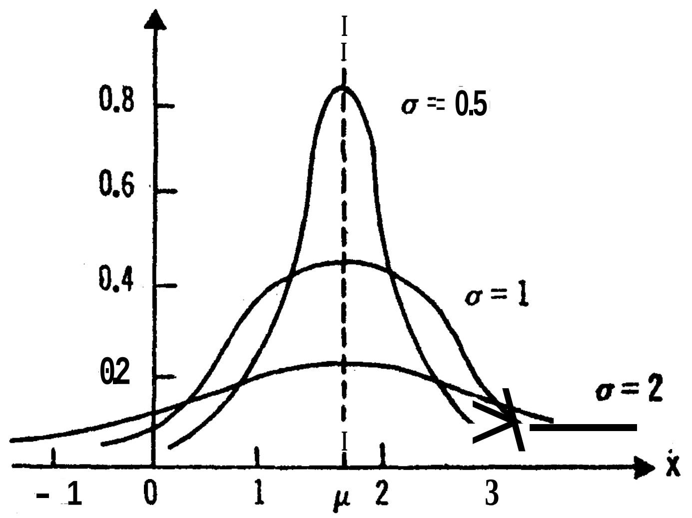
$$(p_{01})\, E_1\, (p_{12})\, E_2\, (p_{23})\, E_3 \,\ldots\ldots$$

with p_{01} as the initial probability, then the probability P_j that a stage E_j will be reached is simply the product

$$P_j = \prod_{i=0}^{j-1} p_{i,\, i+1} \tag{30}$$

Probability here refers only to the attainment of a sharply defined stage E_j by an equally sharply defined path E_i. In general, this does not hold for technology transfer. Functional technological systems can be achieved in various ways and with various degrees of success in terms of functional capabilities. etc.; a goal which cannot be attained by a given time may be attained later; impact is felt in a spectrum of nuances.

A much better approximation is obtained if probabilities in technology transfer are expressed by probability distributions $f(x)$ about a mean



value μ. For practical **purposes—especially** in the absence of empirical **or** theoretical analysis—*a Gaussian* or *normal* ***distribution,*** characterised by the standard deviation σ (or the variance σ^2 respectively [1], is usually assumed. This approximation can be justified by many good reasons, at least for the central **part** of the curve (the extension to plus and minus infinity **has** no physical relevance for **our** problem).

The distribution function is then

$$f(x) = \frac{1}{\sqrt{2\pi}\,\sigma}\, e^{-\frac{(x-\mu)^2}{2\sigma^2}} \qquad (31)$$

and the probability that a value of x within the limits $\mu \pm a$ *can* be attained is given by the area under the *curve* **within** these limits, i.e. by the integral $\int_{-\infty}^{\infty} f(x)\,.\,dx$. A single parameter then determines this probability:

PROBABILITY	**LIMITS**
0,50	$\mu \pm 0{,}675\sigma$
0,683	$\mu \pm \sigma$
0,90	$\mu \pm 1{,}645\sigma$
0,95	$\mu \pm 1{,}960\sigma$
0,99	$\mu \pm 2{,}326\sigma$
1,00	$\mu \pm \infty$

The precision of **an** estimate may be expressed either by **the** so-called " confidence interval " $\pm$ **0.675** σ (for which a 50:50 chance exists), or by the height of **the peak** which is given by $1/(\sqrt{2\pi}\,\sigma)$, or, of course, by the standard deviation σ directly.

Probabilistic refinements have **been** applied to growth curves, especially **S-shaped** (logistic) **growth,** for example **by** Mansfield *(lit.* ref. *157)* **and by** Lancoud and Trachsel *(lit.* ref. *149).* The approach of Lancoud and Trachsel, in a study of the increase in the number of telephone subscribers in Switzerland, seems applicable to technology acceptance in general. In addition to a probability function on the basis of Bernoulli's equation **(which** yielded an over-pessimistic result), they introduced **a** simple " attraction " coefficient, defined by the ratio of telephone subscribers to **total** inhabitants (in a given region) multiplied by a factor to be determined empirically. The " attraction " coefficient (which may become a " value " coefficient in other contexts) takes account of the added attraction that is exerted by **a** large number of subscribers. It **seems** reasonable that such **a** coefficient would equally be applied to technological attractions (such **as** direct long-distance dialling, " storage " of telephone **calls**, and other new **technologies).**

If, in the case of an assumed Gaussian distribution, only the mean value μ is to be adapted during the process, and the distribution function left unchanged, **this** *can* **be** easily achieved by the least squares method.

---

1. **Variance is defined as the second moment of a distribution about its mean value.**

Under the assumption that a given type of probability distribution should hold for every stage of a process, and that this distribution function is characterised by its variance only (for example, a Gaussian distribution) —this is a special case of a non-Markov process—the *propagation of variance* can then be easily calculated for each step and the probability distributed determined for each stage. This is a relatively simple procedure which can be applied to a number of problems pertinent to technological forecasting. It is, for example, systematically employed for technological forecasting at the Battelle Memorial Institute *(lit. ref. 105).*

The first term of the propagation of variance equation evaluates the influence of each factor separately (assuming no interaction between them):

$$\sigma_s^2 = \sum_{i=1}^{n} \left(\frac{\partial S}{\partial p_i}\right)^2_{\bar{p}_i} \sigma_{pi}^2 \tag{32}$$

σ_s^2 = Variance of attainability of S.
S = System parameter S.
p_i = Sub-system parameters (contributing factors).
$\bar{p}_i$ = Mean values of p_i.
σ_{pi}^2 = Variance of attainability of p_i.
n = Number of factors that must be considered.

The analytical determination, or the estimate, of the partial dependencies $\partial S/\partial p_i$ is, of course, the crucial problem here. $\partial S/\partial p_i$ is higher for increased dependence and attains unity if a certain factor is absolutely critical to the attainability of the required systems capability (i.e. if there is no alternative).

If the sub-system parameters or contributing factors p_i are inter-dependent, however, the propagation of variance equation becomes more complicated

$$\sigma_s^2 = \sum_{i=1}^{n} \left[\left(\frac{\partial S}{\partial p_i}\right)^2_{\bar{p}_i} \sigma_{pi}^2 + 2\sum_{j=1}^{n-1} \sum_{k=j+1}^{n} \rho_{jk}\, \sigma_{pj}\, \sigma_{pk} \left(\frac{\partial S_i}{\partial p_i}\right)_{\bar{p}_j} \left(\frac{\partial S_i}{\partial p_k}\right)_{\bar{p}_k}\right] \tag{33}$$

ρ_{jk} = Correlation coefficient between p_j and p_k.

where the second term now takes into account the interactions between the contributing parameters.

For non-Markov processes of a more general type, where the probability functions are not rigid but depend on the course of the process itself, the recently introduced concept of *Bayesian statistics*[1] makes it possible to update probability distributions by the introduction of new data. Any *distribution function can be modified* in this way. Whereas the calculation of the new function (the " posterity function ") is generally a complex task which is left to computers, special forms of the old function (" conjugate priors ") may greatly simplify calculations.

A simple method for assessing relative probability in a non-Markov process is used by Abt Associates in their operational models *(see,* for example, *lit. ref.* 83): for each of the aggregated classes of possibilities the number of paths resulting in the particular outcome is counted and taken

1. R. Schlaifer, who developed this concept (see *lit. ref. 175)* named it after Thomas Bayes, an English clergyman who in 1764 published a paper in the Philosophical Transactions of the Royal Society which for the first time dealt explicitly with the probability of causes.

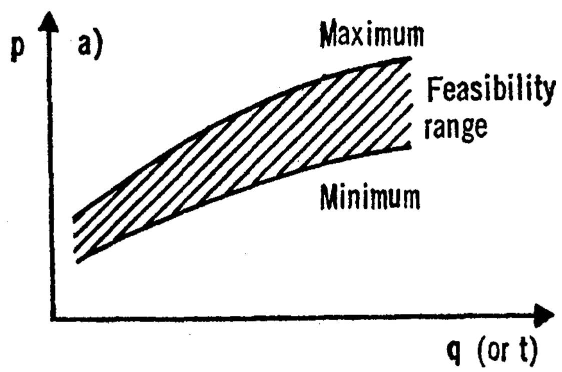
as a measure of probability; for example, an outcome which can be achieved in ten different ways is twice as probable as an outcome than can be achieved in only five ways.

For the general case where probability cannot be expressed by one of the standard distribution functions or by any simple mathematical formulation, ***Monte Carlo technique*** is capable of simulating the process or part of the process. This is an experimental, not an analytical, technique by which a sequence of events is run through repeatedly, with random combinations of probability values applied, until sufficient statistical material is accumulated to determine the probability distribution of the outcome. This technique can be applied with advantage wherever random factors are involved that would make mathematical treatment cumbersome. It also reduces calculations in many cases where a mathematical representation would be possible. Nevertheless, the task of selecting random input data and applying them in a number of runs is usually of a magnitude that can be tackled **only** by computers.

Apparently neither Bayesian statistics nor Monte Carlo technique (which has been developed to a high level of sophistication for the purpose of scientific calculations) has yet been applied to problems of technological forecasting, except at the RAND Corporation where at least Monte Carlo techniques are applied in connection with defence developments. North ***American Aviation*** in Los Angeles, California, has experimented with applications of Monte Carlo technique to decision-making; apparently no large-scale use has been made of it. One may expect that Monte Carlo technique will become a valuable element of operational computer models and will be used to solve partial problems in areas where empirical probability distributions are to be evaluated.

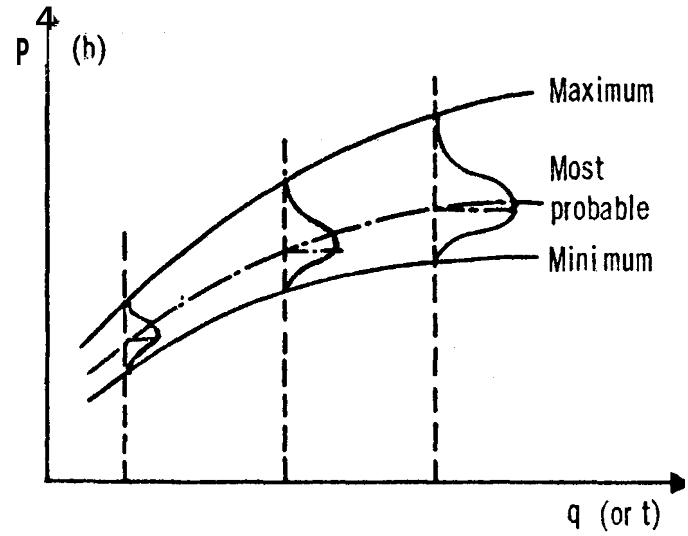
A probability can be introduced into forecasting in different ways:

An intrinsic probability of a future relationship between two or more internal parameters (one of which may be time, but need not be), is estimated *a)* by forecasting a feasibility range (maximum and

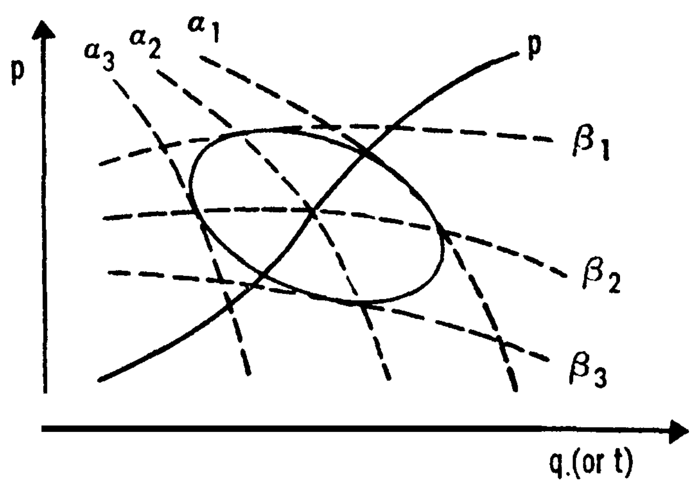


minimum feasible curves); or b) by giving probability distributions (or by giving, apart from maximum and minimum curves, the most probable curve as well; if the latter is not the mean of the maximum and minimum curves, this would indicate a non-symmetrical distribution law); or *c)* by parametric sensitivity analysis if more than two parameters are involved (this representation is discussed below for the more general case of a combination of internal and external parameters).

The influence of predominant external factors, for example overall level of effort or expected influence of one's own work, may be estimated in the same probabilistic way.

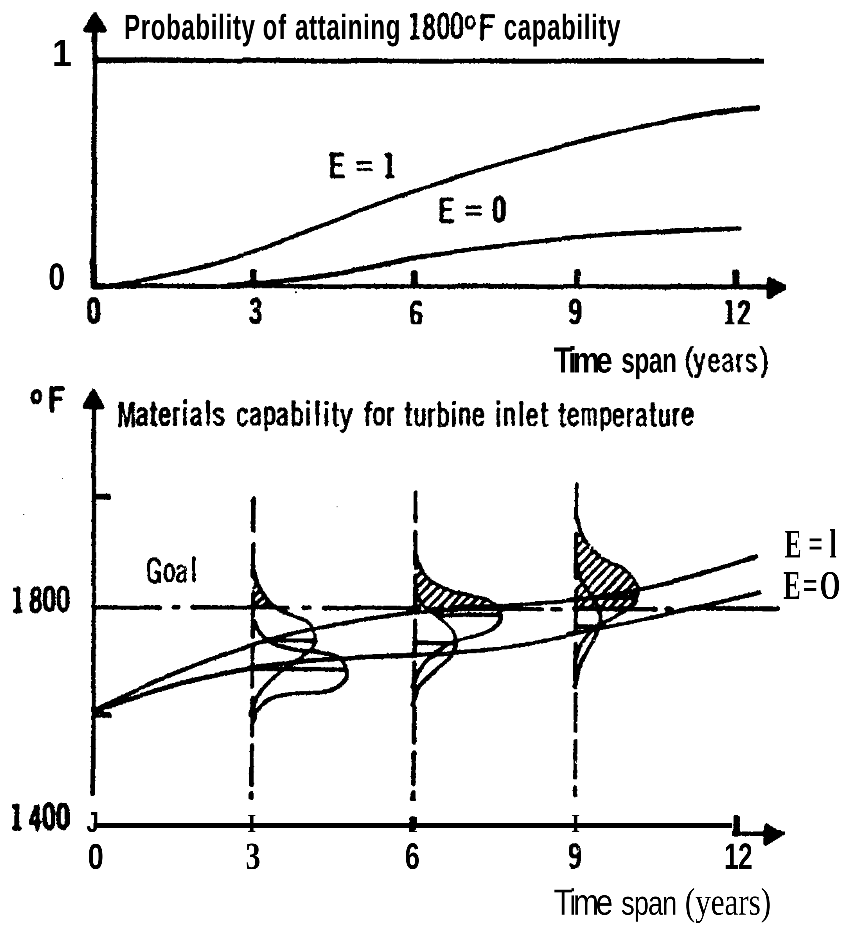


The combined influence of internal and external factors, which are given in a probabilistic way, can be evaluated to assess the overall probability of a given achievement. In particular, the probability of achievement for systems of a higher order (large functional technological systems) may be derived analytically from probabilistic expressions for systems or elements of a lower order (components, materials, etc.) ***Parametric sensitivity analysis*** of this type is used, for example, by the US Navy *(lit.* ref. ***184)*** in the way suggested by the graphic example; characteristically, probability is determined by a family of curves α_i representing a technical parameter, and **a** family of curves β_i representing an operational parameter changing as a result of the evolution of **use** environment. The probability for the system parameter p is **then** an area, and assuming equal sensitivity to α_i and β_i, the ***egg***-shaped area in the graphic example.



General Electric's Light Military Electronics Department in **Utica,** New **York,** used probabilistic input of the **second** type with three-fold assessment (minimum/probable/maximum) as early as in **1960** for their DOLLAR Planning Model *(lit.* ref. ***125).***

McCrory *(lit.* ref. ***105)*** describes how probabilistic estimates of the first two types are considered to be represented at the Battelle Memorial Institute. His example refers to the probability of attaining the materials capability necessary for a gas inlet temperature of 1800°F (982°C). For the influence of external factors the evaluation is carried out for two discrete values which are believed to represent extremes: E = 0 denoting conditions for progress that can be expected without significant participation of Battelle (or the customer); E = **1** denoting conditions for progress which include effort at the maximum level that can be exerted efficiently.

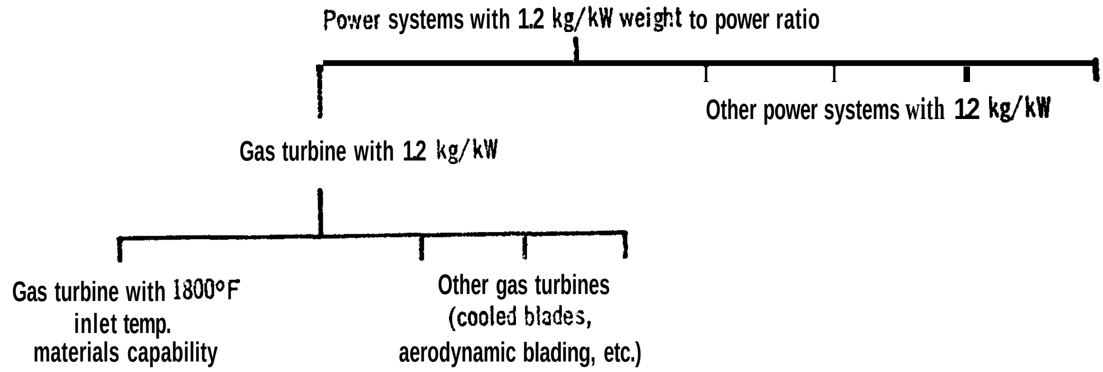


The temperature trends, forecast individually for E = 0 and E = 1, are given with probability distributions for certain time spans. **A** Gaussian distribution is assumed and a confidence level is introduced by estimating the **peak** height over the mean value.

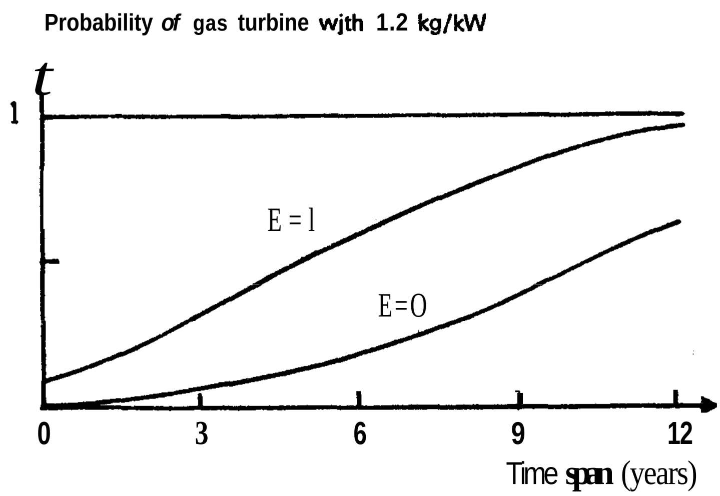
The areas of the probability distribution curves that lie above the 1800°F line are then **a** measure of the likelihood of achievement (availability of the desired materials) in function of time.

For the more complicated problem of deriving the probability distribution for systems of a higher order, McCrory calculates the propagation of variance using equation (33) and assuming Gaussian distribution for all probabilities in his problem. If, for example, the goals are derived from **a** relevance tree, characteristic for normative forecasting (see the following

Chapter II.4.), then the availability of materials for 1800°F gas turbine inlet conditions is only one of several ways to attain the goal of the higher level, which, in turn, is **only** one possible way to the goal set for the next higher level, etc.



In McCrory's example. the result of the evaluation using equation (33) indicates that the probability of attaining a 1.2 kg/kW gas turbine is higher than the probability of attaining the 1800°F inlet temperature material capability. One may conclude, in this case, that *gas* turbines with **1.2** kg/kW weight-to-power ratio are more likely to be realised with lower materials temperature resistance, attaining the goal via one of the alternatives. (This is given as an artificial example, not a Battelle forecast).



In general, one may safely forecast that probabilistic formulations and the corresponding transfer methods to higher levels—desirably not **only** for the levels of technological development but also for the impact steps further up—will become important for exploratory technological forecasting and for exploratory elements within the framework of normative forecasting (as in McCrory's example above). Apart from the work of the Battelle Memorial Institute, Abt Associates (Cambridge, **USA**) are currently engaged in designing operational models which would evaluate probability distributions (possibly using Bayesian statistics and Monte Carlo technique); their present models are based on feasibility ranges.

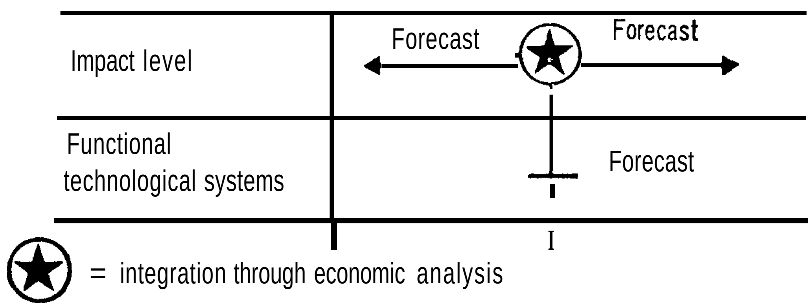
Whereas classical statistics, of which the Gaussian distribution is a result, is already becoming fruitful for technological forecasting, one may speculate about future applications of the methods of ***statistical mechanics*** or even quantum mechanics (technology transfer can be looked upon as a quantum process rather than as a continuous process). While classical statistics is concerned with large numbers of similar particles, statistical mechanics—as introduced into physics by Boltzmann and Gibbs at the end of the 19th and the beginning of the 20th centuries—deals with the various positions and velocities of particles which form a physical system. Each particle moves in a phase space with position and momentum coordinates: characteristically, this phase space is six-dimensional (three position and three momentum coordinates). **A** gas with N molecules has a phase space of 6N dimensions; the motion of the entire gas then corresponds to the trajectory of a single point in this 6N-dimensional phase space.

This is not as hopelessly complicated as it may sound. Solutions can be obtained, and have, indeed, thoroughly revolutionised physics from the rigid Newtonian base to the Gibbsian contingency. Wiener ***(lit. ref.*** 82) says, " It is, **I** am convinced, Gibbs rather than Einstein or Heisenberg or Planck to whom we must attribute the first great revolution of twentieth century physics. "

Technology transfer, too, moves in a phase space characterised by position and momentum of many distinguishable " particles. " It is a non-deterministic process with respect not only to large systems but also to the behaviour of the individual " particles. " Unlike physical systems, however, this process does not move from a state of organisation to the most probable state, i.e. that of chaos, but (we may hope) it is moving, like life, in a direction of differentiation and organisation; the methods of cybernetics, designed for this direction of movement, may therefore become broadly applicable.

II.3.10. ECONOMIC ANALYSIS

Cost/benefit ***analysis*** does not add any new information to technological forecasting. However, it is used to advantage in translating estimates resulting from technological forecasting into economic terms compatible with the economic environments in which the impact of a technological innovation is first felt. Cost/benefit analysis in the context of technological



forecasting **is** thus a special technique for binding together a vertical and a horizontal forecast to form an integral forecast, **which** makes possible an integral view for decision-making by placing the vertical effort and the horizontal impact on the same basis.

The vertical fotecast, usually attempted at the advanced development stage and again at the engineering stage (or repeatedly), prpvides estimates on: development time and costs, production costs (or product prices), and perhaps also operating costs and other operation characteristics. The horizontal forecast provides estimates on: sales in function of time, and, in combination with other factors, profits in function of time. **Risk** factors may be estimated, too, for both the vertical forecast (technical risk) and the horizontal forecast (commercial risk). The combination of vertical and horizontal forecasts gives cash flows in function of time.

A rather crude form of cost/benefit analysis is the assessment of ***return on investment*** by comparison **of** the undiscounted cash flows, or by estimating difference in total cash flows out and in. This approach does not consider time and the effect of interest gained or lost over time. Although it neglects this very foundation of business thinking, it is widely used on the assumption that the time factor can be taken into account in an indirect way (by " feeling " or by using empirical knowledge for certain classes of product developments).

Olsen's formula (reported in ***lit. ref. 146***), developed for Olin Mathieson **(US),** reads simply

$$\text{Value} = \frac{(\text{Invest. return}) \times (\text{Prob. of success})}{\text{Research costs}} \tag{34}$$

where " investment return " means: value of process savings for one year or three per cent **of** the sales value **of** new products each year for five years or two per cent of the sales value of improved products each year for two years. The project is considered worthwhile if the calculated value is three or higher.

Neglecting the probability (risk) factor, this means, in effect, that the criteria are:

Process savings per year	$\geqq$ **3** X Research costs
Average annual sales for new products	$\geqq$ 20 X Research costs
Average annual sales for improved products	$\geqq$ 75 X Research costs

Pacifico's formula (reported in ***lit. ref. 146***), developed for Alcolac **(US),** can be adapted to read

$$\text{Value} = \frac{R_t \times R_c \times (\text{Total gross profit})}{\text{Total costs}} \tag{35}$$

R_t = Chance **of** technical success (as a fraction **of** one).
R_c = Chance **of** commercial success (as a fraction **of one).**

The criterion for a worthwhile project is a value of two, which, in fact, would be a useful criterion only for very short development times. The formula has been applied only to low-risk projects, half of which turned out to be successful.

Hoess (lit. ref. 138) uses, for his **work** at the Battelle Memoral Institute, an expression that relates the rate of return on investment to the profit deviation **from** mean per unit; this is **a** simple transformation **of** the standard relations.

Gordon Teal's Index of Research (reported in ***lit. ref. 146)*** represents a more sophisticated approach, combining economic analysis and decision theory with a four-factor-formula that is not very transparent and apparently holds only for a rather special class of product developments:

$$\text{Index of Research} = I_1 \times I_2 \times I_3 \times I_4 \tag{36}$$

where

$$I_1 = \text{Index of Return on R \& D} = \frac{N}{25S} \tag{37}$$

N = Net profit during the life of the new product.
S = R & D Costs.

$$I_2 = \text{Index of Return on Assets} = \frac{N}{0.135\ A} \tag{38}$$

A = Assets required.

$$I_3 = \text{Index of Dollar Value} = \frac{b}{0.04\ B} \tag{39}$$

b = Billings (sales) made possible by the new product.
B = Total company billings (sales) during the life of the new product.

$$I_4 = \text{Index of Market Capture} = \frac{b}{0.5\ M} \tag{40}$$

M = Total available market.

The criterion for a worthwhile project is a value of one or more for the Index of Research. Although this approach includes an element of normative forecasting (corporate strategy expressed by I_4), it is essentially exploratory in its contents.

Sobelman's " Investment Worth " Model (also reported in *lit. ref. 146)* attempts to take the time factor into account without basing it on interest rates and discounted cash flows:

$$\text{Product worth} = P\left[T + \bar{T}\left(1 - \frac{t}{\bar{t}}\right)\right] - c\left[t + \bar{t}\left(1 - \frac{T}{\bar{T}}\right)\right] \tag{41}$$

p = Estimated average net profit per year from the new product.
T = Estimated actual profit life or market life of the new product.
$\bar{T}$ = Profit life or market life of an average new product.
c = Estimated average development cost per year for the new product.
t = Estimated time required to develop the new product.
$\bar{t}$ = Time required to develop an average new product.

This formula actually examines the difference between total profit and total development cost (PT - ct). The correction factors, given by the second terms, evaluate the deviation from the average product; for the average product, both correction factors become zero, and " bonuses " are added to the product worth for development times shorter than average and profit lives longer than average. These " bonuses " have a rather arbitrary value and do not take account of time nearly as correctly as can the discounted cash flow approach.

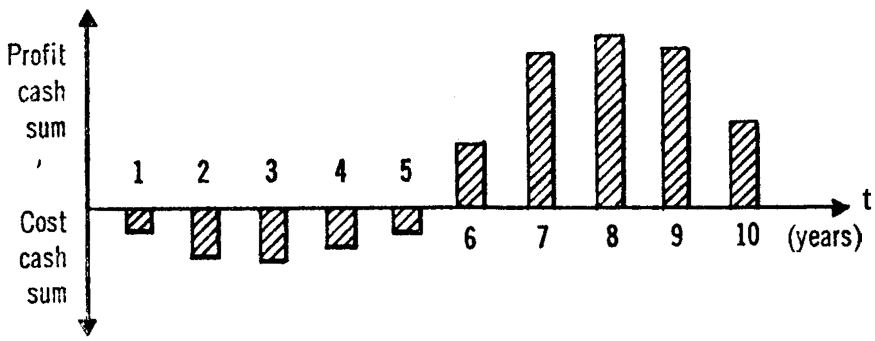
Discounted cash flow techniques, which have been used for quite some time in connection with investment planning for production facilities, etc., can be applied in an analogous way to investment in research and development projects. They yield the ***present net value*** of a project, and this is consistent with economic thinking as applied to other areas of business. Discounted cash flow techniques are the best means of accounting for the time factor in a business environment.

Two basic approaches are commonly used:

Cash flows and interest are accounted for " batch-wise, " usually at the end of each year; one can readily see that this is an (unnecessary) approximation which deviates from the more continuous characteristics of reality in most practical cases;

Cash flows and interest are accounted for continuously, which corresponds very closely with reality.

The basic expression of the ***" batch-wise " approach*** can be readily **stated:**



$$P = \sum_{i=1}^{n} \frac{C_i}{(1 + r)^i} \qquad \textbf{(42)}$$

P = Present net value of the project.
C_i = Cash sum (accumulated cash flow) at end of each year.
i = Number of years from now in which the accounting of the cash sum occurs.
n = Number of years from now in which the last significant cash flow occurs.
r = Discount rate.

The discount rate can be defined in two ways, with a marked distinction **between** them:

The discount rate is the rate at which risk money can be obtained for the project in question—the present net value in that case **indicate** whether available additional (outside) funds ought to be raised for a certain project.

The discount rate is the rate at which risk money could be invested **to** obtain cash flows of equal risk at the same time; the present net value in this ***case*** indicates whether a part of a limited amount of available funds ought to be invested in a certain project.

By evaluating different discount rates, both views can be combined in an optimum way (see below GEC's approach).

Setting the present net value $P = 0$ gives the equation for break-even conditions, which will constitute the basic criterion for determining whether a project is considered worthwhile.

Disman's formula (reported in lit. ref. *146*), developed for Abbott Laboratories (US), modifies equation (42) by two risk factors and derives break-even conditions by comparing an undiscounted cost cash flow with a discounted profit cash flow:

$$\text{MEJ} - R_t \, . \, R_c \sum_{t=1}^{n} \frac{I_t}{(1 + r)^t} = 0 \tag{43}$$

MEJ = Maximum expenditure justified.
R_t = Risk of technical success (in fractions of one).
R_c = Risk of commercial success (in fractions of one).
I_t = Income cash sum (accumulated profit cash flow) at the end of each year.

This approach would produce useful results only on the assumption that the research and development goal can be attained practically instantly, in zero time, and that profitable sales will start immediately afterwards—an assumption which seems to hold even less for the pharmaceutical industry (for which this formula has been designed) than for industry in general.

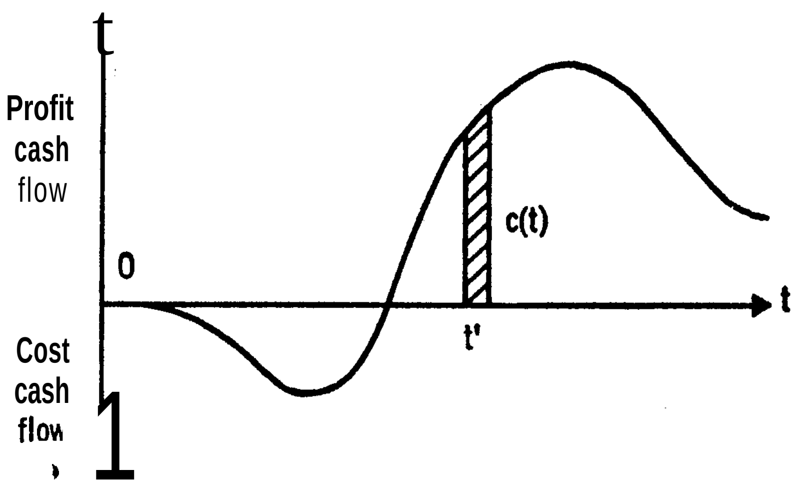
The Noskold Transformation (also reported in lit. ref. *146*), seems to represent a version of the " batch-wise " approach, combining it in a rather obscure way with a comparison with average results:

$$P = \frac{D}{1 + r + \dfrac{r'}{(1 + r')^n}} \tag{44}$$

D = Average annual income from project.
r = Current rate of interest on investment.
r' = Average net return on capital invested in the company.
n = Number of years in which research costs must be recovered.

(The first term " 1 " in the denominator is missing in lit. ref. *146* but has obviously been left out in error, as one may ascertain by comparing for the extreme case in which the last term becomes zero; P = D/r would not make any sense, while P = D/(1 + r) would.)

The basic expression of the " continuous " *approach*—the approach which more closely fits reality—is the present net value P' of each incremental cash flow $c(t)$ at time t' (counted from t = 0 for the present):



$$P' = c(t')e^{-rt'}dt \tag{45}$$

Integration over time yields the present net value of the project

$$P = \int_0^\infty c(t)\,e^{-rt}dt \tag{46}$$

It will be noted that, by chance, equation **(46)** is identical with the Laplace transform if $c(t)$ is taken as the determining function and $P(r)$ as the generating function. This, in principle. would offer the possibility of approximating the curve $c(t)$ by a simple function and of calculating $P(r)$ directly. Corresponding pairs of determining and generating functions are, for example:

$$\left.\begin{aligned} c(t) &= e^{at}\,; & P(r) &= \frac{1}{r-a} \\ c(t) &= \sin t\,; & P(r) &= \frac{1}{1+r^2} \end{aligned}\right\} \tag{47}$$

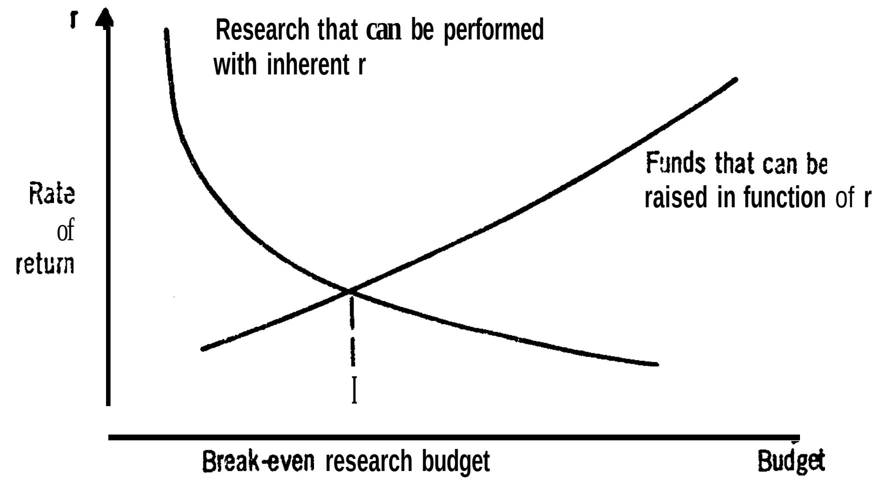
Equation **(46)** is used extensively in industry for the assessment of the net value of projects in the development, advanced development, or engineering stage. Discounted cash flow is considered in approximately one-fourth to one-third of all industrial companies with a defined technological forecasting function, in the form both of equation **(42)** and of equation **(46).** The " natural " development in a firm tends to progress from the assessment of undiscounted return on investment through " batchwise " discounting, equation **(42),** to continuously discounted cash flow, equation **(46).** The 3M Company (US) now introduces, for purposes of technological planning, computerised discounted cash flow evaluation for 40,000 kinds of products (200,000 items).

In a number of companies, such as ASEA (Sweden), the present net value as expressed in equation **(46)** is derived for every research and development project for which the necessary estimates of costs, sales and time factors can be made, and where there are no overriding considerations of corporate policy. The values P are derived for a given minimum value of the discount rate r, which is used as the criterion determining whether a project is to be undertaken or discarded. For European companies, this minimum value of r tends to be around 20 per cent per year (before taxes), and in the US possibly higher, about 30 per cent per year (before taxes)—although the evidence collected on this point is not very extensive. A positive P would be a go-ahead signal, while a negative P would indicate the advisability of discarding the project.

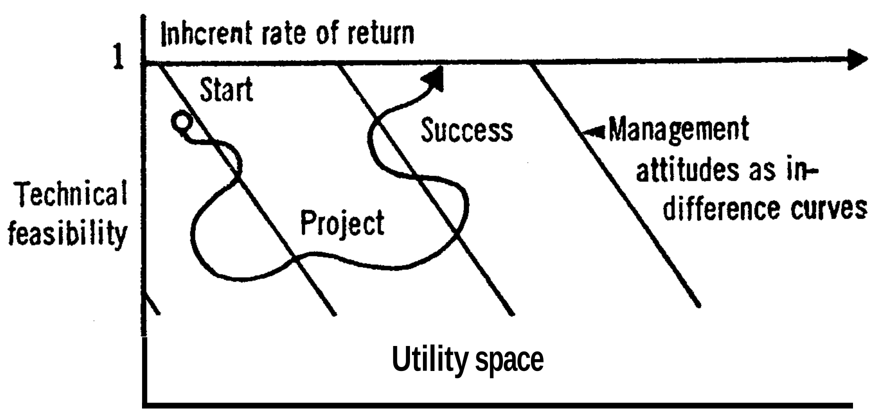
Equation **(46)** can be set zero, so that it holds for break-even conditions

$$\int_0^\infty c(t)\,e^{-rt}dt = 0 \tag{48}$$

and solved for r, which then represents the inherent discount rate or the ***inherent rate of return*** of a project; for this task the identity with the Laplace transform is of particular value for practical calculations. One could then compare the inherent r with the stipulated limiting r which gives a clearer ranking order from high values of r down to the limiting r. However, one may also decide the maximum amount of research possible if funds have to be raised at different discount rates. This is the approach which *GEC* (General Electric Company, UK) is taking in setting up a comprehensive system for the evaluation of research projects. The break-even point is then given by the crossing of the research cost curve and the fund-raising curve. Modifications can, of course, be introduced.



The full *GEC* scheme, baptised *SCAIR* (System for the Selection, Control, and Administration of Industrial Research) and developed by Demetriou, adds to the selection (planning decisions) function, outlined above, a control decisions and an administrative decisions function. For the control function, the cost/benefit analysis is carried out monthly by the group leaders, and the technical feasibilility is reassessed at the same time. The management attitudes (management policy) are fixed from time to



time and represent indifference curves; in general, as expressed in the graph, a lower technical feasibility paired with a higher estimated internal rate of return is equivalent to a higher technical feasibility paired with a lower internal rate of return. A leftward movement of intersecting indifference curves in the course of development is a bad sign and triggers control decisions; a rightward movement is a good sign.

A technical feasibility factor, in the range between 0 and 1, is estimated and is used for making a dynamic assessment for the purpose of helping in the determination of management's attitude towards gain under uncertainty. A “ A gain factor. ”

$$\text{Gain factor} = \frac{\text{Percentage change in technical feasibility factor}}{\text{Percentage compensatory change in rate of return}} \quad (49)$$

is considered at different stages of the project. As it approaches zero, management's attitude becomes more cautious; as it approaches infinity, the tendency is towards a more speculative attitude.

In a similar way, a “ risk factor ” makes it possible to observe the: dynamic development of cost/benefit chances:

$$\text{Risk factor} = \frac{\text{Percentage change in the present value of budgets}}{\text{Percentage compensatory change in rate of return}} \quad (50)$$

As the risk factor approaches zero, management's attitude to losses becomes more cautions; as it increases, an increasing speculation profitability is indicated.

Project acceptance ranking within SCAIR is also primarily based on economic analysis, modified by a decision theory approach. Two formulas are used alternatively or in combination:

$$\bar{r} = f^{1/G} \cdot r \quad (51)$$

$\bar{r}$ = Project certainty equivalent rate of return.
r = Project actual rate of return.
f = Project technical feasibility factor.
G = Gain factor, according to equation (49).

A “ project acceptability index ” places more emphasis on management's attitude to gains or losses:

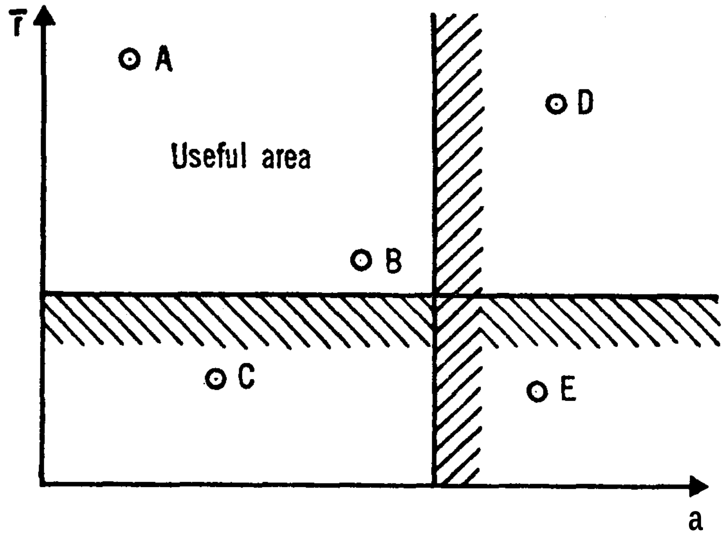
$$a = \frac{kb}{f^{R/G} r^{R}} \quad (52)$$

a = Project acceptability index.
b = Present value of the total project research expenditure.
k = Arbitrary scale factor for placing the acceptability index within some desirable range of value (for example, k can be chosen differently for different classes of projects, according to strategic considerations).
f = Project technical feasibility factor.
r = Project rate of return.
G = Gain factor, according to equation (49).
R = Risk factor, according to equation (50).

Projects will tend to become more acceptable as:

the present value of their budget decreases;
their rate of return increases;
their technical feasibility factor increases;
management becomes more speculative about losses;
management becomes more speculative about gains than about losses.

The results of both ranking formulas can be represented in a two-dimensional way, with stipulated acceptance criteria delimiting the useful **area.** For example, projects **A** and **B** would be accepted, projects **C, D,** and **E** rejected.



G.E.C.'s computerised **SCAIR** incorporates a number of refinements, for example the assessment of financial flows if a certain project is not undertaken, or the evaluation **of** alternatives. The administrative function makes the control system adaptive. In the middle of **1966** SCAIR was in a pilot operations stage, in which it was being tested with 200 research projects. It will in future comprise all development projects sufficiently clear to introduce the necessary estimates.

The combination of economic analysis and utility theory that is used in **SCAIR** is also characteristic of the approach proposed by ***Cramer and Smith (lit. ref. 110).*** For each alternative project, estimates are made **of** net values and probabilities of occurrence. Utility curves are also obtained. Projects can then be ranked on the basis of their expected net value of utility. ***Allen (lit. ref. 86)*** discusses the plotting of discounted cash flow yield curves for a range of assessed probabilities.

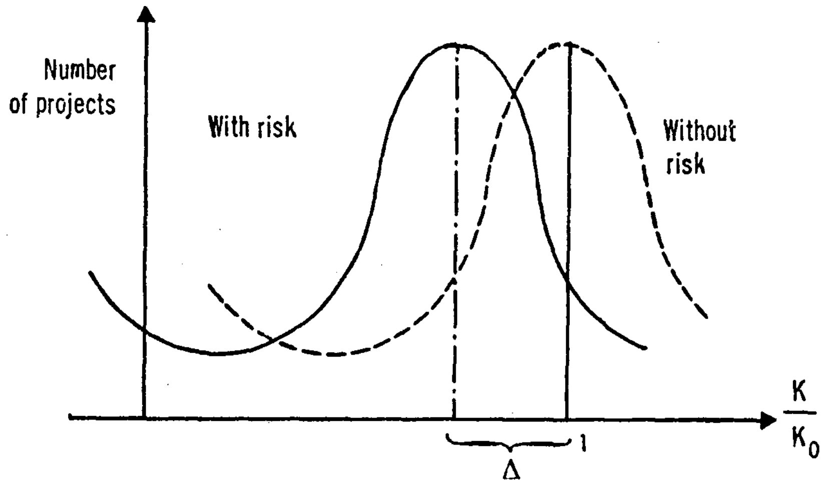
Dean and Senguptu (lit. ref. 113) have developed a complex scheme which seeks to base economic analysis, not on direct estimates, but on a correlation of a company's past experience in product research and process research with a view to determining empirically characteristics of classes of research projects which are supposed to facilitate the assessment of the present net value of projects that fit into these classes. The size of the overall research budget is also empirically related to its " effectiveness. " **A** linear programming formulation, based on empirical anlysis, is then suggested for performing the project selection so as to maximise the total net value subject to a budget constraint. Thus, operations research techniques are coupled with economic analysis on an empirical basis. In a similar way, the ***3M Company*** (Minnesota, Mining and Manufacturing Company in St. Paul, Minnesota) tries to fit new products to correlations of past experience.

Techniques using the operations research approach often try to maximise the total net value of research on the assumption of certain additional conditions being present. Whereas economic analysis, generally on the basis of equation (46) for the net present value, is performed as one of the input elements, these techniques generally belong to normative forecasting (optimising for a certain pre-established goal) and will be treated in Chapter II.4. below.

The conclusion is easily reached that the integration according to equation (46) need not proceed too far into the future, especially if r is high. If, for example, the development time for an average project is five years, it will, in most practical cases. be sufficient to estimate cash flow from sales for another five years, making the whole time span 10 years. If $r = 0.20$ per year, the contribution represented by the income from the sixth year of sales would be even less than one-tenth if cash flow is assumed to be equal for all the years; normally, however, cash flow from sales diminishes after an initial upsurge, especially in product areas marked by a high rate of innovation.

The assessment of *risk factors,* in combination with economic analysis, is becoming a matter of concern wherever an incentive is felt to refine the basic approach. In principle, one might expect that the risk evaluation developed for other forms of capital investment, and for business forecasting, could be modified for the purposes of technological forecasting as well. However, apparently little use has been made of more sophisticated techniques. Risk factors are often estimated directly in terms of technical and commercial risk, expressed in fractions of one.

Bonke is testing a simple model for ASEA (Sweden) which expresses commercial risk in the form of an eccentrically positioned symmetrical probability distribution. The ratio K/K_0 (K = actual capitalised result; K_0 = estimated capitalised result without risk factor) would then be unity



for the peak of the projects curve only if there is no risk. There is also a second peak at zero or negative values for the project failures (due to the technical risk). The eccentricity Δ may be derived for different classes of projects empirically, as well as the form of the distribution curve. The potential usefulness of this approach is not yet known.

Kotler (lit. ref. 148) has proposed a method based on corporate indifference curves in plots of expected profit versus risk, which can be derived empirically from a company's past history.

In brief, economic analysis in general may be described as a widely used technique for achieving the integration of vertical and horizontal technological forecasts at the product (functional technological systems) level and their direct impact level. Discounted cash flow techniques, in particular, are most valuable for linking technical and business thinking at these levels.

Looking further into the future, economic analysis may also be expected to become very valuable for the integration of vertical and horizontal technological forecasts at higher levels, i.e. of environments, social systems, or even society. The prerequisite for its use is the quantification of forecasts at these levels in monetary (or generally in economic) terms, although this may appear heretical where social goals are concerned. But, in the absence of any other quantitative system which is defined for all levels, and in view of the need to introduce such a system if the integration of forecasts over the different levels is to have any meaning, it is reasonable to resort to the oldest and most widely used system: the monetary system. This would mean that values other than economic would be expressed in dollars; a beginning is already being made in this direction by Resources for the Future (*see* Chapter 1.7.). The attempts to introduce cost/effectiveness analysis, which has great success in military administration, into other parts of the US Government (*see* Annex **A.2.10**) is another significant start in the same direction.

II.3.11. OPERATIONAL MODELS

The following designations are adopted here, in accordance with Abt Associates (*lit.* ref. *84*):

Models are representations of processes describing in simplified form some aspects of the real world; for technological forecasting, they attempt to include as many non-technological factors as appears feasible;

Simulation is the operation of a model by manipulations of its elements by a computer, a human player, or both;

Gaming (game technique for simulation purposes) is a special type of model-building, structured so as to permit multiple simultaneous interactions among competing and co-operating players. If a computer is used, the system can be manipulated and the effects analysed by an observer.

In their recent survey of operational model-building in the US (*lit.* ref. *84*), Abt Associates investigated 57 models some of which were not yet finished, and concluded that probably not more than 100 full-scale models existed in the US in mid-1965, (probably an under-estimation since industry was not surveyed). Economics was the first of the social sciences to have undertaken model-building. At present, political, sociological, psychological and other processes are also being studied with models. Most model-building is performed in universities and research organisations.

The following rough conclusions can be drawn with respect to development time and costs of models:

Large-scale models generally take at least two years to develop. The majority of models can be built within six years, and half of them take between two and three years. The largest existing model (Brookings—SSRC) involves 400 original equations.

Development costs vary from $25,000 to **$2.5** million. The peak in the distribution curve occurs within the range of $50,000 to **$100,000** but apparently there are more social-political than economic models that can be built for less than $50,000.

The mode of operation for the **57** models was:

Out of 28 economic models: two manual simulations, three man-machine games, 23 computer simulations;

Out of 29 social-political models: 10 manual simulations, five man-machine games, **14** computer simulations.

Whereas man-machine games until recently could not be efficiently accommodated by computer systems, Abt Associates believe that " with the advent of time-shared computer systems, such games will find increasing application in model development and simulation. "

Typical " manual " games, i.e. games played by human players, can employ a number of players ranging anywhere from two to **200,** the average falling within a span of 10 to 30.

Gaming seems to be an effective means of forecasting the possible impact of new or future technologies. It has been used for some time in this connection by military administrations, mainly for studying the implications for the future of combinations of specific technological and strategic concepts, from the standpoint of both one's own and the enemy's side.

The considerable degree of sophistication attained in **war** games, and **which** has already been put to **use** in business games, can possibly also be made to serve technological forecasting. C.F.B. Stevens of the Pulp and Paper Research Institute of Canada, for example, draws the following analogies: " It seems ... that the use of new technology to compete within industry has some elements in common with war. The objective is now ***the*** market for some service or product—packaging, for example. Most of **this** particular objective is still held by one industry—paper—and is **being** attacked by another—plastics. The defending industry uses relatively expensive and inflexible units of hardware—paper machines—the basic technology of which is a hundred and fifty years old. It has large reserves, but the casualty rate it will accept in products or in companies is small. Most of its corporate energy is used in co-ordinating its large operational units. The attacking industry, on the other hand, is organised around less expensive and newer hardware, and spends more of its energy in forming **new** companies and developing the products, upon which it sustains a high **casualty** rate. "

Open gaming (no constraints to the individual steps) is restricted in many cases to manual operation because the programmation and storage of all possible operational moves would require an uneconomic effort, or might not yet even be technically feasible. Most war games and military technological games are still played manually. This will also hold for more ambitious games which may be developed for technological forecasting in the exploratory direction.

However, with normative forecasting assuming ever increasing importance, gaming in this area will be less and less open, and may become a valuable technique for the evaluation of alternative technological developments. Gaming can be extended up to the highest levels of social systems and society, and is becoming recognised as one of the potentially most suitable techniques for " social engineering " (lit. ref. ***134).*** Technological forecasting games in this sense appear to be under active development at the **RAND** Corporation, especially by Helmer.

Earlier qualitative attempts already sought to provide frameworks for operational models: Gilfillan's **38** principles **of** invention ***(lit. ref. 70)*** can be interpreted as the sequential stages of an invention, particularly **of** a social invention. Rostow ***(lit. ref. 174)*** proposes a qualitative model incorporating " propensities " to develop fundamental science, to **apply** science to industry and to the economy in general, and to accept innovations. Siegel ***(lit. ref. 176)*** justly remarks that these " propensities " are cultural complexes devoid of operational significance.

Rigid computer models are on the threshold of becoming useful for technological forecasting. In particular, " dynamic forecasting " is **serv**ing as a guideline to a number of serious attempts; this term, introduced by Lenz ***(lit. ref. 151)*** to denote the modelling **of** all significant cause-effect relationships which influence the growth of technology in general or a functional capability, may be extended here so as to include technology transfer in general. The hope, of course, is to achieve adequate results with a limited dynamic model. The " Industrial Dynamics " concept **of** Forrester ***(lit. ref. 148)*** for complex business decision-making provides the background to many attempts in this area.

Brown and Cheaney ***(lit. ref. 101)*** point out that analog computers (which represent data by physical values) could be most useful in this field. This would not only mean economic advantages over the use of digital computers but would also facilitate the evaluation of alternatives by simply changing the physical inputs. The derivation of an optimum by simple trial and error could be very time-saving. *Also,* differential equations can often be represented much more easily on an analog **com**puter than on a digital computer.

Rigid computer models that have been developed along the lines of economic model-building could become useful for a part of technological forecasting: for example, Rea's resource allocation model, " ***Research and Development Effectiveness,*** " developed for the **US** Air Force (mentioned in ***lit. ref. 84),*** or the ambitious (and not yet completed) innovation reception game " ***Technological Innovation*** "—a computer game—by C. W. Churchman of the University of California (also mentioned in ***lit. ref 84).***

Lenz ***(lit. ref. 151)*** has attempted to model macro-technological progress in his " ***Knowledge-Progress System.*** " **A** simplified model based on **37** variables and constants and **19** simple mathematical relationships does not need a computer and can be calculated with a simple tabulator. Factors taken into account include: population, education, training, research facilities, facility lifetime, facility obsolescence, etc. The model seems to be of little operational value.

Abt Associates, in a proposal to OECD (7 April 1966), develop ideas or a model which is still predominantly along the lines of exploratory technological forecasting, in spite of a number of normative elements and some provisions for feedback.

It is designed in four stages:

1. The " systematic generation of feasible conformations of the future world, expressed in terms of technological, economic, social, political, and military capabilities and probable felt national requirements. " Estimated upper and lower limits of trends

will be entered, and envelope curve extrapolation will be used. Plausible scenarios can be developed by combination of variables randomly selected by a computer;

2. Relative probability estimates of particular configurations will be made, for example, by assessing the number of possible paths by which a particular configuration can be arrived at;
3. Systematic error correction, or incremental forecasting—a technique already applied in Abt's social-political models—will reduce the " noise level " implicit in technological forecasting. Intuitive expert forecasts of short-term changes will improve, by feedback, if checked against the results of the application of appropriate quantitative corrections to the next prediction round. The minimum " noise level " can be defined;
4. The integration of the previous stages, by computer simulation or by a man-machine simulation, will in the former case yield a prediction of trends, their interrelations, and the structural changes in the technological, economic, military, political, and social variables of the model and, in the latter, present the consequences of alternative planning strategies.

Computer simulations of future patterns of consumer goods consumption, such as that developed and supplied by the Battelle Memorial Institue, Columbus and Geneva, *(lit, ref. 119),* can be further developed for the purposes of technology acceptance simulations. The Battelle model used an ambitious and original approach in relating future demand changes to changes in the population and in its structural characteristics --e.g. education, employment, and income pattern—rather than forecasting changes in the total national income. It has been applied to forecasts of the structure of private consumption in **1975** in the United States, the Common Market countries, and the United Kingdom.

If ***complete business models*** have been designed for all significant aspects of a company, they can be readily used to explore the effect of the introduction of a new product, or of a specific development programme. In this way, alternatives may be tested. The results of technological forecasting obtained through complete business models obviously possess the particular merit of having already taken into account the interactions with the significant horizontally-acting factors. Possible pitfalls can be expected where a model is a " black box model " that does not show explicitly the way in which the factors exert their influence.

Complete business models are still rare in the United States, and are probably not yet available in Europe. Reportedly the only examples of American companies using such models are the Xerox Corporation and the IBM Typewriter Division: the Xerox Corporation uses its model, with 500 programmed variables, systematically (as an auxiliary means) in connection with its technological forecasting function.

Lockheed is at present trying so set **up** a model of the corporation which can be used for technological forecasting on the more aggregate level (" **How** much independent research should the company do? ", etc.). The use of ***partial ad-hoc business models*** for the evaluation of development projects is described in ***lit. ref. 146*** in the words of the research director of Hercules Powder **(US):** " Once we have anything we can name —a new product, or a new process—we build a business model. We try to do this for any research project, no matter how early the stage—except for exploratory research where the objective is scientific discovery ... We started doing this in 1954, after analysing what makes a project successful, so as to tailor our research efforts more closely to our business. The model is built on the same accounting principles that Hercules uses in its day-by-day operations. It contains the same type of data as would be used for a request for a capital appropriation. Into it go estimates for plant costs, costs for service facilities, and working capital to get total operating assets required. Estimates for costs of raw materials, conversion, packaging, warehousing, and depreciation provide total manufacturing costs. To this are added charges for sales costs and corporate overhead to determine total costs of sales. Also going into the model are data on prices and volume—these are the most difficult to estimate—to obtain a return on operating investment. This can then be compared with a standard return based on company experience. Also plugged into the analysis are such factors as research and development costs, time required for completion, and the chances for success. In parallel with the cost aspects, Hercules gives equal consideration to use and market aspects of its model. If applied research has defined the potential uses of a new product, for example, these can be matched against known markets and the unfulfilled needs of potential users. In this way, a market potential can be evolved to guide and stimulate applications development in much the same way that the cost estimates influence process development. " Apparently these ambitious models are run on an analog computer.

Technological forecasting frequently becomes part of an exploratory model, introduced either as a part of the model itself or in the form of ready-made conclusions and alternatives. Abt Associates (lit. ref. 83) are in the process of constructing a model for " Great World Issues of 1980, " more or less along the lines proposed for their technological forecasting model quoted above. Charles Osgood, of the University of Illinois. is building an exploratory global computer model for the year 2000 (lit. ref. 379).

Other models are more in line with normative technological forecasting. But the most important uses of rigid computer models may be expected to be for the simulation of feedback processes. These future potential applications will be discussed in Chapter II.5.

II.3.12. EXPLORATORY TECHNOLOGICAL FORECASTING ON THE AGGREGATED LEVEL

Technology transfer is a quantum. not a continuous process. Vertical transfer is characterised by " mutations " (inventions, innovations) which may introduce important deviation from the process of almost continuous improvement of known technology. Horizontal transfer, although quantised (whole factories adopting new processes, etc.), generally exhibits much smoother characteristics, but is complicated by the interaction of technological with a great number of non-technological factors. It has already been remarked that vertical transfer is easier to extrapolate—the curves of the pace-setters develop in a more regular way than the curves for average technology levels.

The predominant ambition of technological forecasting on the aggregated level seems to be concerned with the more complicated horizontal technology transfer, allowing vertical breakthroughs to occur more or less unexpectedly. This is obviously due to the fact that recognition of the unsatisfactory state of horizontal forecasting makes the neglect of vertical technology transfer appear to be relatively insignificant. Basically, this is the wrong attitude—and the more ambitious attempts such as "MAPTEK" (described below) try to forecast transfer vectors in the three dimensions of our technology transfer model.

The situation today is characterised by two general approaches:

Comprehensive sector studies on a ***disaggregated*** level, using forecasts of both vertical and horizontal technology transfer that are put together like a mosaic at the aggregated level. There are obvious limitations in sector size and time-depth (four to five years for the actual application today). Examples are: (*a*) CECA (Coal and Steel Community) in Luxembourg, forecasting the consumption of specific fossil fuels in the industry of the six member countries, based on studies of individual industries and individual uses and taking into account the introduction as well as the diffusion of new technologies; (b) Quantum Science Corporation in Palo Alto, California (a branch of Samson Associates), forecasting input/output figures for the electronic sector in the United States, based on thorough technological forecasting in the vertical direction (inventions, innovations) and on an appraisal of the individual qualities and competitive chances of innovating companies as well as of upcoming structural changes in the sector; (c) BIPE (Bureau d'Informations et de Prévisions Economiques) in Paris, attempting to forecast the economic impact (total sales figures) of specific new technologies or products on "chains" of industrial sectors (raw materials—components—systems—applications, etc.)

Statistical, econometric or other models on the ***aggregated*** level, including "technological coefficients" to account for technology transfer. These coefficients, which can represent only smooth changes over relatively short periods—in most cases the diffusion of existing technology over not more than five years—are usually derived from a more or less thorough evaluation at the disaggregated level. The updating of the coefficients permits easy updating of the complex model. This approach is used, for example, by the Battelle Memorial Institute in connection with the RAS model (a modification of the Stone model), and apparently in many other places as well. It may also be expected that many statistical economic models will use coefficients that—without full awareness of the fact—implicitly represent the effects of horizontal technology transfer.

There is thus a basic dilemma that so far appears to be unavoidable: the disaggregated approach, in which a mosaic is diligently pieced together in order to make future patterns visible, is reasonably accurate but runs into difficulties of scale, while the aggregated approach is too inaccurate for sectors with a high rate of innovation (which also implies a greater need for accurate technological forecasting). With either of the two approaches, technological forecasting on the aggregated level can provide only partial solutions.

Different versions of ***matrix representation,*** such as the research/research, research/industry, industry/industry matrices developed for the purposes of the French national economy, and intended to be applied to the forthcoming VIth Plan, can also be used for the structuring of exploratory forecasting. However, since much greater emphasis is usually placed on their utility for normative forecasting, this technique of representation will be dealt with in Chapter 11.4.

High hopes were recently raised that ***inputloutput analysis*** (for a general description see the new book by its " rediscoverer "[1] Leontief, ***lit.*** ref. ***152)*** might become useful for technological forecasting. Siegel ***(lit. ref. 176)*** in 1953 had already suggested that " it should be visualised to make forecasts by means of detailed structures of the Leontief-Evans variety. " Various reflections of technological change, according to Siegel, could be introduced explicitly: product of industry innovation, diffusion, productivity increase, substitution of materials, capital expansion. He also suggested a sequence of short runs, each represented by a table embodying **a** set of assumptions, instead of long runs.

Originally, the interest in the application of input/output analysis to forecasting was stimulated by the hope of improving the forecasting of the two common relationships between input and output: (a) the " production function, " expressing the output in terms of major inputs, such as labour and capital, but ignoring such factors as entrepreneurship; (b) the trend of labour productivity ratio over time. On the whole, this hope has not yet been fulfilled.

At the same time, however, Leontief himself has always believed that **his** empirical model for genera! equilibrium analysis would open up new opportunities, and that the future of econometrics depended as much on the " successful, essentially non-statistical search for promising analytical insights " as on the refinement of statistical techniques. Siegel ***(lit. ref. 176)*** emphasised the importance of exposing the obscurities behind broad aggregates and the use of time, and stated: " Even if it is impractical to implement a detailed model (say, of the Leontief-Evans variety), thinking in terms of one would sharpen appreciation of the difference between the expedients of forecasting and the mechanism of the ' rea ' world. "

The dynamic use of inputloutput analysis has become the principal object of study at the Harvard Economic Project, where C. Alimon **has** already built **a** computer model for an inter-industry forecast up to ***1975.*** Forecasting **the** United States economy from input/output tables is restricted to " hindsight " as long as the preparations of the tables by the Office of Business Economics, US Department of Economics, lags so far behind in time (it is slowly catching up—the **1963** tables are in preparation in **1966).** The first attempt to derive general trends from a comparison of tables for different years ***(lit. ref. 103)*** was therefore not too impressive: trends that become visible through a comparison of the **1947** and **1958** tables were discovered and extrapolated, in **1966.**

However, inputloutput analysis has already become a valuable technique for use in connection with manpower and unemployment problems. From **1961** to **1966** the **US** Bureau of Labor Statistics carried out a fore-

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1. A simple form of input/output analysis was practised in France in the 18th century, before Adam Smith. About 1870, Waras compiled all the equations, including those for technological change, but did not solve them.

cast for 1970; the coefficients of technological change were derived from a comparison between the 1958 and the 1963 tables for the US economy. The 1970 forecast has already been published, and a 1975 forecast is under preparation and may be available by about 1968.

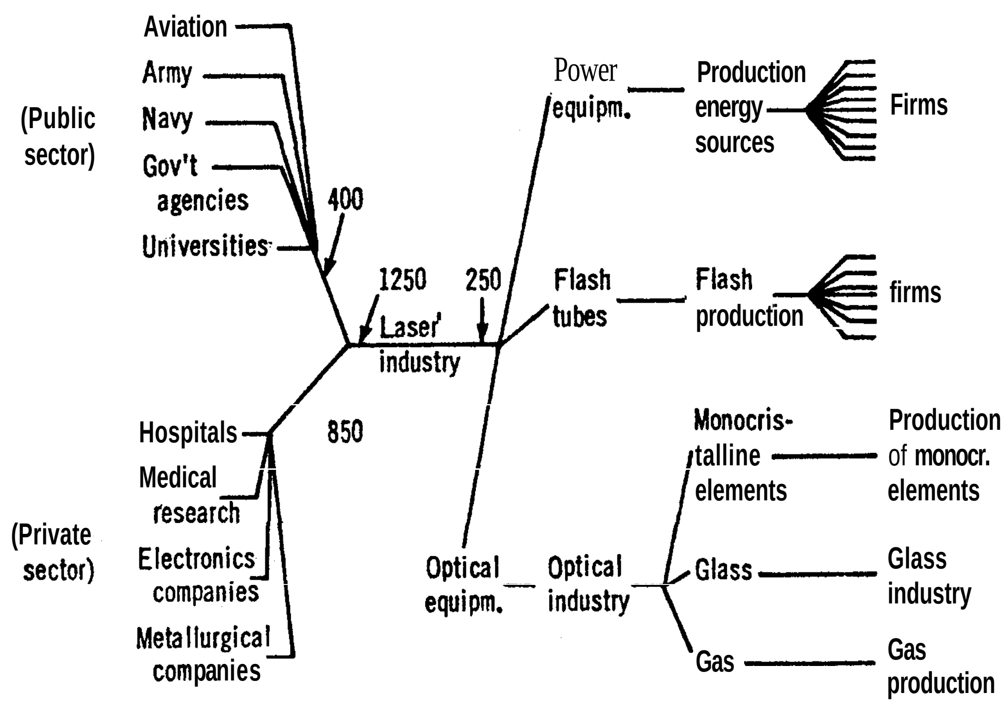
A *RAND Corporation* study for the US Air Force, on the basis of input/output analysis, attempted to forecast the creation of new industries in the aerospace sector. *Arthur D.* Little, in Cambridge, Massachusetts, applied input/output analysis to the identification of suitable research and development programmes in the field of oceanology for the State of Hawaii.

Even if genuine forecasting, i.e. the derivation of new information, on the basis of input/output analysis does not progress very far for some time, one may expect that such analysis will be recognised as a valuable means of studying structural changes in a clear and explicit manner. General trends—such as the increase in volume of activity for the " service sectors, " the invasion of one industrial sector by another, the changes in the supply and demand of raw materials (through technological innovations in synthetic materials, etc.), and many others—can be followed explicitly. For the purposes of medium-range technological forecasting, the changing relationships and interactions between vertical and horizontal technology transfer could become a major subject for study with the help of input/output tables; the general trend now points towards an increase in horizontal technology transfer, with profound consequences for the entire world economy.

So far, input/output matrices have been used more as a means for structuring and representing information rather than for generating new information. The information represented may then be generated on the disaggregated level, and for relatively narrow sectors only. The following two examples have already been mentioned as characteristic of the disaggregated approach:

Chains** (" filières ") of **industries affected by a technological innovation can be regarded as an aggregated input element for an input/output

(Figures in millions of dollars)



table; they are easy to obtain since no feedback or constraint is considered, and the effects of one innovation are, in a first approximation, considered separately from the economy as a whole. They have been applied to employment, income, and investment problems since the 1930's. This technique is now systematically applied to new technologies by BIPE in Paris, for the purposes of the forthcoming VIth Plan. An example, the innovation of lasers and its boldly forecast impact on the US economy in ***1970 (lit. ref. 96)*** may illustrate this approach (see below).

The ***representation of technological forecasting for a sector by input/output tables*** is being developed under the name of " MAPTEK " by Quantum Science Corporation for the electronics sector—at present for **the** United States, with Europe possibly being included in the future. The table used is a square matrix, divided at present into **1000** categories, with a goal of 200 equipment categories by **1968.** The present **1000** categories account for three levels—Equipment, Circuit Function, Component—while the other categories to be added in the future will be for Fabricated Materials and Raw Materials. Forecasts are given for a five-year time-depth. The source of the data is thorough vertical technological forecasting for 10 years and beyond, and an individual appraisal of competing companies and their technical and non-technical (entrepreneurial, management, etc.) qualities. Self-appraisals by companies, dealing for example with expected sales figures, are modified accordingly.

The input/output matrix here also stands for the restraints that act at the aggregated level: The estimated figures are iterated to fit into a consistent input/output pattern of the sector (so that over-estimated sales **figures** are corrected according to estimated demand, etc.) and to fit the national economy and its growth pattern in general.

The following extensions of the MAPTEK system are under consideration (and provide an indication to to the general future potential of input/output analysis):

On-line access to information;

Techniques for analysing the entry of new products; a routine is desired;

" Vector analysis " of needs radiating from each market in various directions;

Techniques for dealing with growth of firms;

Introduction of probabilistic forecasting, a difficult problem **because** not all probability distributions of **the** estimates can be assumed as Gaussian; experiments will start on the assumption of Gaussian distributions throughout, while Monte Carlo techniques may provide an alternative later;

Development of feedback techniques (input/output is linear, the world is not) with the possibility of extending the forecasts from a five- to a ten-year time-depth;

The ultimate goal is simulation (started in **1967).**

Input/output analysis for the future is also practised at the ***System Development Corporation*** in Santa Monica, California, at the ***Battelle Memorial Institute*** in Columbus, Ohio, and in Geneva; research **on new** methodologies in this field is also performed.

Input/output tables may also become a useful tool for companies which are widely diversified and whose branches are closely interdependent. Such a model has been developed by Carbonaro for FIAT (Italy), but has not yet been applied; aoother company model on an input/output basis **is** reported to be in use in a big German chemical company. Other companies use rectangular matrices **for** the representation of their internal input/output data; these matrices cannot, of course, be inverted, and this constitutes a great disadvantage.

To arrive at a consistent pattern, a complete square matrix must be inverted. This puts a restraint (which, however, is not severe for the largest existing computer models) on the size of the matrix which can be handled by available computers. The 1958 table for the **US** economy used 81 categories; the **1963** table will use **400** categories.

Horizontal technology transfer on the aggregate level, in particular the diffusion of existing technology, is an extreme case of technological forecasting which will be mentioned here only briefly, although it is acquiring increasing prominence today.

Much of the essential work in this field today is generated within a group of economists, supported by the Ford Foundation, who co-ordinate a loosely inter-connected research programme among themselves (see Chapter I.5.1.). Apart from an impressive amount of empirical research on diffusion of technologies, productivity ratios, and other aggregated factors (Griliches, Mansfield, and others, see ***lit. refs. 42, 43, 50,*** etc.), ***Mansfield*** has built and tested models to explain the rate at which other firms imitate an innovator ***(lit. ref. 157)*** on the basis of the stochastic epidemic curve (the basic assumption is similar to that of Hartman's model, described in II.3.3., but probabilistic refinements have been applied by Mansfield and Hensley). The model has been tested successfully against the empirical data for the iron and steel, bituminous coal, railroad, and brewing,industries ***(lit. ref. 51).*** Mansfield has also studied the effects of a number of variables on the length of time a particular firm waits before introducing **a** new technique ***(lit. ref. 50)*** and on the intra-firm rates of diffusion **of** an innovation ***(lit. ref. 47).*** Finally, Mansfield ***(lit. ref. 47)*** has investigated technological advances that have occurred in recent years in the railroad industry and the way in which these advances have been introduced; simple models have been tested for some of the phenomena encountered in this study.

On of the major factors acting horizontally is the support of research and development. Mansfield ***(lit. ref. 158)*** has studied the relationship between research and development expenditures and the measured rate of technical progress in a number of American manufacturing firms and industries. By introducing models of production and, alternatively, of organisational or capital-embodied technical change, the rate of return can be tentatively determined from the empirical evidence. Griliches ***(lit. ref. 93)*** has studied the profitability of research expenditure empirically, with striking results in the agricultural area.

To sum up with respect to aggregated level: one may still conclude with Siegel ***(lit. ref. 176)*** that aggregative—such as Keynesian—systems, either rule out, or have little to say about, technological change. Techniques for gaining new information on the aggregated level have become increasingly complex and turn back farther and farther to disaggregated analysis in the hope of deriving relationships of some fairly general applicability. Computers have arrived in time to cope with this flood of data to be evaluated.

Nevertheless, it has not yet proved possible to follow Siegel's call "to go beyond data into the realm of the personality"—or only marginally so, in special and well-defined forecasting efforts such as "MAPTEK." The "profound difference between the actual process of individual decision-making and the pseudo-process implied for a group by an aggregative mathematical expression" that Siegel deplores has yet to be substantially reduced. Is mathematics "too simple a language for social sciences," as Siegel suspects—and more recent evidence seems to bear out?

We have arrived at a point where two developments may gradually converge to put forecasting at the aggregated level on firmer ground: the increasing evaluation of empirical data to build models on a semi-empirical basis, on the one hand and, on the other, the decreasing difference between individual decision-making and group processes—in an era of vanishing individualism.

TECHNIQUES OF NORMATIVE TECHNOLOGICAL FORECASTING

> *There is one quality More important than 'know-how'... This is 'know-what' by which we determine not only how to accomplish our purposes, but what our purposes are to be... Whether we entrust our decisions to machines of metal, or to those machines of flesh and blood which are bureaus and vast laboratories and armies and corporations, we shall never receive the right answer to our questions unless we ask the right questions.*
>
> **Norbert WIENER.**

II.4.1. HORIZONTAL DECISION MATRICES

The matrix approach is a widely known and frequently applied means of checking research and development projects against various horizontally acting factors. Two-dimensional matrices constitute a very easy and quick method for assessing priorities among a number of proposed projects. Three-dimensional matrices can still be handled, but more than three dimensions cannot be represented graphically and are cumbersome as an abstract structure for thinking. It may therefore be said that two-and three-dimensional matrices will find numerous applications in decision-making that takes into account one or another of the important horizontally acting factors.

As for of all normative forecasting techniques, a surplus of proposals has to be given.

The most common use of a matrix in this context is for the optimisation of resources under given constraints. Resources may be not only financial but also manpower or manpower quality or skill resources, research, manufacturing, or other facilities. The matrix, in this case, represents something like an input/output matrix of scientific and technical effort in various fields.

A prominent example of project selection on the basis of resource matrices can be found at the Boeing Company in Seattle, Washington. First, one matrix is built for each project, showing the tasks and disciplines involved as one dimension, and the company resources as the other dimension. Projects fitting into the .given resource structure are then combined into higher-level matrices all the way up to " master " matrices for broad company activity areas. These matrices are used systematically as an auxiliary means of achieving optimum deployment of resources.

Research/market opportunities matrices are frequently used to decide a product *mix,* chiefly by iteration of the matrix. Honeywell (US) which uses such matrices systematically in its Radiation Center, remarks that

" this approach is beeter liked by top men than more complex decision approaches, but not by mid-level men. "

NASA, the **US** National Aeronautics and Space Administration, uses a matrix of missions to examine " communalities. " An example for a three-dimensional matrix, called "***Program Cube Concept,*** " and applied by ***IMC—International Minerals & Chemicals,*** Skokie, Illinois, is described in ***lit. ref. 278.*** It has the three dimensions of market missions (fields), resources, and time. The resource dimension is structured into financial, personal, marketing, sales, production, facilities, raw markets, research and development, and public relations resources. The programme cube is the basis of **IMC's** Project Exploratory Planning (P-E-P). Adequate programme planning affects the full cube, not only its parts. Whereas the market missions and resources dimensions, in a manner analogous to the Boeing concepts, aid in optimising the use of company capacity at a given moment, the dimension of time assures continuity of development in fields of interest.

An example of the use of a horizontal matrix on the aggregated level, for ultimate normative purposes is provided by the ***research/research matrix*** which the French ***Délégation Générale*** a ***la Recherche Scientifique et Technique*** is currently developing. It is being designed to indicate (and, eventually, forecast) the impact **of** progress in one scientific area on another area. At present, dots of four different sizes are used to indicate the importance of the input/output relationships. A scientific information/ research matrix is in the planning stage.

II.4.2. VERTICAL DECISION MATRICES

The use of matrices as a basis for normative forecasting involving vertical technology transfer apparently has not yet been explored very far. One obvious reason for this lies in the difficulty involved in quantifying relations between different levels. A brief discussion of the potential of such matrices is given by Ayres ***(lit. ref.*** *89).*

A two-dimensional ***research/industry matrix,*** used by the ***French Délégation Générale à la Recherche Scientifique et Technique,*** will be applied to problems related to the forthcoming VIth French National Plan. When the matrix was first set up, in 1961, 35 industrial sectors were dealt with. Now a modified scheme with finer subdivision is used; the INSEE scheme of industry, widely employed in France for other purposes, is too finely divided to be used for the simple matrix envisaged at present. As with the research/research matrix, the relations, for the time being, are expressed by dots of four different sizes. The next step will be a quantitative theory of the interrelations between individual matrix fields. A quantitative investment-benefit relationship theory is the ultimate goal. French participation in international co-operative research schemes will also be included in future.

The ambitious **US Air** Force " Project Forecast " (1963) used a science/technology and a mission/technology matrix. Research/programme matrices are sometimes used by ***North American Aviation's Autonetics Division*** in Anaheim, California, " to give the top men a feeling " for the impact of new developments on many fields. ***NASA*** employs a number of " exotic: " matrices as aids in decision-making.

The *Stanford Research Institute* usually suggests, as part of its corporate planning advice to companies, an "information bank" which is a version of a three-dimensional vertical decision matrix that can also be represented in two dimensions (by setting the products, customer, and resources columns side by side):

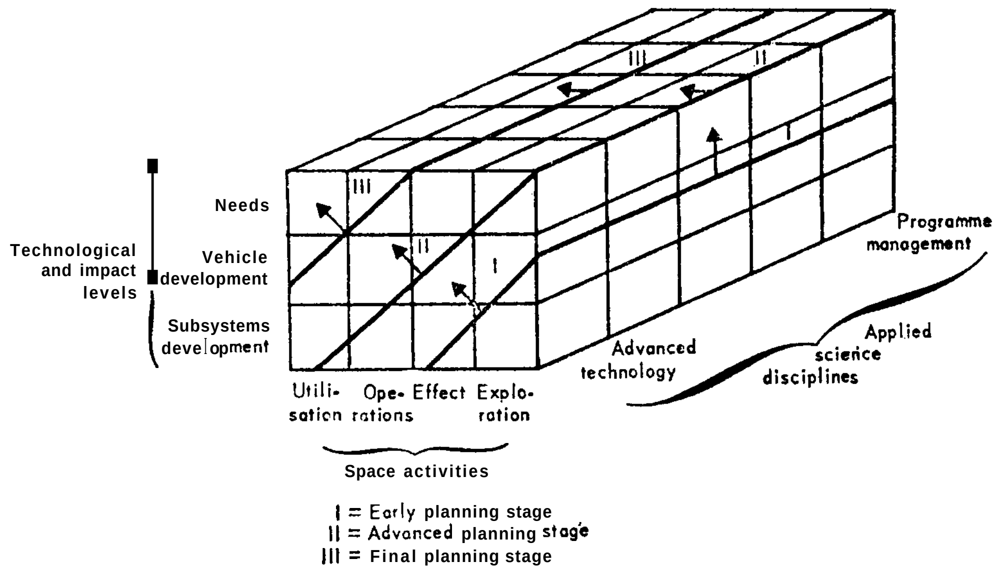
R & D PHASE	PRODUCT		CUSTOMER		RESOURCES	
	WHAT	HOW	WHAT	HOW	WHAT	HOW
Discovery.						
Create.						
Substantiate.						
Develop						

A data bank used by *North American Aviation's* Los Angeles Division, which compiles technological and non-technological limitations and constraints for the purpose of mission analysis, apparently shows a similar structure.

The periodically updated missions/materials matrix of the *US National Academy of Sciences* has been mentioned earlier in the present report (see Section **1.4.2.**).

A very ambitious three-dimensional matrix that reaches to the highest end-use levels of society has been developed by *Walter* at *North American Aviation's* Space and Information Division in Downey, California. It is called the "*National Space Program Total System Development Matrix*" and has been built by Walter for four programme parts—NASA, DOD, ESSA, commercial—with two time-frames for each part—pre-1970 and post-1970, so that the complete programme is covered by eight matrices.

Walter's approach. which has not yet been published, can be described in a highly simplified way[1] as a rectangular prism with the three dimensions: technology and impact levels (component and subsystem deve-



1. This brief description neglects a considerable number of refinements which Mr. Walter, it is hoped, will present in a full published account, but aims at giving a correct picture of the basic ideas.

lopment, vehicle system development, and shortly, up to the needs or social goal level); space activities (exploration of space environment, effect of space environment, development of space operations techniques, utilisation of space environments, etc); and applied science disciplines or research management spectrum (from advanced technology programme to programme management). The principal importance of the matrix for forecasting is the structuring of thinking and the explicit demand for a forecast of end-uses which this structuring involves (" Space is an operational environment for the benefit of man "). Structuring enforces a " total system " approach at the technical levels as well, for example by including the support system (communications, operational facilities, etc.) which comprises the biggest and most critical single item but is often neglected in forecasting and planning for space vehicles. At the planning stage, the matrix functions like a simplified PERT scheme and maintains the " total system " view; as planning and execution proceed, the " cut " (as indicated in the drawing) moves through the entire prism.

This approach, by one of the big American aerospace companies, was prompted by an attitude which has been implicit in the US Department of Defense in the McNamara era—that of " buying " only proposals for which end-uses can clearly be seen. At the same time, it is also a remarkable example of the basic attitude adopted by some of the big US companies of seeking to fit their corporate goals into a framework of national and ultimate social goals; North American Aviation may be the first company, however, to have designed a technique expressly for that purpose!

II.4.3. SIMPLE TECHNIQUES FOR PROJECT SELECTION BASED ON AN OPERATIONS RESEARCH APPROACH

Operations research provides analytical methods of finding, from a large number of feasible combinations. the optimum combination for achieving a given objective under certain constraints. The analytical methods applied so far to project selection are widely used in other operations research problem areas, especially that of management techniques:

Linear programming, a technique for formulating an optimisation problem in linear mathematical relationships-equations, inequalities, or expressions of ranges—and for solving these relationships simultaneously for the desired optimum (usually a maximum or minimum);

Quadratic programming, which extends the application of linear programming by providing the possibility of using relationships that include second order terms—which may be particularly desirable for the approximation of non-linear cost relationships—or probability distributions in a certain range; in special cases, the computational part can be reduced to a linear form and then handled much more easily;

Dynamic programming, a method of solving multi-stage programming problems which are inter-dependent (the decisions at one stage become the conditions governing the succeeding stage); in special cases, dynamic programming problems, such as the minimising of total costs over a number of successive stages, can be solved by quadratic programming.

The most natural way of tackling the problem of optimisation of project selection is to maximise the total net value of projects under a budget constraint. The usual principal input into the problem is therefore a number of estimated net values of projects. The most common form of decision models using operations research techniques is thus found to be a combination of economic analysis, chiefly to determine the present net value of projects from estimated characteristics, and of operations research techniques. Two approaches of this type, by *Dean and Sengupta (lit. ref. 113)* and *Cramer and Smith (lit. ref. 110)* have already been mentioned in section 11.3.10. on " Economic Analysis. "

Asher (Zit. ref. 88) has developed a linear programming model for a pharmaceutical company, with the following variables: possible research projects, value of success, probability of success, cost per man-hour, man-hour per test, available man-hours, and available chemicals. The ranking criterion is the maximum expected net value, taking into account availability of man-hours and chemicals. Using US figures for 1958 as a basis—the pharmaceutical industry tested 115,000 compounds and marketed only 40 new chemical entities a— probability of success of 0.0003 and a Poisson distribution (which describes many random events in nature) are assumed to fit uniform probability of occurrence.

Freeman (lit. ref. 122) proposes a linear programming formulation for determining the size of the research budget and allocating it among competing projects. Net values are specified for each projects, with a probability distribution for each value determined on the basis of past records.

Hess (lit. ref. 135) has developed a dynamic programming formulation to take into account the sequential decision characteristics as they present themselves, for example, in a pharmaceutical company. The objective is the maximisation of the total expected net value, alternatively without and with budget restraints; the latter case is difficult to solve. One important result, under budgeting limitations, is the distribution of optimal project expenditure over time. Hess considers the introduction of " probability of success " in the dynamic formulation in three different ways: direct expert estimate, identification with historical patterns and probability functions, characterisation of the functionality and the parameters of the probability of success (for example, a formulation might be developed for drug screening).

Rosen and Sonder (lit. ref. 172) modify Hess's dynamic programming approach by discussing it in the context of different optimisation criteria for obtaining optimum expenditure patterns: *a)* maximise the expected profit; b) maximise the " Total Expected Output, " i.e. the expected research success; *c)* achieve at least a 55-fold return on non-discounted expenditure (this policy has apparently been considered for a pharmaceutical company: d) optimise the " Life Expected Output, " i.e. the integrated expected success over the expected life-time of the product.

11.4.4. SIMPLE TECHNIQUES FOR PROJECT SELECTION BASED ON A DECISION THEORY APPROACH

This approach is usually taken where the projects involved contribute to corporate objectives in many different ways, not simply by making a profit, etc. Military technological developments are an obvious example of research programmes that cannot be looked at purely from an economic point of view.

In many of the actual applications of simple decision theory models, factors originating in different levels of technology transfer are mixed—horizontally acting factors at the lowest impact level, corporate objective? from higher levels acting on a lower level, etc. Usually, these different types of factors are treated as equal in the calculations. The question arises whether this is a sound approach, although there are generally only two levels that are taken into account in these simple models, (larger models, which will be described in the following section, establish a hierarchic order according to level).

Check lists, used in industry for many years, may be considered a first step in the direction of decision theory. ***Lit. ref 146*** gives an account of the use of check lists in the **US** chemical industry. The volume of the check lists reported on there ranges anywhere up to nine pages (Air Reduction). The number of rating steps is usually between two and five **(W.R.** Grace) and steps are normally expressed, not in numbers, but in qualification such as " Very favourable, " " Favourable, " " Average, " " Unfavourable, " " Very unfavourable"—these are, of course, roughly equivalent to numerical ratings. The " Effort Allocating Guide for Applied Research " (described in ***lit. ref. 166)*** used by the **US** Air Force, Wright-Patterson Air Force Base, Ohio, employs more refined numerical ratings. A typical check list may include items in the following areas: financial, research and development characteristics, production characteristics, marketing factors, corporate position, etc. Check lists are used both in very big and in fairly small companies (for example, Nordiska Armaturfabrikerna in Linköping, Sweden, with 2,000 employees). A few companies have abandoned the use of check lists or are continuing to use them only for part of their projects; one reason for this is growing sophistication and the recognition of the inadequacy of one form for a large variety of research and development projects.

An early scheme by ***Hetrick and Kimball (lit. ref. 136)*** which has apparently been used by the US Navy, is described as attempting a balance of effort in basic research by breaking knowledge up into unknown facts, known but unapplied facts, and applied facts; levels of effort and rates of transition between the three types are assumed.

A number **of** simple models are based on the multiplication of estimated numerical ratings **of** various factors. ***De l'Estoile*** of the French Ministère des Armées uses a refined rating scheme for a four-factor formula composed of: military utility, probability of technical success, possibility of realisation in France, direct and indirect economic impact (including spin-off to the civilian sector). **As** from 1967, the calculations for the large number of projects will be made by computer, and ratings will be added, not multiplied.

Mottley and Newton (lit. ref. 163) developed a five-factor formula for the pharmaceutical company Chas. Pfizer, New York, **but** used a rough rating scheme with ratings that ranged only from one to three, corresponding to expectations such as " unforeseeable, " " fair " and " high. " The five factors are: promise of success, time to completion, cost of project, strategic need, and market gain.

Gargiulo et al. (*lit.* ref. **124**) propose an evaluation system which considers technical, economic, and timing aspects. Eleven factors of assumed equal importance are suggested for which ratings in three value categories—favourable, no opinion, unfavourable—are assessed and recorded on a " project rating worksheet. " No numerical analysis is proposed because no distinction is made as to the relative importance of the **11** factors. Technical and economic factors are grouped to give scores which are expressed in a numerical range from 1 to 10. The selection of factors shows considerable sophistication:

- Objectives of the project;
- Novelty of the project or current approach;
- Technical relationship of the project with past or present activities in the laboratories;
- Technical feasibility of the project in terms of adequacy and interpretability of the methodology involved, the availability of personnel, space, special equipment and support, and the tie-in of the project with other activities in the laboratory;
- Anticipated outputs of the project;
- Assessed enthusiasm of the project supervisor (!);
- Extent of competing laboratories' efforts in the field;
- Use-potential of a product that may result from the project;
- Anticipated stability of the market;
- Patent protection;
- Time span required to attain the objectives of the project.

An interesting combination of economic analysis and a decision theory approach is presented by Ansoff (*lit.* ref. 87). His formula reads

$$\text{Figure of merit} = \frac{E \cdot p_s \cdot p_b}{C \cdot j}(M_t + M_b) \cdot S \tag{53}$$

E = Total estimated earnings over product lifetime.
p_s = Probability of technical success.
p_b = Probability of business success.
C = Total costs and direct investments.
j = Savings factor in C resulting from the shared use of facilities, etc.
M_t = Technological merit.
M_b = Business merit.
S = Strategic fit of proposed project with other projects, products, and markets of the company.

The first five factors represent an economic analysis of the undiscounted project value, including risk factors. The three other factors—technological and business merits, and strategic fit—account for corporate considerations of a higher order. The resulting figure of merit, according to Ansoff, should be proportional to return on investment, which may hold only roughly in certain cases.

In this context, Ansoff also proposes a risk evaluation obtained by dividing the costs of applied research effort by the above figure of merit. This gives roughly dollar cost at risk in the first (applied research) stage per percentage return on investment.

Pound (*lit.* ref. *167*), in his " expected value model, " uses a small-scale relevance tree approach. Numerical weights are attributed to objectives and are multiplied by the estimated contributions to objectives for each specific project. A simple example will illustrate the approach:

	OBJECTIVES	
	MAKE A PROFIT	GAIN KNOWLEDGE
Weights (stipulated)	0.7	0.3
Project A (estimated)...................................	5	8
Project B (estimated)....................................	7	1

Value of Project A = 5 × 0.7 + 8 × 0.3 = 5.9
Value of Project B = 7 × 0.7 + 1 × 0.3 = 5.2

The relevance tree approach is used in important large-scale models to be discussed in the following section, II.4.5.

Beckwith (lit. ref. 92) developed a model for the evaluation of the probability of a given proposal to " capture " a job contract award. The input comprises identity of probable competition, knowledge of factors that influence a contract award, and ability to rank one's own organisation. This model is useful for application within a well-defined programme, for example defense research programmes.

Similarly useful for application within the defense research programme is the formula used by the *US Navy* (lit. ref. 184) to determine the relative research requirement for a Nuclear Weapons Effect Program during an assumed prolonged moratorium on atmospheric tests:

$$(RR)_i = \frac{(RI)_i\,(1 - P_i)}{\sum\limits_{i=1}^{n} [(RI)_i\,(1 - P_i)]} \tag{54}$$

$(RR)_i$ = Relative research requirement for the i-th weapon system.
$(RI)_i$ = Relative importance of the i-th weapon system.
P_i = Predictability of the effects of the i-th weapon system.
n = Number of weapon systems to be investigated.

According to this formula, the less predictable the effect (the less the objective has already been approached), the higher the research requirements.

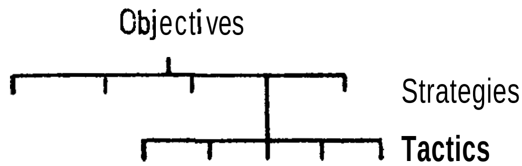
To summarise, these small decision theory models may be said to have been quite useful in structuring preliminary thoughts and in taking into account higher-order factors. The general shortcoming of all these individual approaches is that multi-dimensional considerations such as " project success " are reduced to single probability indices, whereas other, one-dimensional factors have an equally important impact on the overall score.

The application of hierarchic systems, for example relevance trees, to two-level problems such as most of those tackled by the techniques described in this section, without excessively burdening the task of calculations, may lead to a clearer structure of interdependencies while providing improved possibilities for updating and modification.

II.4.5. INTEGRATED DECISION SCHEMES BASED ON RELEVANCE TREES

The concept of relevance trees (or reliance trees) is not new. It was first proposed by Churchman and others, in connection with decision-making in general industrial contexts *(lit. ref. 106)*. A small-scale numerical analysis with a two-level relevance tree by Pound has been mentioned in the preceding section, II.4.4.

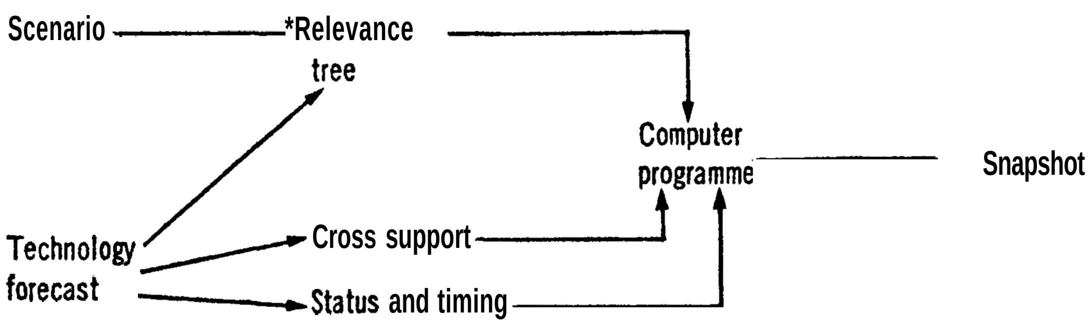
Qualitative relevance trees are employed to aid decision-making and are then called " decision trees. " A technology tree for semiconductor technology is used by one of the big semiconductor companies in the United States. North American Aviation's Autonetics Division in Anaheim, California, is at present implementing **SCORE** (Select Concrete Objectives for Research Emphasis) to relate objectives five to 15 years in the future to strategy and tactics and to define key points. The three-level



relevance tree chosen is patterned on an electronic company's structure for technological planning (see section III.2.). Criteria for selection will include customer (government) needs competition, industry trends, Autonetics' resources. The main aim is to relate distant objectives to action that should be taken today. The most prominent example of a decision tree however is that of the Planning-Programming-Budgeting System (PPBS) of the US Department of Defense (see Annex A.2.4.).

The first large-scale application of relevance trees to numerical analysis for decision-making has been made by *Honeywell's* Military ***and Space Sciences Department*** in Washington, D.C. This is the famous PATTERN (Planning Assistance Through Technical Evaluation of Relevance Numbers) scheme which was first used for Honeywell's aeronautical and space activities in 1963, and was extended in 1964 into a comprehensive scheme covering all military and space activities in which Honeywell is interested directly or indirectly. This scheme, continually being extended and refined, will serve as the best basis for an explanation of PATTERN, which has been described in various publications *(lit.* ref. ***117, 143, 147, 150, 177)***.

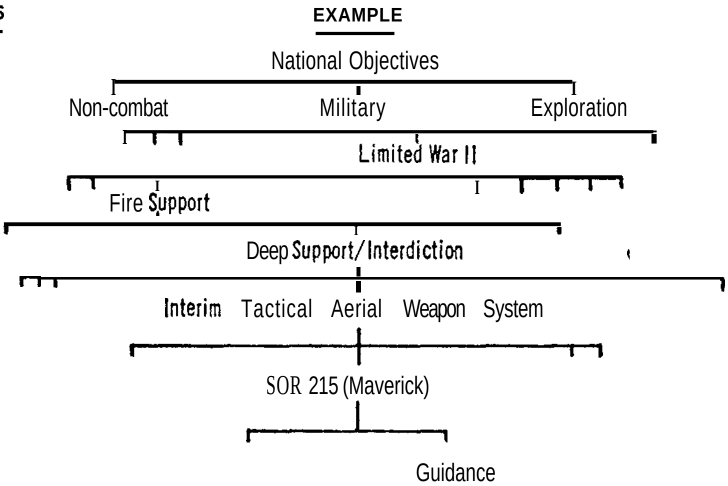
The scheme of tasks to be accomplished before a computer programme can be set up is illustrated in the following diagram:



A qualitative scenario attempts to assess national objectives, activities, **missions,** etc., in the period between 1970 and 1980, and possibly beyond. These findings are then used for the construction of the relevance tree and the assignment of significance numbers, as explained in detail below. **At** the same time, a technology forecast is made at the primary systems level and lower levels, aided by massive trend extrapolation and envelope curve techniques (see section 11.3.4.) as well as other forms of qualitative and quantitative exploratory forecasting. Apart from an identification of primary systems, secondary systems, and functional subsystems and their relationships, used for the relevance tree, two sets of characteristics are assessed explicitly: cross support, which means spin-off to other areas, or general technological growth to be expected from tackling a specific technical system; status (research, exploratory development, advanced development, product design, availability) and timing for systems and subsystems. These input data can be used in the computer programme if such refinements are desired; at present, Honeywell does not use cross support estimates (other than identical systems for different missions, etc.) and **uses** status and timing only to sort out all projects already well under way.

Honeywell's military and space relevance tree, in its 1966 form, looks like this:

LEVEL	NUMBER AND NATURE OF ITEMS
-	National Objectives
A	3 National Activities
B	13 Forms of Activity
C	64 Missions
D	204 Tasks
E	697 Primary Systems (approx. 400 different ones)
F	2,366 Secondary Systems (approx. 790 to 800 different ones)
G	Several thousand Functional Sub-systems



The levels of the relevance tree correspond to levels of technology transfer between social systems (the nation) and technology or technological resources. In the technology transfer scheme used throughout this report, five to six out of the eight levels are covered by this relevance tree—a unique achievment so far for an integrated forecasting scheme!

From the scenario, a number of criteria are derived for the different relevance tree levels. General criteria for levels A, B and C, for example, include: national survival, threat, force structure, capability, prestige; for levels D and E: cost effectiveness, requirements met, scientific implications; for levels F and G: feasibility, effort, risk, capability improvement, operational advantages.

At each of the seven levels **A** to G, a matrix is set up to match issues against criteria. (To be precise, from level C downwards, one matrix is set up for each " family " on the level, e.g. one matrix for each family of seven or eight missions that come under one of the 13 forms of activity; this is only a practical procedure for the purpose of facilitating calculations —logically there should be one matrix at each level.) This matrix has the general form:

CRITERIA	WEIGHTS OF CRITERIA	ITEMS ON LEVEL I						
		a	b	c	....	j	....	n
α	q_α	s^α_a	s^α_b	s^α_c		s^α_j		s^α_n
β	q_β	s^β_a	s^β_b	s^β_c		s^β_j		s^β_n
γ	q_γ	s^γ_a	s^γ_b	s^γ_c		s^γ_j		s^γ_n
$\vdots$	$\vdots$							
$\varkappa$	$q_\varkappa$	$s^\varkappa_a$	$s^\varkappa_b$	$s^\varkappa_c$		$s^\varkappa_j$		$s^\varkappa_n$
$\vdots$	$\vdots$							
ν	q_ν	s^ν_a	s^ν_b	s^ν_c		s^ν_j		s^ν_n
		r^a_i	r^b_i	r^c_i	....	r^j_i	....	r^n_i

$s^\varkappa_j$ = Significance number (how significant is the contribution of issue j to criterion $\varkappa$?).
r^j_i = Relevance number of item j on level i.

The criteria $\varkappa$, the weights of the criteria $q_\varkappa$ and the significance numbers $s^\varkappa_j$) are estimated on the basis of the scenario. The setting up of these matrices is a major effort requiring a synthesis of expert judgement (Honeywell used 20 full-time experts during six months, and their judgement was reinforced by contributions from experts in different departments). This may become one of the important applications of methods for the improvement of techniques of intuitive thinking such as the " Delphi " technique (see section 11.2.3.). Honeywell is at present undertaking a sensitivity analysis to assess the influence of variations in this expert value judgement on the end-results.

Two norming conditions are introduced to assure the homogeneity of the logic:

$$\sum_{\varkappa=\alpha}^{\nu} q_\varkappa = 1 \tag{55}$$

and

$$\sum_{j=a}^{n} s^\varkappa_j = 1 \tag{56}$$

From level C downwards, the matrices set up for the " families " are normed to unity. (This does not disturb the logic applied as long as the sum of the relevance numbers within any branch is unity).

The relevance number is then defined as

$$r^j_i = \sum_{\varkappa=\alpha}^{\nu} q_\varkappa s^\varkappa_j \tag{57}$$

It can be readily seen that the norming conditions *(55)* and *(56)* also imply that the relevance numbers are normed to unity:

$$\sum_{j=a}^{n} r^j_i = 1 \tag{58}$$

The definition (57) of the relevance number is an arbitrary one, but seems to represent a natural choice and well reflects the original problem of analysing the contributions of one item to criteria of different importance.

An example will serve to illustrate this simple procedure: for the three items on relevance tree level A three criteria have been formulated. The matrix with the estimated weights for the criteria and significance numbers reads:

CRITERIA	WEIGHTS	ITEMS ON LEVEL A		
		NON-COMBAT	MILITARY	EXPLORATION (EARTH AND SPACE)
Insuring national survival	*0.6*	0.3	0.6	0.1
Demonstrating credible posture.	0.3	0.1	0.6	0.3
Creating favourable world opinion..	0.1	0.1	0.4	*0.5*
		0.22	0.58	0.20

The relevance figures appear in the bottom row, and are derived according to equation (57). The relevance figure for military activity, for example, is calculated in the following way:

$$0.6 \times 0.6 + 0.6 \times 0.3 + 0.4 \times 0.1 = 0.58.$$

Honeywell calls this scheme the " horizontal value-judgement assignment " and remarks *(lit.* ref. *143)* that " this choice was selected due to the information in the tree being 'upgraded need' in which it is felt a comparative marginal judgement can be made with greater validity, reliability and with much less information than is required of a vertical, absolute assignment technique. In addition, the gain or scale factor of each branch can be controlled, the mathematical subdivision criteria are met without having to take the derivate of an uncertain number which would be required in the vertical absolute method. "

The needs and objectives change with time. Strictly speaking. they should be introduced as functions of time. However, these functions could not be precisely estimated in many cases. At the present stage, iteration to fit a given future period in the scenario and periodic updating seem quite sufficient measures.

The total relevance figure of a particular issue on any level is then obtained by multiplying upwards to the top of the tree (or down from the top to the level of the issue in question, e.g. down to level E for a particular primary system, down to level G for a particular functional sub-system, etc.). The simplest formula for a total relevance figure **R** for a particular functional sub-system would then be

$$R = \prod_{i=A}^{G} r_i \tag{59}$$

However, a number of refinements are proposed by Honeywell. The most important of these concerns the fact that from level D downwards more and more " communalities " become visible—i.e. items (concepts, systems, sub-systems, etc.) that are common to more than one heading and appear more than once on the level in question. It has already been indicated that in the relevance tree scheme given above out of **697** primary systems only about 400 are different, and out of 2,368 secondary systems only about **790** or 800 are different.

If we denote the relevance numbers, which include the refinements, by capital letters—R_i—and examine them at every level from A to G, the proposed refinements will be explained for each level:

On the levels A, B and C no refinements are introduced, so that

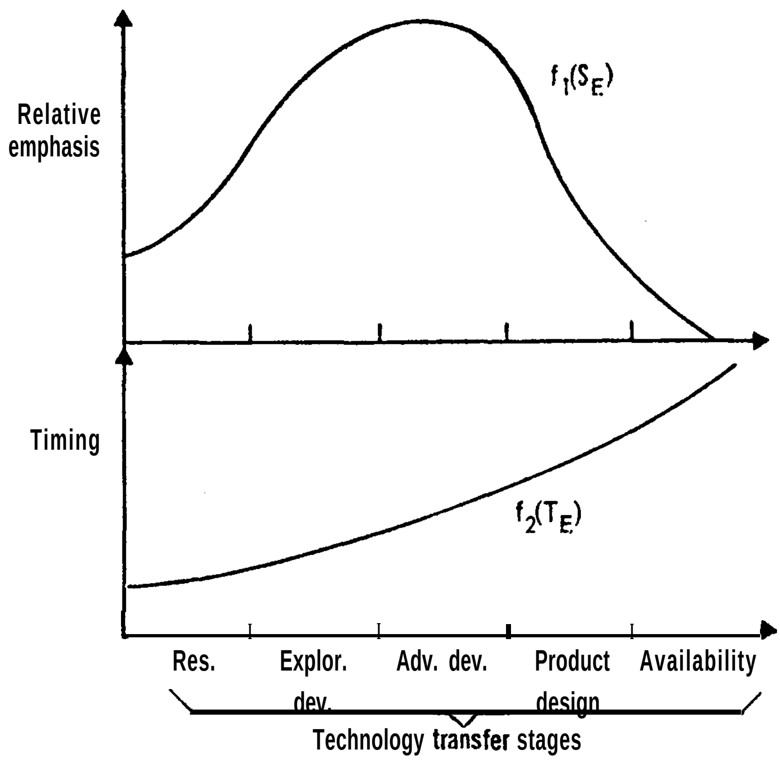
$$R_A = r_A; \qquad R_B = r_B; \qquad R_C = r_C \tag{60}$$

On level D the first " communalities " occur, so that

$$R_D = \sum_{D_o}^{D=D_o} r_D \tag{61}$$

This notation, used by Honeywell, is intended to indicate a summation over the relevance number of a specific issue D_o and as many identical issues $D = D_o$ as appear on level D in addition to D_o.

For level E (Primary Systems), the technology forecast provides a density function f_1 (S_E) for the status of a particular system and a density



function f_2 (T_E) for the timing. Both functions could be entered into the scheme, so that—again with the possibility of "communalities"—the relevance number for a particular issue on level **E** would become

$$R_E = \sum_{E_o}^{E=E_o} r_E f_1(S_E) f_2(T_E) \tag{62}$$

Honeywell, at present, does not use the functions f_1 and f_2, but sets up a simple auxiliary matrix for status and timing, for example:

	RESEARCH	EXPLORATORY DEVELOPMENT	ADVANCED DEVELOPMENT	PRODUCT DESIGN	AVAILABLE
Status		x			
Timing		3	2	2	1

This matrix would mean that the primary system in question is in the exploratory development stage, and that the time required to complete this stage is estimated at three years, the time from advanced development to product design is estimated at two years, etc. For the time being, these indications are used to sort out projects that are available or in the product design stage (because the aim is to look into the more distant future) and to acquire a feeling for the development stages that can be expected for the considered future time period. Honeywell has development work primarily in mind; therefore, systems in the exploratory and advanced development stages are retained for inclusion into PATTERN (for a research laboratory the emphasis would be on the research stage).

Level F (secondary systems), according to Honeywell, would be the appropriate level at which to introduce a "cross support number" $x_F \geqq 1$, which reflects the general technological growth—through a speeding up of other areas—that could be achieved by working on a particular secondary system. This "cross support" effect would go beyond the mere savings resulting from the use of "communalities." The relevance number for level **F**, again taking "communalities" into account, would then be

$$R_F = \sum_{F_o}^{F=F_o} r_F x_F \tag{63}$$

Honeywell, at present, does not make use of this refinement.

Finally, at level **G** (functional sub-systems), the technology forecast again provides, as for level E, a density function f_3 (S_G) for status and a density function f_4 (T_G) for timing. With "communalities," the relevance number is then

$$R_G = \sum_{G_o}^{G=G_o} r_G f_3(S_G) f_4(T_G) \tag{64}$$

Introducing a further factor δ ($r_{A \ldots G}$, S_{EG}, T_{EG}) which "reflects our intentions to pursue in such greater detail an evaluation of uncertainties in the assignment of the relevance numbers at all levels through **A—G**, and the status and timing numbers at their appropriate E and *G* levels in the total structure. -- the simple formula (59) now appears in the modified form

$$R = \prod_{i=A}^{G} R_i \, \delta (r_{A \ldots G}, S_{EG}, T_{EG}) =$$

$$= \sum_{D_o}^{D=D_o} \prod_{i=A}^{D} r_i \cdot \sum_{E_o}^{E=E_o} r_E f_1 (S_E) f_2 (T_E) \cdot \sum_{F_o}^{F=F_o} r_F x_F.$$

$$\cdot \sum_{G_o}^{G=G_o} r_G f_3 (S_G) f_4 (T_G) \cdot \delta (r_{A \ldots G}, S_{EG}, T_{EG}) \qquad (65)$$

The refinements represented in this formula can be extended or modified in many ways. However, the suggestions by Honeywell clearly demonstrate a few of the more obvious possibilities. One of the greatest advantages of the PATTERN technique is its flexibility.

A possible refinement of some importance **is** at present under investigation by Honeywell. and concerns the feasibility of introducing probabilistic estimates for the weights and the significance numbers. In principle, it would appear likely that such a possibility exists.

The more a scheme such as PATTERN is biased towards a particular set of problems, the more basically new information does it seem capable of providing. The total relevance numbers of a completely unbiased scheme would have little more significance than that of a confirmation of the input. **In** the Honeywell example, this bias is represented by the concentration on projects at an early stage **of** development or in the forecasting or planning stage. The principal answers provided by Pattern concern the following points:

" Upgrading -- of research and development efforts, i.e. missions and programme areas in which effort should be concentrated;

Technology deficiencies in relation to systems, concepts, and broad requirements, and a measure of their relative importance;

Relative value of selected technology improvements in a given area, e.g. greater accuracy, lower cost, lower weight, etc.;

Evaluation **of** alternatives, in accordance with main objectives.

The first indications which PATTERN furnished to Honeywell were in some cases surprising. It will be remembered that the numerical example given above for items on level A yielded the following relevance numbers: non-combat **0.22,** military 0.58, exploration 0.20. Earth and space exploration ranked lowest on this level. But on level **C** (mission), the three top-ranking missions belonged to the exploration activity: hydrosphere exploration and use, exosphere exploration and use, solar system bodies exploration. And trailing behind these were missions belonging to the military activity in the strategic, counter-insurgency, arms control, tactical, etc., areas. On level D (primary systems), which is led off by the **space** observatory, Honeywell was able to predict as early as the end of **1962,** through test-runs of the first PATTERN scheme, the future importance of a counter-insurgency aircraft (STOL—short take-off and landing). In **the** field **of** aircraft and missile guidance, in which the company **is** one **of** the leaders, PATTERN told Honeywell that its policy favouring greater accuracy and **less** drift in the systems, i.e. better performance, was basically wrong and that lower cost is relatively more important because inertial guidance can be **applied** to quite a few systems whose total costs are relatively low.

It is evident that PATTERN can also be used for the evaluation of many problems related to research and development, such as qualitative and quantitative manpower planning.

The economics of setting up and maintaining a PATTERN scheme may be illustrated by the effort that went into the Military/Space relevance tree of Honeywell outlined above:

The original set-up was accomplished in six months by 20 experts who frequently drew on the help of experts in Honeywell's various technical departments. Sixteen thousand punch-cards had to be prepared. The cost of the original set-up may thus be estimated at approximately $250,000 to $300,000.

The extension and updating are performed by 14 highly qualified people, half of whom are former military persons and half ex-engineers, all with experience in operations research and systems analysis. Updating is done once a year and comprises the following three aspects: (*a*) modify the scenario; (b) update the system (add or drop); (*c*) shift the weighting numbers. Updating is not a very big job and takes only part of the time of the 14 persons involved; however, part-time activity carried out by a group of this size is perferable to full-time work by two or three people because a better foundation is likely to result from group consensus on value-judgments. Annual "maintenance" costs may be estimated at roughly $50,000.

Computer runs take 20 minutes on a Honeywell 800 computer. The costs of computer use are probably a whole order of magnitude lower than the cost of the manpower necessary for the first two tasks mentioned above.

The flexibility of the PATTERN concept may also be demonstrated by its application in other areas. Two examples of relevance trees, both prepared by Honeywell, may be of interest. To simplify the comparison the levels are denoted by the capital letters corresponding to the levels in the Military/Space tree used above for the explanation of the system.

HONEYWELL'S MEDICAL RELEVANCE TREE

LEVEL	NATURE OF ITEMS	EXAMPLE
B	Objective	Extend Life
C	Task	Diagnosis
D	Approach	Function
E	System	Cardio-Vascular System
F	Sub-system (Organ)	Pulmonary System
G	Factor	Pressure

16,000 punch cards, as many as for the Military/Space tree, were required for the input.

Medical doctors were used in setting up the medical relevance tree. If they were unable beforehand to define what needed to be done in the medical field, they reached a large measure of agreement when PATTERN provided the first answers. As a consequence of this PATTERN application, Honeywell's medical electronics programme changed radically!

The second of the two examples noted here is a relevance tree prepared with the aid of Honeywell for implementation by NASA (National Aeronautics and Space Administration) and is briefly described in *lit.* ref. ***94:***

NASA's APOLLO PAYLOAD EVALUATION RELEVANCE TREE

LEVEL	NUMBER AND NATURE OF ITEMS	EXAMPLE
-	National Objectives	National Space Objectives
A	2 Purposes of Endeavour	Science in space; Utilisation of space
B	**15** Targets	Moon
C	68 Fields of Interest	Composition
D	301 Tasks	'Determine Gross Chemical Composition of Surface Material
D'	**46** Operational Concepts	Manned Lunar Scientific Colony
E	195 Systems	Nuclear Power Plant
F	**786** Sub-systems	Auxiliary Power
G	687 Functional Elements	Power Source
G'	Alternate Subsystems Configurations	Nuclear Reactor, Thermionic Conversion
H	2,329 Technology Deficiences	Waste Heat Rejection; Shielding

Scientific and utilisation experiments are compared at level D (tasks), and technology experiments are compared at level H (technology deficiencies). The evaluation is intended to cover a time-frame of 20 years.

In all, six applications of PATTERN have become known so far:

- Honeywell's Military/Space tree, used as an example for purposes of the detailed explanation given above, fully operational since **1964;**
- Honeywell's Medical Relevance Tree, also outlined above, operational since 1965;
- NASA's Apollo Payload Evaluation Tree, outlined above, in the implementation stage in 1966, at the Marshall Space Flight Center in Huntsville, Alabama;
- US Air Force, for a study " The Role of Air Power in Limited War and Counter-Insurgency, " terminated;
- **US** Air Force, in the tactical fire power area, operational;
- An application to advertising, by a US company, in the study stage in 1966.

The 3M Company (Minnesota Mining and Manufacturing Company in St. Paul, Minnesota), is seriously considering use of PATTERN.

It **has** been pointed out (lit. ref. ***94)*** that PATTERN might well fit in with another decision-oriented approach which is being pursued by General Dynamics at Fort Worth, Texas, in the field of space experimentation. The latter is described as " **a** system for measuring the compatibility **of** experiments with launch vehicles **...** (which) takes into account mission profile, other flight parameters, payload volume and location." However, a remark is added to the effect that this represents only " a rough cut at the problem."

Swager of the ***Battelle Memorial Institute*** in Columbus, Ohio *(lit.* ref. *179),* is in the process of setting up an " ***Objectives Network*** " for the petroleum industry based on the same relevance treee approach as was explained above for PATTERN. Its form is as follows:

LEVEL	NATURE OF ITEMS	EXAMPLE
I	General Objective	Air Pollution Control
II	Broad Alternative Methods	Develop petroleum technology to eliminate pollution-causing constituents
III	Processes and Methods	Develop processes to remove sulphur from high-sulphur crudes prior to major refining steps
IV	Performance and Cost	etc.
V	Development Alternatives	
VI	Applied Research Alternatives	

No quantitative technique has yet been developed for this objectives network. However, as Swager remarks, there are already considerable advantages to be gained from a qualitative structuring: " ... the continued detailing of conceivable alternatives at subsequent level forces considerations of alternatives at the very frontier of science ... the very preparation of it triggers ideas for new alternatives at nearly every level." In addition, there are the advantages gained from a clear view of the relationships between objectives on different levels.

Cetron (lit. ref. 104) has developed *PROFILE* (Programmed Functional Indices for Laboratory Evaluation) for the expected application by the **US** Navy. This can be characterised as a combination of a vertical relevance tree for the higher levels and a mixed horizontal/vertical evaluation at the task level based on a decision-theory approach. Based on the same philosophy as PATTERN, it seeks to arrive at a simpler calculational scheme.

A relevance tree developed for MEL, the Marine Engineering Laboratory, may serve to illustrate Cetron's approach:

LEVEL	NUMBER AND NATURE OF ITEMS	EXAMPLE			
A	1 Objective	War			
B	3 Types of Conflict	General War	Limited War	Cold War	
C	Forms of Activity (4 for Gen. War)	Strike Warfare	Antisubm. Warfare	Command Support	Operations Support
D	Missions (28 for General War)	Undersea Surveillance			
E	Tasks (unlimited)				

For each task an evaluation is undertaken in ten **task** contribution sectors, representing different horizontally and vertically acting factors (they will be enumerated below). A set of weight numbers is assigned to the ten task contributing sectors for each of the three types of conflict on level B—i.e., a total of 30 weight numbers are assigned:

	TASK CONTRIBUTION SECTORS	a) GENERAL WAR	b) LIMITED WAR	c) COLD WAR
1.	Value to Naval Warfare	q^a_1	q^b_1	q^c_1
2.	Task Responsiveness	q^a_2	q^b_2	q^c_2
3.	Timeliness	q^a_3	q^b_3	q^c_3
4.	Applicability to MEL Long-Range Plan	q^a_4	q^b_4	q^c_4
5.	Probability of Achieving Task Objective	q^a_5	q^b_5	q^c_5
6.	Technological Transfer	q^a_6	q^b_6	q^c_6
7.	Manpower	q^a_7	q^b_7	q^c_7
8.	Facilities	q^a_8	q^b_8	q^c_8
9.	Funding	q^a_9	q^b_9	q^c_9
10.	Intrinsic Value to MEL..	q^a_{10}	q^b_{10}	q^c_{10}

Norming condition is that

$$\sum_{i=1}^{10} q^a_i = 100; \qquad \sum_{i=1}^{10} q^b_i = 100; \qquad \sum_{i=1}^{10} q^c_i = 100 \tag{66}$$

The evaluation of task contributions is different for each of the 10 contribution sectors:

1. Value to Naval Warfare: Weighting Factors are assigned to the missions, with the norming condition that within one type of conflict (for example for the 28 missions which come under " General War ")

$$\sum_{j=1}^{28} \alpha_j = 100 \tag{67}$$

The forms of activity (level C) enter only in so far as a weight factor may be initially assigned to each of them and subsequently divided among the missions belonging to the given activity. These global weight numbers may be decided and updated centrally, while the split between the missions is left to the operator of the scheme.

The contribution of a task in this sector is then assessed by estimating significance numbers s^1_j for each of the 28 missions, thereby estimating the contribution of a task to each mission, and summing up to obtain the relevance number for this sector:

$$r_1 = \sum_{j=1}^{28} \alpha_j s^1_j \tag{68}$$

It can be seen that evaluation in this sector is analogous to evaluation in PATTERN.

2. Task Responsiveness: Weight numbers β are assigned to each field (where applicable) of a matrix of 10 aspects of task responsiveness (such as " Immediate Fleet Problem—ship inoperative ") by four project stages

(Research, Exploratory Development, Advanced Development, Systems Design and above). There is no norming condition. The relevance number for this sector is given by the weight number in the matrix field into which a given task fits:

$$r_2 = \beta \tag{69}$$

3. Timeliness: Weight numbers γ between 1 and 10 are assigned to five stages in the engineering and the exploratory development phase. Again, the relevance number in this sector is given by the weight number of the stage that applies to the task:

$$r_3 = \Upsilon \tag{70}$$

4. Applicability to MEL Long-Range Plan and Mission: A matrix is designed of 10 Long-Range Plan areas (such as " Deep Submergence ") by 15 MEL Functional Areas (such as " Fuel Cells "), and all fields for which a contribution of a given task can be seen are checked. The relevance number of this sector is then the number N of fields checked:

$$r_4 = \text{N} \tag{71}$$

5.-9. Weight numbers between 1 and 10 are assigned to alternatives described in words. The relevance numbers of these sectors are given by the weight number of the fitting alternative, in a manner analogous to the procedure for the third contribution sector (timeliness).

10. Intrinsic Value to MEL: Weight numbers δ between 1 and 2 are assigned to eight recognisable values. The relevance number is the sum of the weight numbers for the values that are enhanced by a given task:

$$r_{10} = \Sigma\delta \tag{72}$$

The total rating of a given task is then (for General War)

$$\text{R} = \sum_{i=1}^{10} q^{a}{}_{i} r_i \tag{73}$$

The " planning matrix " on the task level is seen to be similar to some of the horizontal and vertical decision matrices discussed in sections II.4.1. and II.4.2. The weight numbers assigned in the given example are not always convincing; for example, a technology transfer contribution " Supports one system " is rated 9, and a contribution " Supports two or more systems " is rated only 10. This is merely a matter of adjustment, however. The described model has been tested, reportedly with good results.

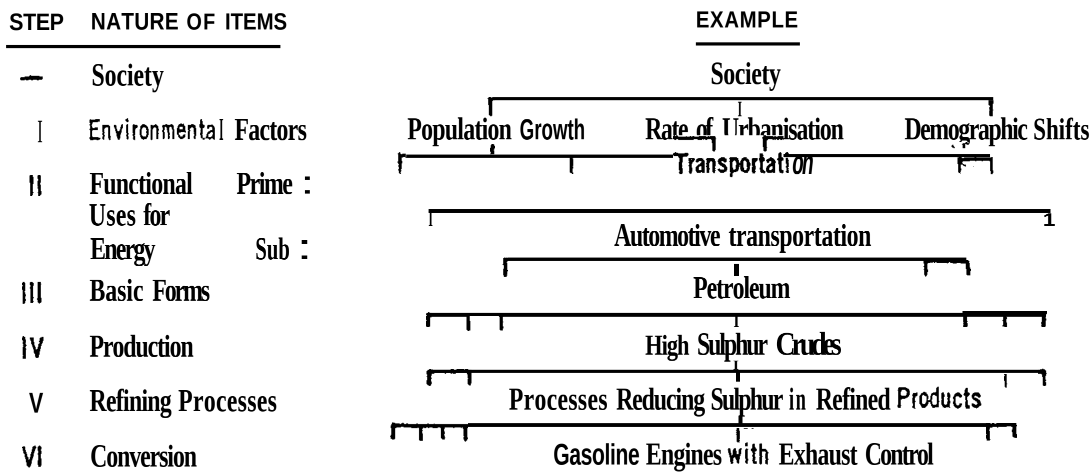
From the perspective of a more general critique of PROFILE, the arbitrary employment of various logics in the same system, and the mixture of a hierarchic relationship with horizontal and vertical partial decisions, may be considered dangerous because of the lack of transparency. The advantage gained is that of possessing an easy calculational scheme.

NASA, US National Aeronautics and Space Administration, in addition to using PATTERN for a problem area (see above), is experimenting with a scheme of its own which also Seems to make partial use of a relevance tree. The scheme is described as a mix between option theory, operations research, and decision theory, and helps to analyse the direction of technological progres and to indicate the areas in which research and development might be most fruitful. It contains an intuitive system (such as the assignment of weight numbers in some of the above-mentioned schemes) for which technical personnel are used. A greater role than originally intended will, apparently, be entrusted to the intuitive system due to encouraging results of a comparison between intuitive thinking and elaborate operations research analysis. The scheme as first set up, was " too detailed, " was gradually simplified, and by 1966 was " pretty acceptable. " At present, it comprises fewer levels than PATTERN; they correspond roughly to: Goals—Missions—Requirements—Problems, with provision for taking into account the numerous " communalities " at the requirements and the problems levels. NASA is not yet ready to publish details of its scheme.

Saint-Gobain in Paris, France, employs a non-numerical relevance tree to examine the alternatives for new production processes.

Finally, ***Zwicky (lit. ref. 190)*** is well aware that his exploratory morphological method (see section 11.3.7.) calls for a complementary normative forecasting method to select from the opportunities. He is working on a scheme which is based on the " theory of marks " and promises to discuss it in a forthcoming book on the " Morphology of Truth. "

Swager (lit. ref. 179) also points out the usefulness of ***a*** horizontal ***relevance tree*** concept for forecasting structural changes due to horizontal technology transfer. His qualitative ***Graphic Model Relating Possible Changes in Petroleum Technology and Changes in the Environment of Energy Utilization*** could, in principle, also be used as a tool of exploratory forecasting, but is nevertheless chiefly normative in character, as the examples show:



Essentially, this model consists of something like a horizontal relevance tree. No quantitative procedure has yet been designed for it, but Swager remarks that " when the same issues are considered in relationship to a specific company the quantitative boundaries of the qualitative terms firm up. "

'The horizontal relevance tree may not be as easily adaptable to quantitative evaluation as the vertical one, because it is not explicitly linked to desirable objectives. **Is** any one **of** the environmental factors, listed above—-population growth. rate **of** urbanisation, demographic shifts—desirable? They are simply measures of changes on the largest scale.

However, as has been noted by Swager and by Cheaney and McCrory *(lit. ref. 105),* likewise of the Battelle Memorial Institute, such horizontal- and to a certain degree vertical-relevance trees constitute a good framework for ·· critical path " approaches for identifying necessary research and development activities and for evaluating alternative paths. These aspects will be briefly discussed in the following section, II.4.6.

A few remarks concerning the ***input*** to relevance tree schemes in general may be useful. Three types of input data are generally needed:

Identification of objectives, systems concepts and requirements, and technological opportunities at various levels ranging from components and functional sub-systems to complex functional systems.

Criteria for the assessment of values at each level of the relevance tree and numerical weights for these criteria.

Numerical significance estimates of items (policies, technological systems, etc.) in relation to the criteria, for each level of the relevance tree.

The sources which, for example, Honeywell uses at present for this input, are: a technology forecast, using qualitative and simple quantitative (trend and envelope curve extrapolation) types of assessment, for the technological parts of the first and third points, a scenario for the non-technological part of the first point and for the second point; military planning documents for the identification of concepts; expert consensus (or average) for the numerical estimates of the third point.

It seems quite feasible for input under the first point to be put on a much better and more comprehensive basis through a morphological approach (see section 11.3.7.) which could, to some extent, be handled in an integrated computer programme for updating and extending the relevance tree. The man-made technology forecast would then concentrate on the recognition and formulation of suitable basic parameters and their interrelationships. The backbone of such a morphological presentation of opportunities could be prepared centrally, especially for well-defined areas such as defence and space. Screening of the " morphological box ·· for feasible items, or for a selection of items considered feasible within a given time-frame, could also be performed centrally.

At least the items on the top levels of the relevance tree (for example, on the Honeywell tree levels **A** to C, i.e. down to the 64 missions, or levels **A** to D, down to the 204 tasks corresponding to complex concepts), should be provided centrally if national interests are at stake. For a company to have to recognise mission for national defense and space activities is not a desirable state of affairs. **A** loss of information is unavoidable if thinking at highest government levels is simulated by an outside group, even if it happens to be located next door **(PATTERN** designers actually have windows facing the White House).

This is even more true **of** the input under the second point (criteria and weights), as far as higher levels are concerned. It should not be left to a company to recognise, predict (!) and weight criteria that are supposed to be equally relevant to all developments within sets of broad national **and** social objectives.

If decision-making techniques on the basis of a common principle—for which the relevance tree commends itself as the best approach known *so* far—becomes more widespread, it is to be hoped that a central agency of the type asked for by **US** Vice President Hubert Humphrey (a Presidential Advisory Staff on Scientific Information Management) may be able to furnish periodically updated " head-ends " of relevance trees, possibly for various time-frames. The branch agencies, companies, etc., would then complete the relevance tree on the lower, technological levels and could introduce refinements and modifications or even deviations from the relevance tree technique on these levels.

One of the major advantages accruing from the use of common " head-ends " would be a more homogeneous—and, within limits, a comparable—output in technological forecasting. Another advantage would be the enforcement of clearer and more explicit long-range planning of governing policies—which would have to be pursued as consistently as possible, with major changes only in emergency cases. It appears that a number of government agencies, especially in the United States, but also in France, are gradually moving towards such a pattern of long-range planning in areas of high national and social interest.

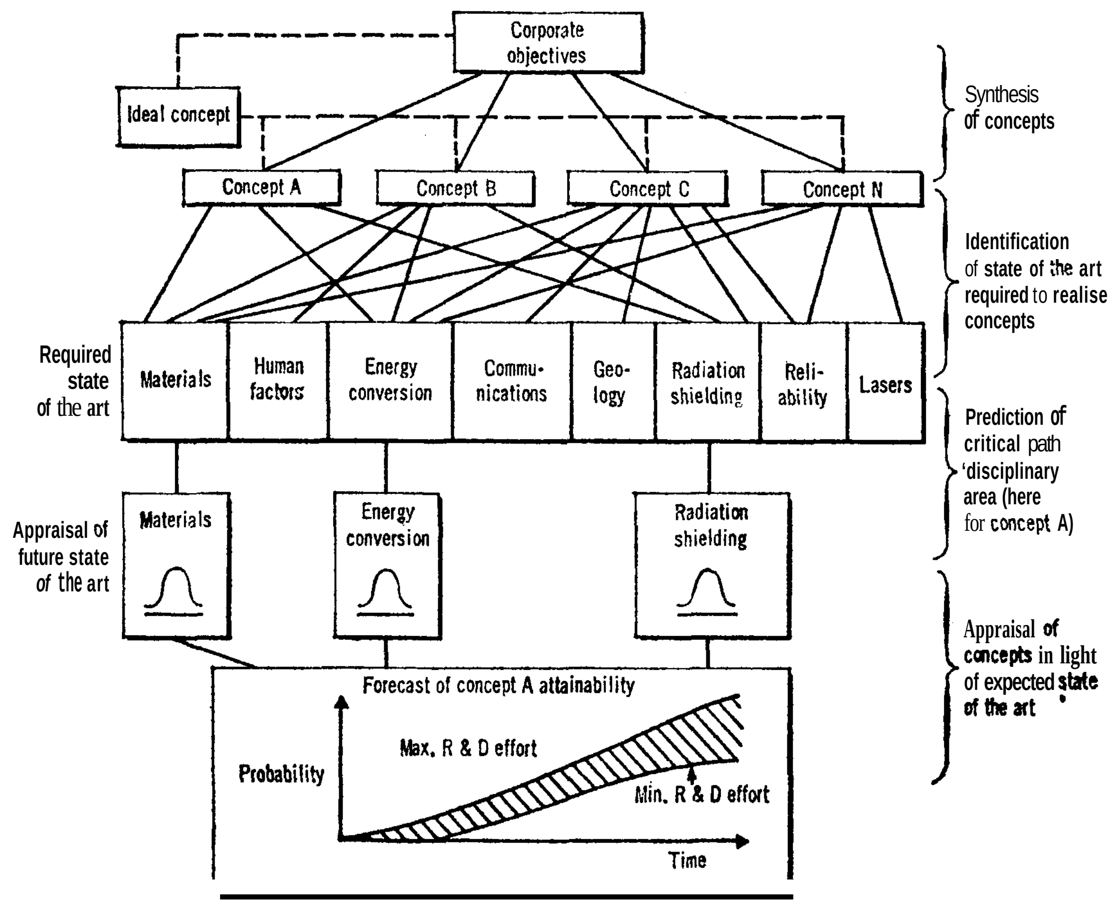
11.4.6. SOME APPLICATIONS OF NETWORK TECHNIQUES

The use **of** network techniques, especially CPM (Critical Path Method) and PERT (Program Evaluation and Review Technique), has become a valuable management tool for the control of complex system design and production **tasks.** ***CPM*** is based on " flow charts " showing the different steps of all branches of the project and on their analysis in order to select an optimum " path " between the first and the last stages, where the criterion for an optimum may be lowest cost, shortest time, etc. ***PERT,*** developed for the Polaris missile programme, is a probabilistic approach characterised by an analysis of uncertain input data and input relationships (for example, uncertain time of completion of a sub-system) and the calculation, usually by computers, of the probabilities of time (or time and cost) factors in the entire project. Both techniques evaluate alternative ways and help to discover " critical " factors.

As Ayres *(lit.* ***ref.*** *89)* remarks, " systems studies of this kind are, in a specialised sense, forecasts which are partially self-fulfilling. Having discovered by analysis the method of minimising completion time, management is automatically in a better position to achieve that minimum**...** The designing of a large expensive system generally cannot be optimised with respect to a single ' model ' of its future environment, but must take into account a number of plausible alternatives. The system design, in turn, helps to determine the direction of technological progress (again we have a form of self-fulfilling prophecy). "

Here again, technological forecasting becomes submerged in the technological planning process in general.

In the framework of the *Battelle* Memorial *Institute's* " Design Method " *(lit. ref. 214)* McCrory *(lit. ref. 105)* proposes a ***strategy for concept-oriented forecasting*** based on a Critical Path Method approach. McCrory's example of a typical flow chart illustrates his ideas:



The chart is almost self-explanatory: starting from a corporate objective, and keeping an " ideal " concept in mind, alternative concepts **A ... N** are postulated and relevant disciplinary areas are identified. The state of the art which is required in these areas to realise a concept is assessed, and time-dependent probability distributions for the attainment of the state of the art are estimated. Finally. these state-of-the-art probability distributions are combined into a forecast of a specific concept attainability in terms of a probability range over time.

An important part of this approach is the identification of critical paths (disciplinary areas, functional sub-systems, etc.). For this task, McCrory proposes a relevance tree approach ranging from the corporate objective through alternative concepts down to sub-systems and their predominant parameters—at which point an intuitive morphological approach takes over to identify alternative sets of parameters that form alternative sub-systems. McCrory does not propose a formal technique for this part. Finally, for the combination of probabilistic assessments of future states of the art to derive a probabilistic statement about the attainability of a specific concept, McCrory has developed a technique using a propagation of variance approach that has been outlined in section 11.3.9.

Swager, of the Battelle Memorial Institute, explores both vertical and horizontal relevance trees (*see* section 11.4.5. above) for a possible application of critical path methods.

Network planning techniques with considerable forecasting implications seem to play an important role in ***General Electric's*** Atomic Power Department in San José, California. Project " Sunrise, " set up in 1958 by Cohen and Zebroski as a development programme incorporating alternative ways of achieving an economic breakthrough of Boiling Water Reactors by 1965, led to the well-known striking success—at half the cost that would have to be risked for the more laborious " paths " which turned out to be unnecessary detours. " Sunrise " was a dynamic programme, making it possible at various stages to switch from one path to another when obstacles were encountered or when unexpected progress suggested a better path (for example, natural circulation was dropped when significant improvements in pumps became available—pumps permit higher reactor power). " Sunrise " was a descriptive approach which involved no routines but included a large catalogue of developments which might become available. The planning criterion was the minimum feasible outcome that would pay.

For General Electric's fast reactor development, which is expected to lead to an order for the first large-scale power prototype in 1969, a similar descriptive network programme was designed by Zebroski. Unlike " Sunrise, " which was aimed principally at answering the question, " What effort is required to produce a certain economic effect? " the fast reactor programme is primarily geared to such questions as " What development should be undertaken if the present fast reactor effort fails? " ($2 billion are committed to this effort up to 1975 in the world as a whole) and not so much with questions concerning plans in case of a breakthrough. This is due to the enormous and long-lasting impact-especially economic—which a breakthrough in this area is expected to have.

Abt Associates (US), in a model for the US Air Force, have incorporated PERT to discount the value of a weapon system in accordance with bottlenecks encountered on individual paths. Network techniques are reportedly also employed in connection with technological forecasting by Siemens & Halske, Munich (Germany).

This section on network techniques should, finally, take note of an article by *Rosenbloom (lit. ref. 173)* which discusses a possible application of *PERT* to the assessment of *cost/time trade-off* effects. No practical attempt seems to have been made as yet in this apparently promising direction.

11.4.7. OPERATIONAL MODELS

Gaming, already discussed in its exploratory aspects (section 11.3.11), becomes much simpler for processes that fit closed cycles. Normative forecasting is characteristic of more or less closed systems—which may nevertheless be far from the deterministic extreme of a fully closed cycle. Gaming for normative purposes, it may be expected, will be considered as important as, if not more important than, exploratory gaming.

An added feature of normative gaming is the possibility it provides of programming alternatives and human reactions that are feasible under constraints without requiring unreasonable information storage volumes.

Closed-cycle gaming is therefore much more amenable to computer simulation than is open gaming. The main advantage of closed-cycle gaming would be the possibility of fast runs. Manual gaming is a long and slow process, " the last thing one goes to " as the British Defence Operational Analysis Establishment in Byfleet, Surrey, affirms. According to their experience, the best time ratio between simulation and actual process that can be achieved is 4: 1. With preparations, etc., simulation of a two-day battle requires six weeks' work. In Byfleet, even closed gaming is usually performed manually, with a " control " person sitting in the middle, while in the United States a number of big computer programmes have been developed for military purposes.

Gaming is applied systematically by the aforementioned ***British Defence Operational Analysis Establishment*** (DOAE), to define desirable weapon ranges and decide between alternative weapon systems for the same mission (for example hovercraft—amphibious vehicles—helicopters, for unloading ships). These games are, to some extent, prepared by cost/effectiveness studies of weapon systems, although less rigorously than is usual in the US. A series of games is then played to decide between systems of equal effectiveness. If, for example, mobility is the mission and several weapon systems are equally effective in this respect, a game is played in which mobility is increased on one side: the outcome may be an indication that one weapon system is as effective as the " competitors " but requires smaller forces. Another question that might arise in the same context would be the desirability of supporting research development of an estimated size in order to obtain higher mobility. The important British decision, in January **1966,** to buy American **F-111** aircraft instead **of** developing British systems for the same set of missions was aided by gaming; the **F-111** was assessed to be twice as effective, but also twice as expensive as the British alternative, so that additional criteria were needed for a clear decision.

In the United States, gaming apparently plays an even more important role in military planning for the assessment of the relative merits of future weapon systems. Much of the sophistication in this area has been contributed by the RAND Corporation in Santa Monica, California. The rigorous cost/effectiveness approach of the McNamara administration provides quantifiable data in practically all areas of military interest. The fact that computerised games seem to play a certain role in these areas has already **been** mentioned.

Business games have been pioneered in the United States since the 'early **1950's** by such companies as General Electric and IBM as well as by management consulting firms. A number of games, such as the IBM Management Game and the AMA (American Management Association) Game ***(lrt. ref. 95)*** deal with investment possibilities in research and development and include simple programmed relationships simulating pay-off from these investments, thus making possible an attempted " optimisation " of the research and development budget. However, these decisions are made at an aggregated level. Business games seeking to decide between alternative technological possibilities—analogous to the weapon systems games—seem thus far to have been applied rarely if at all. The reason is easy to see: until recently general business horizons did not extend much farther than the aim of maximising profits and this could be pursued better by economic analysis and other simple methods. The existence of sets of missions and goals, which create criteria for unconventional cost/effectiveness relationships, is only now beginning, to some extent, to dominate business decisions in the United States.

Games are usually applied to complex situations that cannot be penetrated by other means. However, games may also become an effective approach to the stimulation of creative thinking:

Gordon and Helmer, the authors of the **RAND** report on the first large-scale testing of the " Delphi " method, have, in **1966,** prepared a " *Game of* the Future " *(lit. ref. 379),* following up an initiative by Kaiser Aluminium **(USA). A** number of leading American industrialists have received a list of **60** possible developments between **1966** and **1986.** These include, for example, electricity generation doubled, car traffic banned from urban centres, manned lunar basis, etc., and represent a mixture of technical, economic, political, and social issues that already provided the background **for** the " Delphi " test. The participants are formed into groups of two, three, or four. Each participant builds a " world of **1986** " using a combination of the 60 given possible developments, and tries to persuade the other participants in his group to " invest " in his programme. The winner is the participant who enlists the highest support for his " world ".

Great hopes are sometimes expressed for a future application **of** normative gaming to social issues (already being attempted in part, by the " Game of the Future "). General Electric's TEMPO Center has sounded a warning: all attempts at the Centre to simulate social situations have failed because stress cannot be simulated!

A particular advantage of gaming lies in the fact that it facilitates the determination of the important parameters and some empirical relationships of a given problem, so that models can be subsequently developed.

Rigid computer models for normative forecasting could benefit from *game* theory—not to be confused with gaming—developed by Von Neumann and Morgenstern ***(lit. ref.*** *164)* and providing a rigorous means of determining an optimum strategy in situations of conflict. It is a typical normative technique which has been applied by the RAND Corporation and others in the United States, to problems of military strategy, politics and reportedly to some social issues as well.

Game theory uses such elements as concepts of pure and mixed strategy, the role of chance events, matrix representation of pay-offs, etc. It yields not only simple optimum strategies such as maximisation of profit, but also optimised mixed strategies in circumstances where any single strategy would involve vulnerability to certain conceivable harmful eventualities; the result would then represent an optimum regardless of the tactics chosen by an opponent or, in general, regardless **of** other conceivable events. Game theory is of the greatest value where conservative strategies, which assume the worst conceivable or feasible counteraction, are sought. **A** disadvantage of game theory is that it cannot handle very complex problems.

Game theory does not yet appear to have been applied to technological normative forecasting, although apparently very suitable to it.

A number **of** normative business models **of** a more conventional type are in **use,** primarily in the United States; they mainly combine horizontal (market) factors for the decision evaluation. One example is the ***Demon*** model of the big advertising firm *BBDO*, (Batten, Barton, Durstine, and Osborn in Buffalo, New York) for new consumer products. It is described as a mapping of optimised decision networks exposed to evaluation going beyond linear programming formulation. Input includes corporate goals, cash-flow, investment ceilings, etc., and all constraints on the deployment of funds. Typical answers are: go ahead nationally; don't go; move on to another mode in the decision network. Successions of decision points permit switching between different modes.

The ***3M Company*** (Minnesota Mining and Manufacturing Company in St. Paul, Minnesota) took " Demon " as a basis for its own " ***New Products Model*** " which was in experimental use in **1966.** An attempt is being made to put it in a more industrial frame, so that it may deal with other than consumer products. Finally, an econometric type of model is expected to emerge from it which could be applied to decisions concerning new products in various national regions or in different countries, (e.g. where to build up sales of a given product, and where not to); this stage is still in the future, however.

Wereas these business models are horizontally oriented, military environments seem more prone to promote vertical models.

Rea at Abt Associates is at present developing a model for the ***US Air Force Systems Command*** which is described as follows ***(lit. ref. 84):***

> " This decision model will assist Air Force long-range planners to select those weapon and support systems which should be given increased emphasis for future development. The results expected from its use include further study of the most promising systems, new programmes to overcome technical problems standing in the way of future development decisions, or action toward acquisition. The model will permit comprehensive examination of the many factors that must be considered in this decision process such as national military policy objectives, military functions, technological feasibility, costs, and resources expected to be available in the future. Mathematical algorithms are used to relate systems performance to objectives, and optimisation techniques are used for the allocation of resources by fiscal year over an extended time period to competing system concepts. The planner is able to ' converse ' directly with the use of a remote console operating a computer in a time sharing fashion. The model has a hierarchical structure, and therefore can be used to assist with any resource allocation problem in either government or industry where program costs and expected values to the objectives of the organisation can reasonably be estimated. "

An older proposal for the US Air Force by *Thomas and McCrory* of the Battelle Memorial Institute in Columbus, Ohio, *(lit. ref. 181,* mentioned in ***lit. ref. 101),*** ontlined a model for the evaluation of several alternative weapon concepts and of the probability of their development within a certain time span. The decision space can be represented by a suitable electrical analog. It is not known whether this model—one of the first concrete ones to have been proposed—has been applied to practical problems.

Two normative computer models are at present under development for the US Army:

B. Deun, of the Case Institute of Technology in Cleveland, Ohio, is developing an ambitious model for the priority ranking of research and development projects, and

the *Cornell Aeronautical Institute* is attempting to build an "LRTP Mathematical Model" (lit. ref. 109) which is based on the evaluation of converging curves.

They are not at present being considered for use.

11.4.8. SYSTEMS ANALYSIS

Systems analysis was first developed by the RAND Corporation in 1948 to optimise complex problems of military management. It is easy to see that even relatively small numbers of variables, each attaining a few alternative values, lead to problems of unmanageable size[1]. Systems analysis reduces the problem, without substantial deviation from the rigorous concept, by such means as: mathematical shortcuts to reduce the sequential analysis of all possible combinations, e.g. by linear and quadratic programming and other techniques of operations research; assessment of the sensitivity of the problems to parameters and dropping of unimportant variables; aggregation of variables into composite factors; formulation of optimisation criteria in a suitable form. While systems analysis is without doubt primarily an art, it is an art which requires special mathematical skill as well. More recently, the term "total systems analysis" has also been applied to evaluations employing a mixture of qualitative and quantitative methods, both at a high level of sophistication.

Systems analysis is primarily the domain of "think groups" such as the RAND Corporation and System Development Corporation, both in Santa Monica, California, and General Electric's TEMPO Center for Advanced Studies in Santa Barbara, California. It has been said, moreover, that Europe has not yet developed the proper attitude for acquiring similar skill, that emphasis on the optimisation of partial problems—the typical approach of operations research—tends to obscure the view of the total system. It may be added, from the standpoint of technological forecasting, that normative thinking and "total systems" viewing can be expected to grow on the same terrain. In metaphorical terms, one may also call to mind McLuhan's (lit. ref. 374) age of "implosion that now follows or succeeds the centuries of explosion and increasing specialism."

In the TEMPO programme, applications to technological problems in the military area are concerned, for example, with: continental defense and strategic warfare, involving mathematical models of weapon systems in future environments (reducing the risk of later cancellation); cost of total weapon systems, including optimisation of maintenance and logistics (for example logistics of spare parts) over the whole expected life of the system. The RAND Corporation handles numerous systems analysis problems involving weapon systems.

In the business area, TEMPO has recently developed models for General Electric's utility business, optimum deployment of personnel, and

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1. n variables, with k alternatives each, yield k^n combinations.

long-range business strategy in general. Military strategical techniques can be readily applied to business strategies—the sequence of steps has been found to be practically identical.

In areas of civilian technological forecasting, a typical " complete systems study " by TEMPO embraces market (demand) factors, supply alternatives, and cost/effectiveness analyses. The entire array of variables **for a** broad problem, not all of which will normally be quantifiable, is first identified. Variables belonging to the behavioural sciences are coming more and more into play (even for military evaluations, where the Peace Corps may be treated as an alternative to weapons). Sub-optimisation can be carried out to some extent, but satisfactory methods for dealing with the system as a whole are still lacking. A prominent study recently conducted on this basis concerned potentials for nuclear merchant shipping in the period 1965-1985. Five alternative basic technologies were evaluated, and the results were modified by non-economic factors derived from qualitative evaluation of social and political environments. The result was given in the form of the time-dependent number of nuclear ships of each class (bulk carrier, tanker, freighter, etc.). Other " complete systems studies " by TEMPO have included: commercial communication satellites, North American water and power requirements, the gold industry in the United States. Tentative studies are being carried out for the " city of the future " (the city as a communication network, etc.).

The RAND Corporation, apart from numerous studies in the military technological areas, has applied systems analysis to such problems as the planning of future urban environments and the transportation of the future (land transportation vehicles of the 1990's, etc.).

The ***System Development Corporation*** (SDC) pioneers systems analysis in the social fields, especially in advanced educational planning.

It is difficult to draw a sharp dividing line between the technique of systems analysis and other approaches which seek to examine complex systems. The approaches taken by General Electric's Atomic Power Department, by some of the big oil companies (in Europe as well as in America), or by some of the aerospace giants such as North American Aviation's Los Angeles Division, sometimes seem to be close to the systems analysis technique. At the same time, Lundberg's warnings against an untimely introduction of supersonic transport ***(lit. ref. 323, 324)*** represent a partly quantitative, partly qualitative systems analysis which modified the results achieved from scrutinising the technico-economic system of supersonic transport.

The Stanford Research Institute in Menlo Park, California, **is** trying to apply systems analysis to the interactions between science, technology, and society, in a multi-disciplinary approach.

Systems analysis will be organically incorporated into future systems **of** information technology, at least to the extent that such systems provide **a** data pattern for it.

Chapter 11.5

FEEDBACK TECHNIQUES

Today the future tends always to be viewed, hence methodologically approached, as if it were the mere extension of the present. Thus, we wander in static time.

Hasan OZBEKHAN.

11.5.1. TENTATIVE IDEAS

Feedback systems (or " cybernetic models ") constitute the ultimate idea behind all of the more elaborate forecasting techniques. No full-scale technique 'has yet become operational in the technological forecasting area. But the need is felt with particular urgency in view of the fact that the normative direction of forecasting has moved to the centre of attention. Moreover, in their essentials, the elements and partial techniques applicable to feedback systems are now available.

Zebroski, of General Electric's Atomic Power Department, formulates the fundamental problem as consisting of the need which the process of basic learning has for a feedback from actual developments. " The transition is poor in most societies and is often left to the entrepreneur. " Zebroski is trying to develop suitable feedback techniques for the industrial environment of General Electric.

It is obvious that the total systems approach will be enhanced by feedback techniques.

Feedback will have to be studied much more closely in future. The more effectively progress is planned—and one may expect improvements from technological forecasting in general, and considerable " straightening out " from normative forecasting in particular—the more pronounced will be the feedback effect. **As** has already been pointed out in connection with the role of time and historical inertia (Chapter I.3), the pace of progress is probably sufficiently sensitive to feedback from planning to be capable of undergoing marked change.

*Abt **Associates*** already use a feedback technique in their models for reducing the " noise level " of expert judgment by iteration (see Section 11.3.11). Strictly speaking, all iterative systems are feedback systems (see also section 11.3.6.).

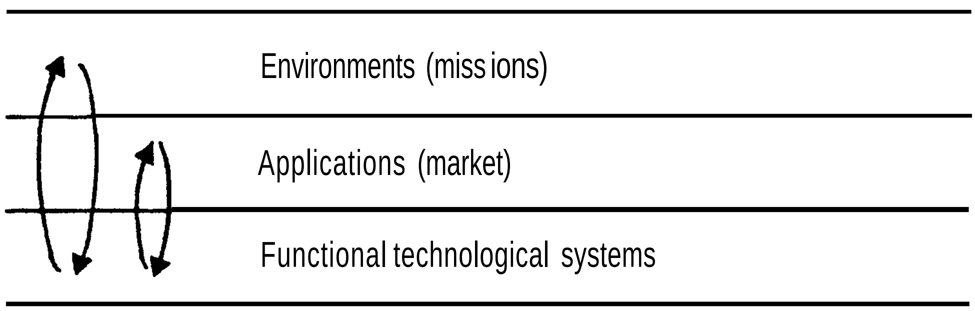
Lenz's proposed model for the progress of technology in general *(lit. ref. 151),* mentioned in section 11.3.11, conceivably could also be programmed for feedback cycles between education and research output, etc., but is hardly useful for any practical purpose.

On a specifically technological level, Cheaney and McCrory, as well as Swager of the Battelle Memorial Institute *(lit. ref. 105, 179)* develop their ideas for partial techniques, which have been discussed in several **of** the preceding sections, in such a way that they may be subsequently fitted together to form feedback models. Battelle's " Design Method " approach *(Zit. ref.* ***214)*** to planning—into which the forecasting techniques are supposed to fit—incorporates some feedback loops: e.g. as between the design feasibility stage and the state of the art; between the production and marketing stage, via market acceptance, and the recognition of need; or between the production and marketing stages, via technical acceptance, and the state of the art. This at present constitutes **a** framework for thinking, but is intended to be developed further into a fully-integrated system in which technological forecasting would be included in quantitative feedback loops.

Zwicky attempts a feedback system by mating his exploratory morphological approach with a normative technique based on the theory of marks.

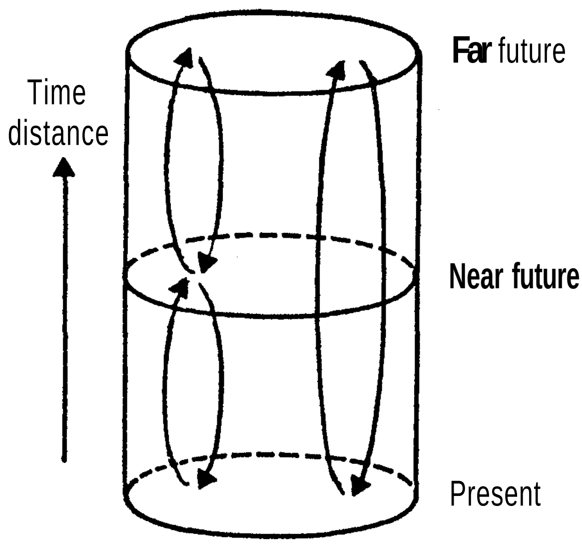
One may distinguish between ***two*** basic types of feedback models:

1. Models with feedback loops between different levels or extensions of technology transfer, e.g. between the different stages of a technological development and its impact. An anticipated tech-



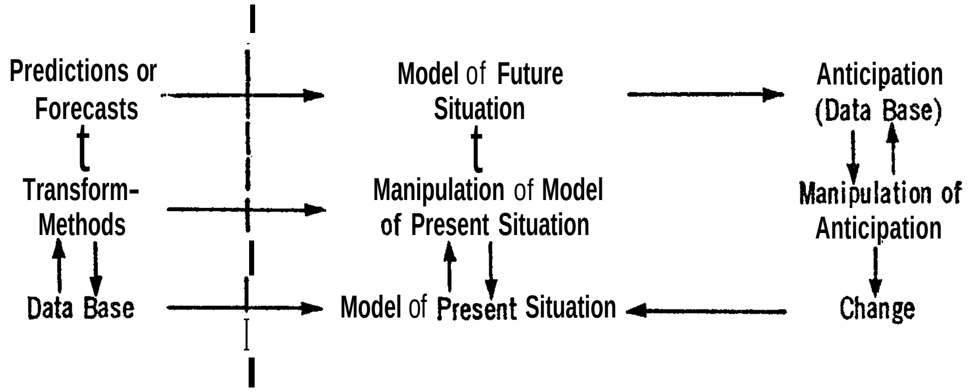
nological system for a given mission may, for instance, after careful evaluation or some research, turn out somewhat differently and in its turn, modify the mission, or an unfavourable market forecast for an anticipated product may act to modify the product concept.

Models with feedback loops between different " time-cuts, " i.e. between situations (complete scenarios) expected at different time distances; the simplest feedback would be that between a future scenario and the present.



Whereas the first type of feedback model is characteristic of the needs of technological planning (the tentative ideas mentioned above belong to this type), the value of the second type is stressed for broad social planning, or large-scale -- social technology -- ranging up to the planning of an entire future world.

Ozbekhan, of the System Development Corporation *(lit.* ref. *165),* recently outlined a framework for a feedback model for " social technology, " which is based on the second type but permits the inclusion of feedback loops of the first type. Ozbekhan's basic scheme looks like this (turned by 90 degrees to adapt it to the upward time direction adopted in this report):



The left-hand column represents, for our problem, the technology transfer space. " Transform-Methods " comprise the techniques of technological forecasting. The middle column represents the pattern emerging from the totality of actual or forecast developments (with an assumed high degree of probability); a model of the future would then be the most probable projection we are capable of making of a future situation. The right-hand column, finally, represents " alternative world futures, " to use the terminology of Herman Kahn, or " futuribles, " to employ that of Bertrand de Jouvenel—in short, " intellectively constructed models of possible futures -- that describe not only what will be but also what can be and what should be.

As Ozbekhan points out,

> " The important point in the structuring of anticipations is that they must result in the creation of a data base and even of a model bank upon which one can draw to specify possible futures. Policy, strategy, and proramme decisions depend upon concepts of the future that are based, not simply upon extrapolation of past trends, but upon ideas of dynamics, the relations among influences, which when sufficiently understood, are expressed in terms of models, theories or formulas. And the data and model banks that go with fully developed anticipations can be made to contain these elements in cumulative sufficiency if not profusion. "

The significance of the feedback loops in the above scheme is evident. The most important feature is the feedback between anticipations (" possible futures ") and forecasting and planning for an actual future. A few comments by Ozbekhan may serve to elucidate this point further:

> " As can be seen, it is possible to conceive of twin data bases. one describing the present and the other being an anticipation, and with essentially the same transform-methods exercise and manipulate both of them. The application of transform-methods to the present situation will yield a scheme of consequences which permit one to judge, in the light of a given current situation, the problems inhering in the development of particular programmes. These consequences represent the description of a future situation derived from certain present constraints.
>
> On the other hand, one can construct an anticipation and develop a data base for it and manipulate it backwards, so to speak, to see how the preferred future situation which the anticipation represents can be made to suggest the changes which the present situation must undergo to conform to it. Here again, the important point to remember is that a planning system thus expanded permits the introduction of objectives and policy-goals as part of the anticipation and these become operational elements in defining the changes that are needed in the present--in suggesting the sets of policies that need to be applied, the inter-related and interactive programmes that need to be pursued if the anticipated preferred future is to be translated into current reality.
>
> Thus, we reach the essence of what I have called futures-creative planning which is a mode of planning that uses the future as an operational means to effect changes in the present, and through such changes brings the conceived future into being. "

In this framework, which represents the ultima ratio of a feedback model for forecasting, the decisive difficulty lies in the fact that normative forecasting, involving the whole task of identifying and valuing future goals. becomes multi-dimensional. This increases the inherent dangers and pitfalls of applying values like " good " or " bad " on the basis of a limited consensus, or insufficient knowledge. Normative forecasting, as a systematic approach, is a new dicsipline in itself—it is exposed to such extension before it has even had time to develop solid one-dimensional concepts.

This difficulty has to be surmounted because, as Ozbekhan says:

> " The projection of today's values and today's standards upon tomorrow is again one of the ways of extending the present and thereby defecting the very purpose of futures-creative planning ... If we truly visualise futures that are different, we must visualise them insofar as possible in terms of value systems that are also different and consequently of institutional patterns that are different. To be able to do this, there can be no doubt that the structuring of anticipated value systems, that is, the foreseeing of the different modalities of good and bad within future contexts must of itself represent a major part of the work involved in futures-creative planning. "

As an example in the technological area, Ozbekhan mentions the changes in the meaning of production effected by technological advances " in ways so deep and significant as to make it highly probable that within the span of some years it will be difficult to rationalise in the traditional manner the relationship between individual work and individual income.

In other words, the automation of production is creating a wholly new situation.. " The broad solutions could be of a drastically different nature:

Anticipated value	*Conclusion*
1. Automated technologies are bad.	1. Artificially maintain some levels of scarcity to distribute income according to an old value formula.
2. Automated technologies are good.	2. Define and describe some compensating values to counterbalance their disruptive effect.

It is this problem of future values that has prompted Qzbekhan to promote the idea of " look-out " institutions (*see* chapter 1.7.). In this context, ***McLuhan's*** ideas ***(see*** section **11.2.5.)** can be expected to become most fruitful.

The implementation of elaborate feedback systems in the framework of Ozbekhan's proposal calls for developments in information technology which. according to the leaders in this field, are well under way. Cybernetic forecasting models are reportedly being prepared at present by Russian economists and mathematicians for application to the Soviet economy.

11.5.2. TECHNOLOGICAL FORECASTING AND THE EVOLUTION OF INFORMATION TECHNOLOGY

To some extent, technological forecasting does not have to await the advent of new or bigger types of computers or highly sophisticated software the need for which places the implementation of integrated information technology systems in some areas a few years further into the future. If an integrated technological forecasting system on this basis is still not an imminent prospect, this is largely due to the fact that this branch of information technology has not yet received very much attention and will probably be led by " precursive events " in the general military and business management areas, much as " manual " technological forecasting has been led by the precursive establishment of corporate long-range planning functions.

Of all the companies, consulting firms and institutes concerned with the development of information technology, the ***System Development Corporation*** in Santa Monica, California, may be the only organisation actively engaged in studies dealing with the marriage between technological forecasting and information technology. The incentives have become clear from the preceding section.

The principal objective of technological forecasting in this context is **not** to extend and combine forecasting techniques that are amenable to handling by computers, but to place them in a wider framework, for example, comprehensive management information systems, and to extend the possibilities of interaction with the latter. The concept of technological forecasting as construed in this report includes manifold horizontal relationships between technological factors and between technological and non-technological factors on all levels of technology transfer. These relationships, which may be viewed in frameworks of different sizes up to Ozbekhan's feedback model described in the preceding section, can be included in comprehensive information systems. The relationships for vertical forecasts would probably present the easier problem in such a system.

A technological forecasting function within a fully-integrated management information system may include some or all of the following features:

1. Automatic selection and updating of information (technological and non-technological, such as market factors), taken from the entire "information pool" represented by the system;
2. Automatic trend fitting, evaluation, and extrapolation, and other types of evaluation of past experience, with the possible derivation of composite empirical patterns where feasible;
3. Automatic evaluation and extrapolation of contextual maps, of both a technological (parameter configurations, etc.) and a non-technological nature; continuous matching of anticipated contexts against changing reality and "triggering" decisions where convergence is found;
4. Morphological research to state and screen all possible, and perhaps also all feasible, configurations;
5. Cost/benefit and cost/effectiveness analyses of all kinds, updating and matching them against changing environmental information;
6. Continuous monitoring of given sets of goals (corporate objectives, strategies, tactics) for possible changes that may become apparent through company contexts—internal or external;
7. Updating of weight and relevance numbers in the case of overriding changes occurring in other parts of the system, or of centrally introduced changes;
8. Ranking of technological projects according to possible variable optimisation criteria and information represented by the entire system or influenced by other parts of the system (for example, variable policies for funding research projects, depending on obtainable funds, etc.);
9. Feedback effects on many technological levels, "learning curves," etc;
10. Possibly the formulation of strategies in relatively simple cases.

Even such a comprehensive information system would not in the least eliminate human judgment in technological areas, but would rather enhance its importance and its quality by providing a much broader basis for decision-making and a much more systematic multi-dimensional evaluation than could be achieved otherwise. The procedure would still be essentially a "man-machine dialogue" and the result could still be qualified as "informed judgment"—the point is that it would be better-informed judgment.

The technological forecasting sector does not need the more complex real-time evaluation required for other sectors in an efficient information system. This facilitates the technical problems and improves the economic side considerably.

Some of the partial techniques needed for the accomplishment of the desired functions, as outlined above, are readily available. This is certainly true for the first point, where techniques of the required types are already in use or are feasible with today's technology. M. Adelson of System Development Corporation, in a paper on " The Future of Planning " (partly discussed in lit. ref. *165),* advances the idea of data banks:

> " Such banks corresponding in some illustrative sense to libraries of books and periodicals might represent repositories of information organised in terms of entire fields and conceptual models. It is possible today to develop, store. retrieve, and use data bases in diverse areas such as manpower expenditure, manpower allocation, and similar variables associated with both military and non-military system developments; unemployment, demographic information, education, crime rates, traffic patterns, community growth patterns and arrangements, productivity, training, etc. There is the possibility, of course, of developing entire models, that is, specific theories to be used in relationship with each other in such banks and these could be so arranged as to be oriented to the answering of policy and other questions for a variety of users. The development of such automatised data bases and theory as well as model banks can obviously provide the planner with a wealth of manipulable information both as to facts and inter-relationships and cross-impact patterns which have not been available until recently. "

As to the second point, Dennis Gabor *(lit.* ref. 378) described a feasible " Prediction Box " as far back as 1960. This is a special type of simple computer that evaluates trends by taking past samples at Nyqvist intervals (half of the available frequency band width) and predicts the trend on the basis of the usual least-mean-square-error criterion. This criterion also has the desirable property of leading to a steady improvement of the predictor from run to run. " It must be admitted, " Gabor says proudly, " that such a machine has some claim to be called intelligent. There is many a game in which it can beat humans, for the simplest reason that it has not only unlimited patience and a precise, quantitative memory, but also because it is free from illusions. "

It was also noted earlier *(see* section 11.3.6.) that General Electric's TEMPO Center operates a computer model which, essentially, performs functions outlined under point 4: morphological research, and feasible future systems emerging from interactions in that framework.

Point 5, cost/effectiveness, is obviously a field in which considerable sophistication has already been reached for computer applications up to the refinements of systems analysis.

Similarly, the other points also appear perfectly feasible from the standpoint of today's state of the art. Graphic information processing (curves, network schemes, etc.), of potential importance in technological forecasting, is well under way and has been partly realised. The remaining problem is one of *size* and of integration with other functions of information technology systems.

As technological planning moves increasingly into types of environment and society that represent " closed " forms, the performance of technological forecasting functions in such large systems will improve. This is also true for information technology systems dealing with the great issues of society, such as those to be developed for the futures-creative feedback model outlined in the preceding section; the evaluating of discrete alternatives would be required.

The future may show, however, that heuristic (goal-oriented) machines will gradually take over some of the evaluations and decisions that have been man's exclusive domain so far. The Diebold Group (US) foresees the advent of heuristic machines 10 years from now, with first applications in scientific areas.

Part III

THE ORGANISATION OF TECHNOLOGICAL FORECASTING

FORECASTING INSTITUTES AND CONSULTING FIRMS

See also Annex A.1 for a description of technological forecasting activities by such organisations identified in 17 places.

> *Through prolonged close contact and friction with the objects of their study, the minds of experts finally acquire a pictoral, mothlike, fiddling perfection.*
>
> Laurence STERNE.

The role of forecasting institutes (or rather of forecasting functions in research institutes) has been very important in the initial phase of the widespread introduction of technological forecasting in industry. The Stanford Research Institute, which started its Long Range Planning Service back in 1958, has probably done more for the recognition of the potentialities of such forecasting than has any other successful forecasting service[1]. Almost everyone in the US industrial environment has heard of the report series made available by the Stanford Research Institute and Arthur D. Little. This is not so in Europe, where even many companies which take an interest in technological forecasts have not yet heard of these subscription series.

All the major regular technological forecasting offered is part of a " package " which includes subscription to report series as well as other services (see Annex A.l.). This, in turn, is one of the corporate planning and management consulting services offered by the institutes and consulting firms. With the exception of the Stanford Research Institute, there are no distinguishable " forecasting groups, " the forecasting function being regarded as an integral part of the management services performed by the institute or firm. None of the institutes acts merely as a publishing house in this area. Of the three big American research institutes which lead in technological forecasting—Battelle Memorial Institute, Arthur D. Little, and Stanford Research Institute—only the latter two publish report series.

The services offered by institutes and consulting firms have addressed themselves so far mostly to ***medium- and large-sized industry.*** The four most ambitious service " packages " have not yet had widespread diffusion beyond

1. A **number of recent Czech publications show that the notion of technological forecasting has been introduced into current thinking behind the Iron Curtain, mainly through the interest aroused by knowledge of the ambitious Stanford Research Institute effort in this field. However, no subscription requests have yet been received from Iron Curtain countries by the major U.S. forecasting institutes.**

the " upper strata ", a fact for which the relatively high participation fee may be partly responsible:

	ANNUAL PARTI-	NUMBER OF PARTICIPANTS	
			SHARE
			~ 40
	5,000	> 100	~ 10?
	10,000–50,000	~ 50	
	4,000	[illegible]	[illegible]

Industrial investment in these ambitious " package " services may be readily calculated at approximately $ 4 million per year. And numerous *ad hoc* studies with considerable technological forecasting content are performed for industry every year by institutes and consulting firms—at an average cost of $20,000 each—accounting for an additional $ 10-12 million.

The ***total investment of industry in technological forecasting performed by special institutes and consulting firms*** can thus be conservatively estimated at about ***$15 million per year*** at the present time—with the United States and Canada accounting for nine tenths and Europe for one tenth. There are, of course, additional investments in all types of economic forecasting, which may include some aspects of technological forecasting (such as the " National Economic Projections " of the National Planning Association subscribed to by a large number of companies).

The principal incentives that lead medium- and large-sized industry to subscribe to these " packages " are two-fold. The forecasts:

- are based on comprehensive input information in all technical areas (A.D. Little and Stanford); the Stanford reports go still further and represent interdisciplinary research in broad future political, social, and economic, technological environments with a focus on the consequences for technologically oriented users;
- represent the " average " expectation against which progressive companies like ,to check their own above-average expectations and the feasibility of moving ahead through an aggressive strategy.

There is no doubt that most of the subscribers to the "package" services perform their own in-house technological forecasting. The input from outside the company is generally considered to be of value in the context of this in-house forecasting activity: horizons are widened, the more general aspects, such as the social and the aggregative economic, are added, and valuable suggestions for application and service engineering—i.e. horizontal technology transfer—can be acquired in certain branches (e.g. the instrument sector, which is obliged to follow possible applications in practically all industrial sectors—the value of the Stanford reports in this connection is confirmed for instance by Hewlett-Packard).

Judgments regarding the accuracy of the forecasts vary considerably, but they are generally of a positive character.

One criticism is frequently encountered, however. It concerns the **omission** of background material and analytical reasoning (the " logical story ") from forecast reports. The institutes and consulting firms believe, in general, that forecasts are services to vice-presidents, and that vice-presidents are not interested in, or have no time to study, the background material and the arguments underlying the conclusions. This view was not confirmed **by** industry in the course of the present **QECD** investigation. The discussion meetings, annual client meetings, and inquiry services that are included in such " package " services do not constitute **a** satisfactory substitute for a full background story. A service provided by the Stanford Research Institute must be mentioned in this connection. The Institute maintains an information centre where all the background material is filed with annotated copies of the reports. Personal use of the information centre—or the sending of photocopies upon request—goes a long way to fill the background " gap," and is highly esteemed by industry. Starting in 1967 the Institute plans to include the complete microfilmed background material with each report provided in the regular subscription service.

Moreover, single-page summaries of the Stanford reports can **be** ordered by participants in any number of copies. This has proved to be of great value. **The** companies circulate the summaries and keep the full reports in a central place, sending them out only when asked for. RCA, for example, circulates 50 copies of the Stanford summaries.

Apart from services intended for medium- and large-sized industry, there are a number of forecasting services principally geared to advising the investment business. " Samson Trends " have had relatively wide dissemination in this connection, although they are also extremely valuable for industry in the electronics sector.

What may become one of the main functions of forecasting institutes, however, has been generally neglected so far: a service for *small **business.*** In various countries the position of small industry is expected to become increasingly difficult because, ***inter** alia*, it cannot afford the " radar system " provided by technological forecasting. Small business activity is often restricted to narrow product lines, while forecasting is of real value only when developments in broad fields can be considered and alternatives properly assessed by analysis of large systems. Even if a small company could afford one of the large " package " services, it might not possess the means of fully evaluating such **a** service. The solution of this problem may possibly be found only at national level, with an aggressive central information service co-operating with forecasting institutes that provide the input. This would require, on the part of the institutes, a corresponding policy modification which made possible a comprehensive and regular forecasting input not regarded as being for the exclusive use of the subscriber—the central small business information centre.

Forecasting institutes have played an important role in the early development of techniques and of proper attitudes in technological forecasting. At present, a new " round " is under way in which some of the institutes are active in the development of the forecasting techniques needed primarily in social technology. It is significant that institutes such as the RAND Corporation and the System Development Corporation are contributing to the accomplishment of this task, and are even taking the lead. Abt Associates, the Battelle Memorial Institute, and Quantum Science Corporation are among the " inventors " and " innovators " of special techniques.

Chapter III.2

INDUSTRY

... a great society is a society in which its men of business think greatly of their functions.

Alfred North WHITEHEAD.

III.2.1. TASKS FOR TECHNOLOGICAL FORECASTING

Lenz (*lit. ref. 151*) has formulated the main incentive for technological forecasting as follows:

" Effective forecasting of technical progress is a necessary part of today's managerial decisions. The race for progress is one on which bets must be placed, and from which there is no abstaining. Indeed, most managers cannot even control the magnitude of their betting, since it is closely linked to the net worth of the segment of the economy over which the manager exercises control. Since some estimate of future conditions is inherent in each managerial decision, the actual question is whether such an estimate should be made unconsciously as an implicit part of the decision, or whether it should be arrived at deliberately and stated explicitly. The principal reason for an explicit forecast is to place it ... so that its validity may be tested. The explicit forecast offers the additional advantage of revealing the method, data, and premises used in making the forecast. "

More pointedly, Lenz even relates the " conditions of no-forecast " to the " conditions of non-survival "—a relationship which certainly exists if no forecast at all, systematic or intuitive, is made.

On the other hand, many companies guard against too much analysis. At Lockheed Aircraft Corporation (US) it is felt that ideas should be scrutinised only before the phase of substantial funding: "It is cheaper to try a few poor ideas than to keep a staff for comprehensive analysis." Moreover, early scrutinising is believed to be fatal to emerging new ideas. Georges Doriot warns that " the United States might kill itself by analysis."

It has been repeatedly emphasised in this report that the tasks of technological forecasting extend far beyond the simple exploration of technological opportunities. In fact, important tasks for technological forecasting may be recognised in connection with each of the five "top-level management guidance tasks" which Quinn (*lit.* ref. *217*) develops for his research planning system:

1. Establishing meaningful objectives for research;
2. Seeing that the organisation is attuned to the company's major long-term technological threats and opportunities;

3. Developing an overall business strategy into which research **is** integrated;
4. Developing a procedure which evaluates research projects in the light of company goals and capacities;
5. Organising research and operations for a maximum transfer of technology from research to operation.

Quinn adds: " Significantly, the most profitable opportunities and the most serious threats offered by technology frequently come from **looking** at old problems in entirely new ways—not from traditional approaches gently mutating accepted technologies. "

Moreover, technological forecasting will also become increasingly important in providing guidance for horizontal technology transfer, in connection with the present general trend towards an integration **of** the complete line products—systems—services.

III.2.2. THE EVOLUTION OF LONG-RANGE PLANNING IN INDUSTRY

The McGraw-Hill Economic Department, which conducts periodical surveys of American industry, estimates that while in 1947 approximately 20 per cent of all companies attempted business forecasts over time-spans of three years or longer, 90 per cent did so in 1966.

The Stanford Research Institute has recognised the existence of a clear movement in the direction of long-range planning in American industry since 1954, a finding which closely agrees with those of other surveys (*lit. ref. 193, 197*). In the majority of cases, a sliding five-year plan became the framework for corporate long-range planning, with less formal plans often extending 10 years or more into the future.

Scott (*lit. ref.* 220) places the appearance of technological forecasting as a marked tendency in American industry in the late 1950's. This is in close agreement with the findings of the present **OECD** investigation.

The trend towards the integration **of** technological long-range forecasting and planning, along with a simultaneous move from product-to function-oriented frameworks, as discussed in Chapter I.6., is only now making itself felt.

One may thus recognise a six-year cycle for the initiation of " management innovation" in these areas in the United States:

1953-54. . . corporate long-range planning
1959-60. . . technological forecasting
1965-66. . . integration of technological forecasting and planning and orientation to functions.

A number of leading companies have been running a few years ahead of these dates. Today, both long-range planning and technological forecasting are considered to be assets essential to a company's image—a fact to which a number of advertisements in American newspapers and popular magazines bear testimony.

The development in Europe cannot be so clearly divided into cycles. The Stanford Research Institute situates the beginning of substantial interest in corporate long-range planning in 1964, which would indicate a 10-year phase shift as compared with the United States. However, technological forecasting started in many European countries at about the same time as, **or** even before, the initiation of formal corporate long-range planning.

Another major line of evolution in management concepts is now beginning to be influenced by technological forecasting. After a shift from horizontal to vertical organisation—with marked decentralisation into product lines (in the **US** believed to be inevitable for companies with more than $400 million annual turn-over)—the future trend towards function-oriented organisation involves the re-establishment of central co-ordination which now takes the form of guidance towards future goals! Whereas the verticalisation of American industry became almost complete in the **20** years following World War 11, it is in full progress in Europe. For European companies there seems to be an opportunity for a " short-cut " and a direct change from a horizontal product-oriented structure to a function-oriented structure.

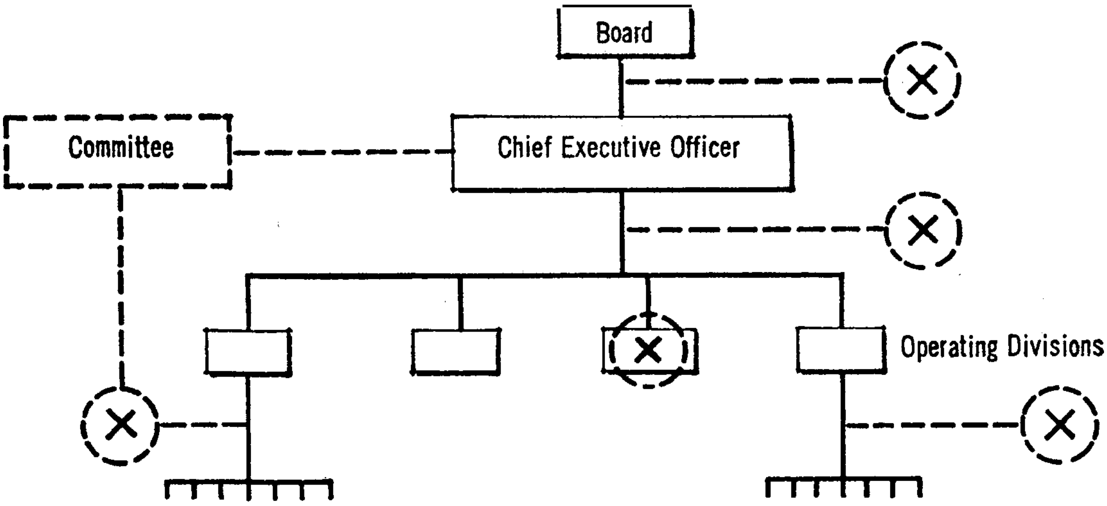
The emphasis on vertical product lines and product strategies, which sometimes determines almost 100 per cent of a company's business, has given rise to the concept of research and development as constituting a " product." Three basic attitudes towards this " product " may be distinguished today:

— Research and development is considered as one of many alternatives, competing with, ***inter alia,*** acquisition, taking licences, buying shares, etc. This is for example, the approach of the Swedish ASEA company (which incorporated a strong product-oriented management as long ago as the mid-1920's). Technological forecasting in the form of economic analysis of all development projects on the basis of discounted cash flow methods (see section 11.3.10) is used for the evaluation of the " product " R & D.
— A systematic search for research and development (Incentive **A.B.,** Sweden—mainly " hunting " for academic research) or for opportunities for planned diversification (The US firms Litton, Textron, Standard Oil of Ohio, American Research & Development Corporation, and to some extent, Du Pont). Technological forecasting plays a certain role, but financial considerations usually dominate.
— The systematic evaluation of outside inventions for acquisition or joint development and exploitation in special " research development branches " established by the corporation (Union Carbide, also planned by Ford Motor Corporation, both US). Technological forecasting is the main tool for decision-making.

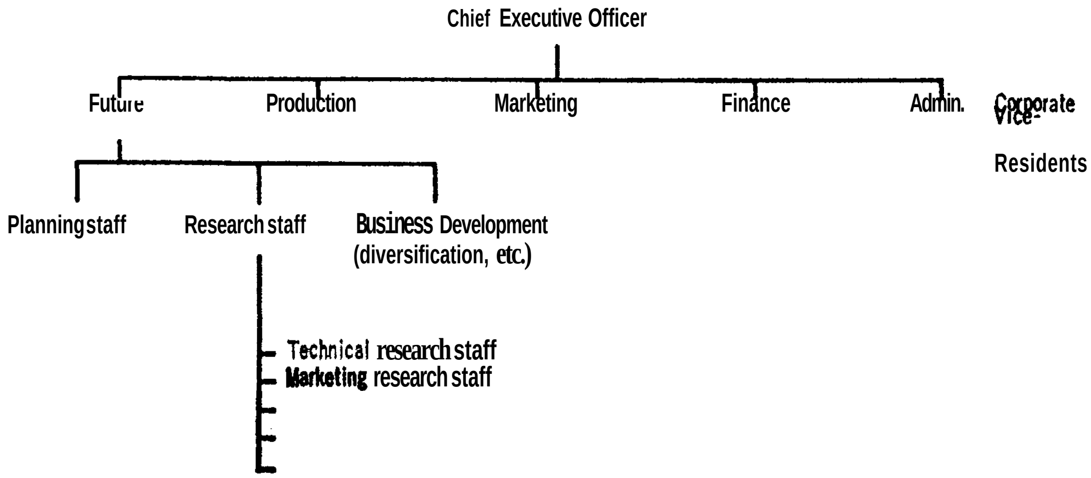
III.2.3. THE POSITION OF THE TECHNOLOGICAL FORECASTING FUNCTION IN THE CORPORATE STRUCTURE

The " normal " way in which technological forecasting is first incorporated into a complex company structure is as a refinement of a corporate long-range planning function. The shift towards a vertical, decentralised organisation is usually followed by the operation of horizontal, corporate-level staff functions which have the task of recognising and analysing non-routine problems and of proposing solutions. Another frequently encountered organisational form is that of horizontal, corporate-level management committees which are sometimes supported by a small staff.

Corporate long-range planning is often carried out in these two ways. The Stanford Research Institute distinguishes five positions (marked by **a cross)** for the " normal " American company. There is a marked trend in favour of a corporate-level staff group and away from management by com-



mittees. The Stanford Research Institute's pattern for an "advanced" American company already points towards function-oriented management, at least as far as new products are concerned (see also section III.2.5.).



In general, technological forecasting is much more closely related to corporate long-range planning than to research and development. In companies where no full structural integration of forecasting, planning, and research exists, actual technological forecasting, or its co-ordination, is often much closer to top management than is research. This observation is borne out by the surprising results of an investigation conducted by the renowned American management consulting firm McKinsey *(Zit. ref. 205):* not less than half of the good ideas in the American electrotechnical, chemical, and drug industries were originally suggested by top management! In several cases, Corporate Vice-Presidents and Chief Scientists act as the heads of horizontal staff groups, and participate actively in the performance or in the co-ordination of the technological forecasting function. Churchill's warning that one should not " attempt a major task from a subordinate position." is obviously applied to technological forecasting in a number of advanced companies.

The higher the management levels concerned, the greater the importance of maintaining official and—even more vital—unofficial channels of communication and feedback. This is particularly relevant where the management concept favours the stimulation of new ideas at all levels (RCA, and others).

The ***decentralisation*** of technological forecasting is characteristic of many large, decentralised American companies. It has little or nothing to do with the concepts of centralised or decentralised research but is clearly due to the following reasons:

- Wide diversification and decentralised marketing; technological forecasting is often coupled with the marketing function, especially where much emphasis is placed on application engineering;
- The tendency to have technological forecasts made by bench people rather than by full-time forecasters; this is more pronounced in the United States than in Europe;
- The differentiation between functional and non-functional research and development often leads to a corresponding division of the technological forecasting task: whereas forecasting in the functional areas (actual business, and its extensions) is handled in a decentralised way, top management concentrates on non-functional areas (diversification, etc.); examples are Royal Dutch/Shell and Union Carbide;
- Technological forecasting in the defence research area is often handled separately, for security reasons and because of the usually well-defined normative framework; examples are Bofors (Sweden), CSF (France), Elliott-Automation (UK) and RCA (US).

Typical ***centralised*** responsibilities include, in most cases, technological forecasting tasks of the following types: corporate strategies, diversification, inter-divisional (or inter-disciplinary) potentials, very long-range forecasting, and social research. Long-range forecasting is decentralised, however, if a company is dealing with a great number of radically different businesses (Litton, Textron, and to some extent Union Carbide).

A company can conceivably use four different sources for the inputs to its special technological forecasting (apart from gaining a more general view by subscribing to report series put out by forecasting institutes and consulting firms):

1. A permanent in-house function;
2. In-house task forces (possibly enriched by outside consultants);
3. A "think group" (such as General Electric's TEMPO Center, or, to some extent, Honeywell's Military & Space Sciences Department);
4. Forecasting institutes or consulting firms contracting to do the forecasting job for the company.

Type 2 is very rarely encountered, while type 4 is not contemplated, at least as far as medium- and large-sized and ambitious industry is concerned. It is generally acknowledged that the use of external forecasts makes sense only if the company has a corresponding in-house function which is capable of absorbing and adapting them.

The general approach today is that of type 1—a permanent (not necessarily very formal) in-house activity— sometimes supplemented by specially contracted outside forecasts.

Quinn (*lit. ref. 217*), in an evaluation of 35 US companies carried out as far back as about 1960, discovered that most of them had in-house activities of one **of** the following three structural types: staff analysis group, research committee, ***ad hoc*** special study groups. Among the few combined approaches which he encountered, one is particularly interesting: in an electronics company, technological forecasting was assigned to newly hired PhD's who were considered to be uninfluenced by past company biases, and was coordinated by a Vice-President. The following section **III.2.4.,** provides an evaluation of forecasting activities encountered during the preparation of this report.

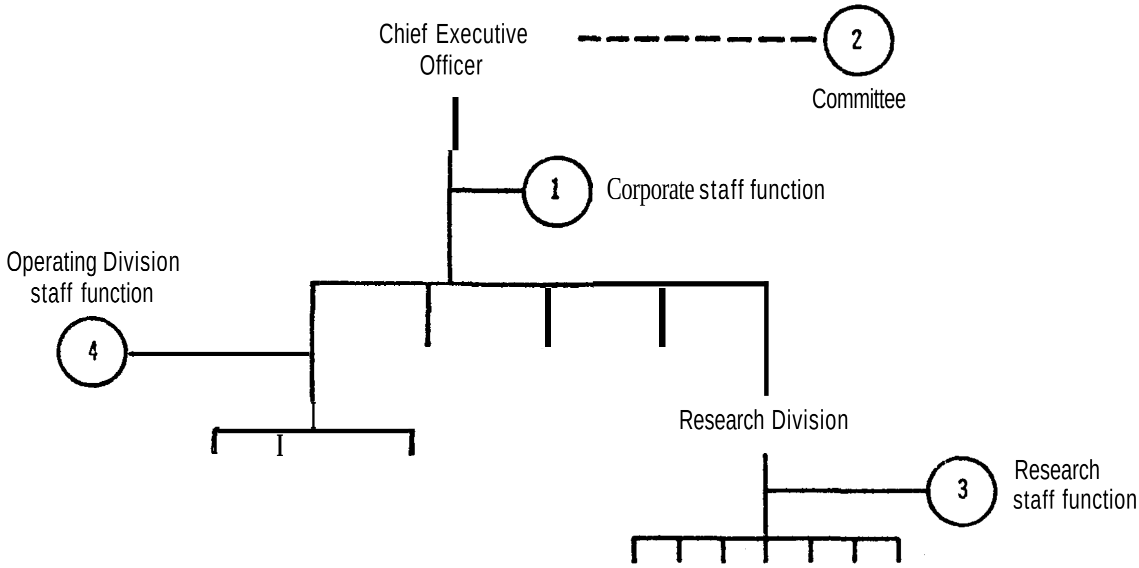
III.2.4. A STATISTICAL EVALUATION OF TECHNOLOGICAL FORECASTING ACTIVITIES IN 62 COMPANIES

The following evaluation is based on the **1965-66** situation in **62** companies, **39** (or **63** per cent) of which are either located or have their headquarters in Europe or Israel, and **23** (or **37** per cent) in the United States. They represent entities at the corporate level (e.g. General Electric is treated as one company), so that sometimes a large number of relatively independent forecasting activities—as high as 50 to 100 for some corporations—are grouped under one entry. This is therefore an evaluation of **62** companies, but at the same time of many more distinguishable activities (which frequently represent quite different approaches within the same company—for example for the **123** departments of General Electric, the **60** businesses of Union Carbide, or the six divisions of North American Aviation).

The smallest company evaluated has 2000 employees; the other end of the spectrum includes the biggest companies in the world.

Fifty-four (or **87** per cent) of the companies have a permanent or periodic technological forecasting function, the eight others perform irregular, but frequent, forecasting on an ***ad hoc*** basis. Forty-five companies (or **73** per cent) have the forecasts periodically written up **in** a formal way, or include them in their formal long-range plans; five companies do this more frequently than once a year (every three, four, or six months).

The ***position of the technological forecasting function in the corporate structure*** can be described by means of four " standard positions ":



This is a simplified scheme. For example, the " Research Division " may also be a corporate-level Central Research Laboratory, and the staff functions in **3** and **4** may be replaced by part-time functions **of** directors, project leaders, or bench people.

The statistical evaluation of the occurrence of these positions yields the following result (figures in brackets refer to the **23 U.S.** companies considered separately):

POSITION	TYPE	COMBINATION		ALONE		FAVOURED COMBINATION
		COMPANIES	PER CENT	COMPANIES	PER CENT	
1	**Corporate staff function.**	46(20)	74(87)	10(1)	16(4)	**1 + 4 alone : 16(6) companies** **1 + 4 + other: 12(9) companies**
2	**Committee**	15(8)	24(35)	4(0)	6(0)	**1 + 2 + other: 10 companies** **2 + 4 + other: 6 companies**
3	**Research (staff)function.**	20(10)	32(43)	5(2)	8(9)	**1 + 3 + other: 14 companies**
4			50(65)	1(0)	2(0)	**1 + 4 see above**
—			10(17)	2(1)	3(4)	
—	**Task forces**	3(1)	5(4)	1(0)	2(0)	
—	**Company-wide ad hoc effort**	4(0)	6(0)	1(0)	2(0)	

It is seen that in most of the cases—mainly big companies were evaluated—the technological forecasting function represents an interaction between two or more positions. It is significant that Europe/Israel accounts for almost all the single-track approaches.

There can be no doubt that a corporate staff function (with an average of about three to six people engaged full time in technological forecasting) is considered best suited to the performance and co-ordination of technological forecasting, and that this approach is clearly favoured over that of entrusting the forecasting to research operations. The combination of a co-ordinating and synthesising corporate staff function with decentralised forecasting in the operating divisions—which already points in the direction of an integration of forecasting and planning (see section **III.2.5.**)—is employed by **45** per cent of all companies, and by 65 per cent of the evaluated **US** companies (including combinations with other functions as well).

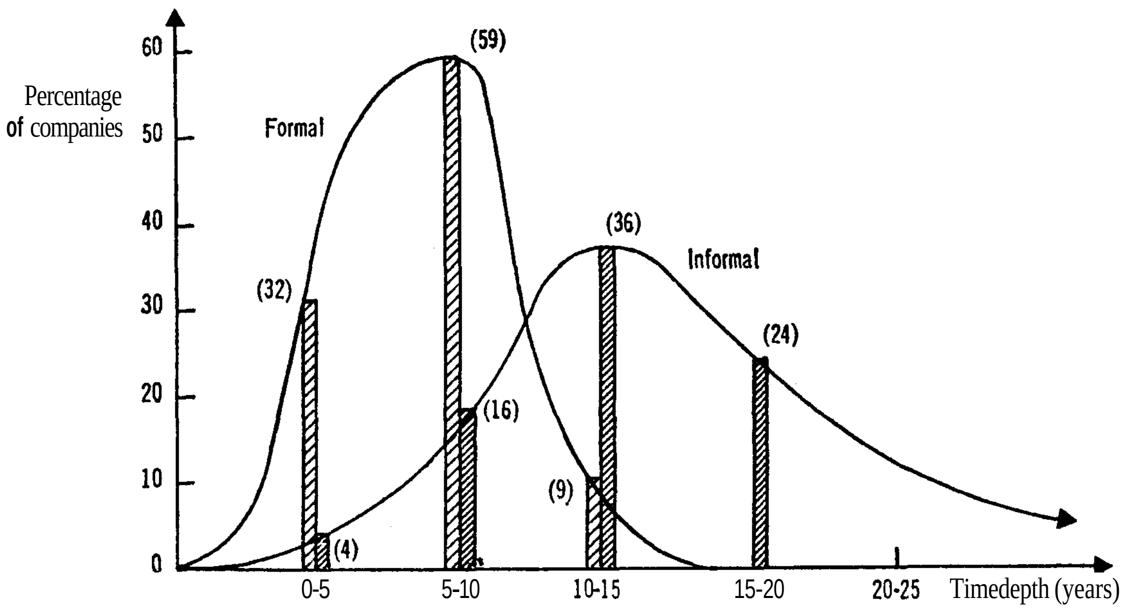
In two cases, the corporate staff function approach was recently abandoned or reduced: General Motors disbanded a full-time technological forecasting group which had functioned for **2** ½ years, but carries on with its " Research Policy Committee ", aided by scientists from the laboratory; Du Pont discontinued the preparation of 10-year scenarios at three-year intervals by the corporate-level Development Department (the last scenario was done in 1963), but carries on with five-year forecasting in the Industrial Departments. In both cases there were complex reasons for doing so.

The " *specialist* " ***approach*** of using special " technological forecasters " is much more popular in Europe, a fact which is also demonstrated by the relatively large number of corporate staff functions which are alone in dealing with the forecasting tasks (see above). The **US** approach clearly favours the integration of forecasting with other functions, or a combination of co-ordinating and synthesising special " forecasters " with bench people and/or executives (figures in brackets refer to the 23 US companies considered separately):

TYPE OF PERSONNEL	COMPANIES	PER CENT
Special " technological forecasters " alone ...	19 (2)	31 (9)
Bench people and/or executives alone...	18 (9)	29 (39)
Combination of both types ...	25(12)	40 (52)
	62(23)	100(100)

An inter-disciplinary approach is usually taken, and the most frequently encountered split between scientific-technical and economic personnel is **50:50.**

The time-depth is often different for formal and informal forecasts. Among the companies surveyed, formal forecasts range up to 15 years, informal forecasts up to 50 years. The percentage distribution can be graphically represented as follows:



The distribution curve for formal forecasting reflects the average time required today for a technology transfer cycle from scientific discovery to technological innovation—15 years. However, formal forecasting clearly exceeds the usual five-year range of formal corporate long-range planning. The much greater time-depth of informal forecasting serves mainly to permit the formulation of long-range objectives and the preparation of technological options.

In Europe, the time-depth of technological forecasting is frequently not **so** well defined as in the United States, thus reflecting the prevalence of a predominantly exploratory approach to forecasting in Europe—with the expectations for different developments " landing " at different time distances.

It was not possible to assess, therefore, whether the above distribution curves differ as between Europe and the United States; the general impression is that they do not differ greatly.

Special features of the evaluated activities include the following:

- In several companies, technological forecasting staff functions are so organised as to bring them into close co-operation with other staff functions, especially marketing and product planning. An example of a more complex interaction is provided by the Corporate Planning Department of Esso (UK); it comprises the following groups, all of which participate in technological forecasting: economic forecasting, business appraisal, science and technology, energy forecasting, mathematics and operations research;
- Technological forecasting staff functions sometimes assume an " educational function" for the entire company if decentralised forecasting is also carried out (3M Company, ASEA);
- Committees sometimes attain a position of much weight through the participation of top executives; at General Motors, for example, the Chairman of the Board is a member of the Research Policy Committee;
- Decentralised technological forecasting can follow a different rhythm from that of the corporate synthesis; at Boeing, divisional forecasts are prepared quarterly, the corporate synthesis once a year;
- Among the few " task force " approaches encountered, L.M. Ericsson's is original in that inter-disciplinary temporary Junior Committees are appointed in order to obtain fresh new ideas;
- Among the company-wide comprehensive efforts encountered, two stand out: (*a*) Unilever's " Research Conference," a one-year effort in 1965-66 aiming at a 5- to 10-year time-depth and at finding " new windows," representing already the second big effort after " Britain in 1984" (*lit.* ref. *256*), carried out in 1959-60; 16 international study groups, composed of scientists of the 11 Unilever laboratories, stimulated their colleagues to forecast, synthesised the material and merged it with economic forecasting (provided externally) and social forecasting. (b) A concentrated endeavour by the Westinghouse Research Division in 1965-66, involving interviews with all high company executives and aiming at a 10-year time-depth and at the definition of areas of particular interest, along with estimated ratings for profit potentiality and the probability of reaching a commercial development stage within 10 years; 70 areas were identified, and the executives' judgment was revised in a second (iterative) step; a technological forecasting group subsequently translated the findings into objectives at the level of fundamental science and technology, and defined the research strategies. Esso (UK), in addition to continuous formal forecasting, undertakes a special exploratory long-range forecast every three years.

III.2.5. THE INTEGRATION OF TECHNOLOGICAL FORECASTING AND PLANNING AND THE TREND TOWARDS A FUNCTION-ORIENTED STRUCTURE

It was pointed out in Chapter 1.6. that technological forecasting and planning have an inherent tendency to integrate up to a point where forecasting is no longer a distinguishable discipline. It was also observed that long-range forecasting and planning favour a function-oriented organisational structure. The following Chapters, III.3. and III.4., will demonstrate the existence of a very marked tendency in this direction in military and government areas as well.

After a strong move from horizontal organisation to product-oriented vertical organisation, the new tendency, which follows upon the incorporation **of** long-range planning, now implies once again horizontal control of a function-oriented hierarchic structure. The principal incentives behind the new reorganisation were outlined by Michaelis[1]:

Product-oriented structures act partly as an obstacle to innovation.
Function-oriented structures permit planning aligned with long-range objectives and social goals.

Dealing with the future is an increasingly important aspect of the top management function; a function-oriented American electronics company emphasises that " general management, above all, must look at future technology", and the management **of** the Xerox Corporation (US) "spends more time on 1975 than on today."

The change from technically oriented strategies to market-oriented strategies, which deeply affects the organisation and the basic policies of a company, also gives rise to structures built around functions rather than products. Examples are the **3M** Company (Minnesota Mining and Manufacturing Company), which became market-oriented in the mid-1940's, and Vickers (UK), which made the switch in 1960 and at the same time established a normative function to "pinpoint areas of the future."

The basic distinction between functional and non-functional research is characteristic of large companies with a function-oriented principle underlying their structure. Functional research, in Shell's terminology, also includes long-range developments which are in line with functions performed at present (for example, deep sea drilling at a depth of about 600 metres —which is expected to play a role in **20** or **25** years—is considered "functional" as an extension of present oil drilling techniques). Non-functional research is related to functions outside the scope of currently performed functions, for example the preparation of future diversification. The technological forecasting efforts dealing with functional and with non-functional research, respectively, are in such cases usually completely separated. Du Pont and United Aircraft, for example, assign forecasting in the functional area to their vertical operating divisions, whereas non-functional forecasting, penetrating farther into the future, is performed by a horizontal staff group. Shell handles both types of forecasting on a horizontal corporate level, but they are completely separate. **IBM** is so organised as to distinguish between functional research, non-functional research, and general research in fundamental science and technology.

Many companies today try to incorporate an orientation towards functions and long-range corporate objectives through "***matrix management***". The general pattern in large companies favours a product- (or programme-) oriented structure for the operating divisions, and a function- (or discipline-) oriented structure for the research division or the corporate-level research laboratory on the administrative side. An ever-changing function-oriented

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1. At the Conference on Technology Transfer and Innovation, 15-17 May 1966, Washington, D.C.

structure is superimposed to deal with inter-disciplinary functions and projects, with temporary project groups and project managers. The product/function matrix for management thus basically represents a flexible "task force" approach on the basis of a rigid administrative structure.

A similar approach may also be followed in structuring the entire forecasting and planning activity, with the use of a system/technology matrix for the purpose of combining powerful systems development management with long-range technological options. The decision-making structure of ***North American Aviation's*** Los Angeles Division for their independent research and development effort (i.e. outside government contracts—usually referred to as IR & D) may serve as an example or such a complex "matrix management" approach. Technical decision-making is divided into three areas: (1) Systems-oriented planning; (2) Technology-oriented planning; and (3) Systems-oriented technology planning. The step-by-step procedure in these areas is as follows:

1. ***System-oriented planning*** (41 per cent of total effort) deals with major new systems not yet in a commission stage and takes a long view (for example on hypersonic aircraft, which is 10 to 15 years in the future). Starting from recognised needs, the procedure can be represented in the following flow scheme:

a) identification of target areas
↓
b) Systems feasibility studies (50 per cent of effort under [1])

Mission analysis
↓
Parametric studies
↓
Base-point design
↓
Advanced design
↓
Evalidate

First *two* steps performed by a special Operations Analysis Group

→ Define technology (25 per cent of effort under [1])

c) Study contract
↓
Test bed ←
↓
d) Major systems development programme.

Every future system has a full-time project manager.

2. ***Technology-oriented planning*** *(52* per cent of total effort) concentrates on performance, weight, function, reliability, cost improvement, etc., and follows these steps:

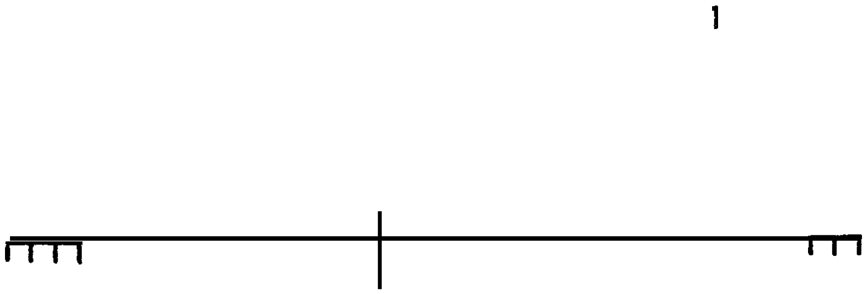
a) Technology base (e.g. weight)
↓
b) Ideas for improvement (e.g. plastic matrix composition with boron)
↓
c) IR & D feasibility → Research contracts
↓
d) Contracts for scale-up flight tests
↓
e) Application to new programme.

3. System-oriented technology planning (7 per cent of total effort).

The striking emphasis on technology-oriented planning is characteristic of the aerospace sector and of several other rapidly innovating sectors.

The *American Telephone & Telegraph* (A.T. & T.) group with its research branch, *Bell Telephone Laboratories,* provides an example of a fully integrated forecasting and planning scheme. In 1950, A.T. & T. introduced the " Systems Engineering " approach which is essentially a function-oriented approach with considerable feedback. The complex structure of the A.T. & T. group comprises three main parts: A.T. & T. is the parent company and the holding company of the 21 operating telephone companies; Bell Telephone Laboratories is the research and development company; and Western Electric is the manufacturing entity. The internal structure of the Bell Telephone Laboratories distinguishes Basic Research (approximately 1500 graduate staff), Development (approx. 3500 graduate staff, sub-divided into an exploratory and an applied side), and Systems Engineering (approximately 1500 graduate staff). The Systems Engineering Section is composed of mature scientists and engineers who formerly did bench work and now perform mainly evaluation work (60 per cent of their time is spent on writing); they: prepare complete proposals; look at all major technology areas; set up inventories of technological options and alternative solutions to problems; develop criteria for effectiveness, such as development time and costs, operating costs, etc.; bring together specialists' estimates for specific projects in accordance with these criteria; advise on the allocation of research funds; and perform field testing. Technological forecasting is carried out as a decentralised but closely interlinked process in A.T. & T. (mainly five groups in the Engineering Department, providing a strong normative component), and Bell Telephone Laboratories (mainly three groups in the Systems Engineering Section). An example of how multiple-stage technological forecasting ties in with planning and actual development is given in *lit.* ref. *52.*

At least *two American companies,* one in the electronics and one in the aerospace sector, structure their integrated technological forecasting and planning in accordance with a function-oriented decision tree (or " goal hierarchy", or " innovation management structure," as one company prefers to call it). The general form of such a tree can be represented as in Chapter **I.6.2.**, i.e.:



In one company a Senior Vice-President for Corporate Development has responsibility, at one and the same time, for the corporate-level research laboratories and the horizontal scientific and economic staff functions which serve to implement and co-ordinate forecasting and planning within the framework of the scheme shown above. **A** total of **50** people are intensely involved in long-range planning and its implementation (in a company with $ 400 million annual turnover, as of 1965). Approximately **75** per cent of the activities in the corporate-level research laboratories contribute to specific programmes, and approximately 80 to 90 per cent of divisional research and development do so. The predominantly exploratory remainder, which is still outside this normative scheme, is nevertheless committed within a framework of long-range technological objectives, and is " pushed " into strategies and action programmes once their relevance to business objectives has become clear.

The Corporate Objective, including a " Technological Objective " outlining the technological " main streams " of interest to the company, is written up in one document which is revised every year. The Business Objectives are formulated by the divisional Vice-Presidents, and are also updated annually. Technological forecasting enters mainly on the strategy level, which is concerned with creating markets: a 10-year forecast is prepared for each strategy in close co-operation between the scientific and the economic corporate staff functions, based on material provided by bench people in the divisions and in the central laboratories. These 10-year forecasts are revised annually under **a** procedure that involves everyone up to the President's Office and the President himself; the actual work required to review the complete scheme is spread over the whole year, with a number of strategies reviewed by Corporate Development and the President's Office once a month on the average. Sales estimates are made for each strategy, and programmes assessed both in respect to goals (strategic value) and in cost/benefit terms. Intra-company strategies are, for the most part, recognised and formulated on the corporate level. **A** series of company-wide meetings of key specialists and top executives including the President is held to discuss the 10-year forecasts and plans for all the strategies (each of which is covered once a year) and to modify the formal document, which is then strictly adhered to for one year.

Integrated technological forecasting and planning at the ***Xerox Corporation*** in Rochester, New York, is co-ordinated by a corporate-level staff function (four people) under a Vice-President. The research and development forecasts originate mainly in a staff function (two people) at the Research Engineering Division, where a 5- and a 10-year " Research and Engineering Plan " is prepared, and in the operating divisions, where " gap filling proposals" are prepared and evaluated. Individual product plans are set up for the whole expected life-time of a product, i.e. on the average for 10 to **12** years. The corporate staff group merges these inputs in a "Technological Plan," which is mainly function-oriented and indicates milestones of expected or desired achievement. It forms the basis for discussions in depth at frequent strategy meetings, for research conferences, and for the occasional formation of temporary inter-disciplinary task forces. The corporate staff group, which co-ordinates these continuous activities, also prepares plans in six different versions for time-depths of 1, 2, **3, 4,** 5, and 10 years. The 10-year plan serves mainly to determine whether physical impossibilities will be reached, and to align planning with long-term objectives (informal technological forecasting penetrates even much further into the future) ; there is also a 10-year revenue forecast which influences the five-year strategic plan. Finally, a five-year " sliding " research plan emerges which becomes part **of** the corporate five-year plan. It is reviewed twice a year: a Spring Planning Conference concentrates on " gap " identification (and is followed **by** gap-filling proposals from every part of the planning structure, including the operating divisions), while a Fall Planning Conference concentrates on formulating and reviewing long-term objectives.

A probably unique example of a very large function-oriented company with vertical operating structure but entirely horizontal forecasting and planning is provided by the *Royal Dutch/Shell* group, with headquarters in The Hague and London. After central planning for research and development throughout the **1920's** and **1930's,** a subsequent period of decentralised research management was considered to have produced unsatisfactory results. **As** a consequence, the centralised research and development management, **as** outlined below, was established in **1955.**

All research and development is divided into functional and non-functional research. Technological forecasting and planning are carried out in an integrated way. Shell operates **30** laboratories with **7,000** people in various countries, two of which carry out about half the research programmes (Amsterdam and Emeryville, California), the other **28** being specialised in different areas.

Technological forecasting in areas of non-functional research (especially fields of potential diversification) is completely separate from functional research and handled by a Diversification Department reporting to top management. It also performs very-long-range forecasting and merges technological and social aspects. Frequently the people in this department are subsequently given important line responsibilities in the new areas of activity which they helped to prepare.

Forecasting and planning in the functional research areas (i.e. in areas where functions and activities already exist) are handled by a fairly extensive corporate-level horizontal structure incorporating the following sub-divisions:

- ***a*)** Technical Co-ordinators for each broad business function, **who** may have extensive office facilities for such functions as " oil production " or " chemicals." Quantitative forecasting is performed **for** a three-year time-depth and, in a separate forecast, for a time-depth ranging **up** to **15** years. All projects contributing to a given function, originating anywhere in the company, are scrutinised by economic analysis, with extensive use being made of formal techniques including the assessment of probabilistic inputs, ranges of success, and ranges of timing;
- ***b*)** Research Directors (not to be confused with the Laboratory Directors), **who** co-ordinate regional groups of laboratories, " translate " the projects into terms of research and development tasks. They also assume the responsibility for " carrying over " functional research projects which cannot yet be assessed on the basis of economic analysis **;**
- ***c*)** The Group Research Co-ordinator deals with multi-functional problems as they are encountered in long-range planning, and decides where functional research is to be carried out;
- ***d*)** Regional Co-ordinators who follow political and economic developments in different parts of the world.

The operating procedure is characterised by the following main **steps** which translate the conclusions of medium- and long-range forecasting (informal forecasts penetrate 40 or 50 years into the future) into the annual budget—no long-range plan is formally drawn up:

1. Approximately once a week a working-level meeting is held by the Technical Co-ordinator; in this way, the total research field under his broad business function is covered every month. Under the chairmanship of the Technical Co-ordinator or his deputy, the meeting brings together development, marketing and patent people in addition to a representative of the Group Research Co-ordinator's office. Background papers and written statements are prepared in advance and provide the basis for a free discussion—" brainwashing " is consciously avoided;
2. These meetings lead once a year to a functional research programme and a budget formulation which are referred to committees on higher levels;
3. In May of each year a Research and Planning Conference is held for each broad function, attended by approximately 15 people including the relevant Technical Co-ordinator, a representative of the Group Research Co-ordinator's office, and representatives of the laboratories active in fields contributing to the function in question. Budget recommendations are formulated in the light of long-range objectives and potentialities;
4. In June of each year an Executive Meeting is held in which all the top executives from the horizontal corporate-level structure outlined under *(a)* to *(d)* above come together. The one-year budget is approved;
5. Strategies and programmes are modified in the light of the approved budget and implemented in the laboratories concerned.

The vertical operating structure, represented on the technical side by Technical Directors, is organised along the lines of the same broad business functions as those represented by the corporate-level Technical Co-ordinators.

Royal Dutch/Shell, as the largest company outside the United States, may well serve as the largest scale example of centralised technological forecasting and planning and also of an essentially function-oriented structure.

III.2.6. CORPORATE OBJECTIVES AND SELF-MOTIVATION

Successful and creative management can be attained only partially through structures, organisational schemes, and techniques employed. It is not merely rhetorical to say that the spirit of management is more important.

A fully integrated forecasting and planning system requires entrepreneurial qualities at each level and for each planning step, and thus depends essentially on self-motivation in creative people at all levels. An American company in the electronics sector has adopted a policy of having as many " general managers " as possible (the term " general manager " does not signify a hierarchic position here, but an employee who has access to literally all data and facts about the company and who is informed of all plans and policies). Before formal forecasting and planning were instituted, there were eight " general managers " in the company; five years after the establishment of a formal planning system, there were 150, and the goal is to have 1,000 " general managers," situated at all hierarchic levels.

The predominant attitude in industry is still far from that exemplified here, which calls for a certain greatness on the part of the top management people. The concept of the 1,000 " general managers " has to be confronted with the example of the European company which was sufficiently advanced in its thinking to establish a technological forecasting staff function. However, since in this company knowledge of top management policies and plans for the future is considered a status symbol which excludes all except the highest ranks from pertinent information, the technological forecasting group is not told about long-range corporate objectives—in fact, the type of future for which it can forecast and plan is either an extension of the present or the result of pure guesswork.

Self-motivation becomes fully effective only where the corporate objectives tie in with supreme social goals. " The corporate leader who does not try to conduct his company so as to instill pride in his people is doomed these days", states the President of Xerox Corporation (*lit.* ref. 227). Maximum company profit is not a challenging goal for professional people.

A.T. & T. and its research branch, Bell Telephone Laboratories, enter into " total commitment " only where company goals tie in with social goals. It has become the primary concern of top management to " translate " goals to the people on the working level, and to create self-motivation among them so that they will *(a)* understand the goals, (*b*) understand their own role in the achievement of these goals, and *(c)* direct their efforts to meeting economic and technical specification because they understand the relevance of the specification to the goal. The aim is to combine individual creativity with collectively oriented effort in order to achieve " relevant innovation." The most powerful organisational means is that of a feedback system as opposed to the usual one-way forward-facing system.

Myers (*lit.* ref. *215*), on the basis of a case study of an American electronics company, points out that "just as the non-manager is dependent on his boss for motivational opportunities, so is the manager dependent on his boss for conditions of motivation which have meaning at his level. Since the motivation of an employee at any level is strongly related to the supervisory style of his immediate boss, sound motivation patterns must begin at the top. " Myers also discusses the particular importance of self-motivation to innovation, and of the appropriateness of management systems, such as that of his company, to the fostering of self-motivation. " Management failures in supervision do not, of course, stem from intentional malice. They may result, in part, from a lingering tradition of 'scientific management' which fractionated tasks and 'protected' employees from the need to think, and perpetrated management systems based on automaton conformity. But more often such failures stem from the managers' insensitivity to the needs and perceptions of others, particularly from his inability to see himself as others see him. "

To a large extent, self-motivation is a problem of communication within the company. Communication, in turn, depends on the " transparency " of hierarchic and vertical barriers, or informal " bypass " channels (see also lit. *ref. 209).*

The recent A.D. Little study of weapon system developments (lit. *ref. 44*), mentioned earlier, concludes that for 63 successful information-generating " events," the following organisational styles and research managements were responsible:

59 events: "Adaptive" environments;
3 " unable to define;
1 " only one man involved;
0 " "authoritative" environment.

Many companies of an innovating type, especially in the United States, have adopted a policy of stimulating the generation of ideas at all levels. An interesting example is provided by United Aircraft where self-engendered "idea groups" emerge in areas where broad goals and company objectives are assessed systematically (by a corporate staff function) and the results fed to the working level.

Self-motivation is enhanced by the establishment of independent research and development (IR & D - with private risk money) in companies which depend on government contracts for their business, i.e. chiefly in defence and aerospace.

The example of the vertical decision matrix developed at North American Aviation (see section 11.4.2.) shows that even the development of forecasting techniques can be influenced by the desire to link company planning to supreme social goals and to create self-motivation.

III.2.7. A VERY ROUGH CALCULATION OF INDUSTRIAL INVESTMENT IN TECHNOLOGICAL FORECASTING

The available figures may permit an attempt at a first rough calculation of the investment in technological forecasting made by ***medium- and large-sized American industry.*** The assumptions made will rest on very uncertain grounds, but at least an assessment of orders of magnitude may be expected.

Assuming that the majority of medium- and large-sized firms in US industry (with perhaps over $100 million annual turnover) have a systematic in-house technological forecasting function and subscribe to one of the ambitious forecasting "packages" offered by forecasting institutes and consulting firms (see Chapter 111.1.)—and taking account of the fact that there are also non-industrial subscribers—a conservative figure may be arrived at of 500 or 600 companies in this category which have a defined technological forecasting function. Estimating the average annual in-house effort (full-time and part-time) at five man-years and the total average costs, accordingly, at $ 100,000 per company, one may conclude that approximately $50 million are spent by these companies for in-house forecasting, and an additional $ 10 to 15 million for technological forecasting performed by institutes and consulting firms (see Chapter III.1.). The ratio of 5: 1 for in-house to outside investment appears to be a sound one.

A further, very rough estimate may now be made that these companies account for one-third of the total industrial research and development expenditures made in the United States (estimated by McGraw-Hill at a total of $ 15,2 billion for 1966). Their share would then be $ 5 billion.

For the "upper 500" in innovation-minded American industry one may therefore assume an ***investment in technological forecasting of the order of one per cent of total research and development expenditures,*** of which four-fifths are spent on in-house and one fifths on outside efforts. In companies where a large portion of the research people are systematically involved in forecasting, this percentage may be higher—perhaps up to 10 per cent in special cases (this figure was actually given by three companies, referring to working time).

One may now go a step further and attempt to find some indication of the aggregated return on this investment, although this necessitates treading on rather dubious ground. According to the McGraw-Hill survey (*lit. ref. 54*), American industry expects $94 billion worth of sales in new products in 1969 (the value calculated in 1965 dollars and "new products" defined as those introduced in the period 1966-1969). Assuming that (a) industrial research and development expenditure in the period 1962-1965, roughly $40 billion, is mainly responsible for these new products and (*b*) that the same percentage (45) of industry which indicates its major effort to be in new products development (McGraw-Hill) can be used as the proportion of total research and development expenditures being devoted to new products development, an average is arrived at of $4.5 billion per year spent on new products research and development. Related to the $94 billion in new product sales in 1969, this indicates roughly a 5 per cent investment in research and development in new product sales (a plausible figure, although it would be considered unfavourable by leading companies). Assuming further that much more than a 45 per cent share of technological forecasting is focused on new products, an investment in technological forecasting of the order of ***0.1 per cent of total new product sales*** is indicated in present circumstances.

Considering only the proportion of new ideas due to systematic technological forecasting, such forecasting would indeed be a very worthwhile investment: at the Xerox Corporation and in a leading American semi-conductor company systematic technological forecasting provides approximately half the ideas leading to future new products ("gap filling"), while BBC Mannheim (Germany) increased the number of ideas by a factor of 4 through technological forecasting. One may conclude—admittedly embarking at this point on very uncertain ground—that technological forecasting is instrumental in doubling the profit due to new products in rapidly growing companies. If a 10 per cent net profit after taxes is assumed (plausible for new products), one arrives at the highly simplified conclusion that the "catalyst" of technological forecasting makes possible a "research and development reaction" leading to a profit gain which is 50-fold the investment in the "catalyst."[1] This last train of thought, of course, is not applicable to aggregated sectors, but only to individual companies.

For Europe, the figures are lacking for even such a tentative calculation. Both research and development and technological forecasting are on a comparatively lower investment level. However, the relative role of technological forecasting may be assumed to be still less important than in the United States.

1. This must not be confused with return on investment which can be measured only against the total investment leading to a profit, i.e. the total research and development effort following the triggering effect by forecasting. It is for this reason that the image of a "catalytic" action of technological forecasting has been chosen. A typical effect of this type may, for example, take place in the following way: For each dollar invested in technological forecasting, $100 are invested in research and development, of which $60 may be on new products. Of the latter amount, $30 are in areas defined by technological forecasting—they result in $50 profit.

Chapter III.3

MILITARY ENVIRONMENT

See also Annex A.2. for a descriptive account of technologicalforecasting activities identified in military environment in France, Sweden, the United Kingdom, and the United States and in NATO'.

Z would not, if Z could, attempt to substitute analytical techniques for judgment based on experience. The very development and use of those techniques have placed an even greater premium on that experience and judgment, as issues have been clarified and basic problems exposed to dispassionate examination. The better the factual basis for reflective judgment, the better the judgment is likely to be. The need to provide the factual basis is the reason for emphasising the analytical approach.

Robert **S. McNamara.**

The early recognition of the importance of technological forecasting in the military environment has greatly contributed to the general development of the art. It was pioneered especially by Theodor von Kármán, the eminent scientist in the field of gas dynamics who broke new and fertile ground by his report in **1944** on the future of aircraft propulsion—" Toward New Horizons " ***(lit. ref. 319***)—**which** is often referred to as the first technological forecast in a modern sense. Von Karman later initiated the concentrated technological forecasting effort, at five-year intervals, of the **US** Air Force (see Annex A.2.4.) and technological forecasting in NATO (see Annex A.2.5.).

The decisive innovations which von Kármán introduced and which distinguished his approach from older forms of military technological forecasting, can be summarised in three points:

- He replaced intuitive thinking by thorough and comprehensive analysis in a well-defined time-frame (15-20 years);
- He considered basic potentialities and limitations, functional capabilities and key parameters, rather than trying to describe in precise terms future functional technological systems;
- He put much emphasis on the evaluation of alternative combinations of future basic technologies, i.e. on the assessment of alternative technological options.

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1. Canada performs mainly short-range forecasting, although in the framework of a sliding five-year plan; Israel has included a formal technological forecasting function in her military planning, but details were not available.

It needed only a similarly clear concept for achieving the normative assessment of future military functions—missions and tasks—to arrive at military technological forecasting as practised today.

The introduction of an economic concept, developed by means of the cost/effectiveness approach for the evaluation of weapon systems was also decisive for the feasibility of continuous technological forecasting and its marriage with military planning. First introduced in a systematic way in the United States, this concept is now spreading to other countries. As remarked in Swedish military environments, the basic criteria for big and small countries have to be somewhat different. A small country has to take into account "indirect" effectiveness, such as mobilisation in friendly big countries if a small country is attacked, political and economic discrimination, etc.

The normative approach which develops out of the dialogue between strategies and tactics, on the one hand, and technology, on the other—with policies and threats providing the broad guidelines—has become so strong that it is believed to have caused some "overstress" in the United States. According to this view, which is defended, for example, by the RAND Corporation, TEMPO, and the Hudson Institute, the complexity of modern weapon systems may be partly due to pressing the technological frontiers too hard (*lit.* ref. *29).* The cost/effectiveness approach, which has dominated American military developments since 1961, may eventually bring some "relief." The more recently initiated long-range technological forecasting efforts in the US Navy (see Annex A.2.4.) also put considerable weight on exploratory forecasting, especially in the "Scientific Opportunities" volumes, and on an iterative process between exploratory and normative forecasting.

The *form of* organisation can be seen in terms of an analogy with industry: the integration between technological forecasting and planning favours a *function-oriented* organisation; this also corresponds to the requirement of adaptability to missions and tasks, which in modern military environments are formulated in functional terms and no longer in "product" terms (services and their weapon categories). The best example of a function-oriented organisation with full integration of centralised forecasting and planning can perhaps be found in Sweden (see Annex A.2.2.). It may also be assumed that the centralised approach in France and the United Kongdom (Annex A.2.1. and A.2.3., respectively) has been chosen partly to conform with a function-oriented concept.

In 1967, Canada will abolish completely the traditional form of organisation divided into the three services (Army, Navy, Air Force) and will adopt a function-oriented structure for the Armed Forces as a whole.

The complex structure of military technological forecasting in the United States (outlined in Annex A.2.4. as well as the author's knowledge permitted) can be explained partly by the dissolution of an earlier centralised periodic effort by the Eisenhower Administration. Since the beginning of the McNamara era in the US Department of Defense, in 1961, medium-range technological forecasting and planning—within a five-year time-frame—has become part of the overall Planning-Programming-Budgeting System (PPBS), which is strongly normative and entirely function-oriented. Although evaluations are partly carried out in a decentralised way, this phase of forecasting is centrally co-ordinated and synthesised. On the other hand, long-range technological forecasting is carried out in a decentralised and essentially uncoordinated manner by the three services. Although in this long-range framework broad missions are still formulated in terms of functions, the separate approach by the three services means that the old instrumental and " product "-oriented perspective is still basically present.

Moreover, no fully efficient use, for the purposes of US military technological forecasting, is being made of the assemblage of highly-qualified scientists at the Institute for Defense Analyses. The ad *hoc* tasks accomplished by its Research and Engineering Support Division—for example, the recognition of a new fundamental potential in the development of heat-resistant materials, having very far-reaching consequences (see section II.3.3.)—indicate that it might provide that type of technological forecasting whose importance is also being increasingly recognised by industry: the systematic investigation of fundamental potentials and limitations and the provision of focus to fundamental research.

A centrally co-ordinated long-range forecasting effort, which is synthesised and integrated into " top management " thinking, may not only extend the time-frame of overall function-oriented planning but also improve the performance of fundamental research and of the early development phases. In industry, the medium-range forecasting and planning phase, including costing and cost/effectiveness studies, is often entrusted to a decentralised structure (with, or sometimes without, central co-ordination and synthesising); but guidance for fundamental research, forecasting and planning in the " non-functional " research area, and the preparation of " diversifications " are practically always central functions. This rule is followed all the more closely where forecasting and planning have become fully integrated in an entirely function-oriented planning process. The example from industry may prove to be of value in the military area.

In the ***relationship between military administration and industry*** technological forecasting is to some extent a sore point. Occasionally industry, under contract, contributes forecasts for military purposes, and it can—if active in the defence area—use most of the military forecasts. However, military forecasts are not always highly esteemed by industry in the latter's own field of speciality. The wider consensus sought in military forecasts—especially in big concentrated efforts, such as the US Air Force's "Project Forecast "--does not always seem to improve the forecasting vision. These problems, however, appear to be solvable through continuous technological forecasting efforts which place emphasis on a carefully balanced participation of industry. In France, the aerospace industry, for example, has testified to an important positive impact from the work of the military technological forecasting centre in the Ministère des Armées.

In the United States, it is primarily—or at least to a very large extent—up to industry to forecast, propose and " sell " new ideas. This is in contrast, for example, to the situation characteristic of the relationship of the aerospace sector with NASA, the National Aeronautics and Space Administration, which strongly " leads " in the development of new technologies and systems in its area. The reason for this may be seen in the better-defined goals and missions of NASA and in its centralised technological forecasting related to these goal and missions.

It is certainly not an undesirable state of affairs for industry to provide many ideas in the realm of technology. However, there seems to be relatively great uncertainty concerning long-range missions. This is partly due to changes which may not always be avoidable in a field of the highest concern to national policies. On the other hand, apparently currently valid long-range goals and missions are not stated clearly enough (whereas the five-year missions are clearly expressed in the framework of PPBS). Today, American defence industry is often forced to guess the long-range objectives pursued by the Department of Defense and the services.

Section **11.4.5.** showed that forecasting techniques based on relevance tree schemes include assessments of high-level objectives and missions in numericai terms. One of the main tasks of a defense contractor operating a relevance tree scheme has been, thus far, to assess national long-range policies, the relative importance of types of warfare, and missions and tasks—to the best of his ability to derive these from the various policy statements and planning documents (which, however, do not normally cover the time-span required for long-range forecasting).

The top of a typical relevance tree is very similar in structure to a decision tree such as that underlying the Planning-Programming-Budgeting System of the US Department of Defense, and can be made fully identical, both trees representing the same function-oriented approach. Furthermore, the top structures of different versions of relevance tree schemes will normally be very similar and could also be made identical. Only one step would then be needed to incorporate in all military and contractor planning schemes the centrally formulated, " correct " assessments of broad objectives, missions and perhaps also military tasks: the distribution and periodic updating of such tree tops (or their equivalent computer tapes) by a central agency, whether the Department of Defense or the special Presidential Advisory Staff on Scientific Information Management urged by **US** Vice-President Hubert Humphrey.

A RAND report ***(lit. ref.*** 29) is very explicit in stating the Air Force's responsibility:

> " The challenging requirement to forecast the distant-future military environment leads the Air Force, almost inevitably, into a second burdensome responsibility—the responsibility that most significantly alters the character of traditional government-industry relations. Since the Air Force's forecast of long-range military developments, and hence of long-range weapon system needs, must perforce remain highly uncertain, private enterprise cannot risk the vast sums needed to develop distant-future weapon systems. And since the Air Force must consequently accept the financial risks of developing such weapons, it must take up the burden of estimating their ***technologicalfeasibility*** as well as their ***military value.*** The Air Force must become the diviner of technological, as well as military, potentialities.—However unlikely a **task** this may seem for a military department, the assignment is inescapable."

The same report also points out that:

> " Forecasting efforts surely ought to be encouraged and expanded whatever our development philosophy—even though there is always an unfortunate temptation to translate forecasting efforts into specific projections of the future rather than into enumerations of the crucial uncertainties against which we should hedge. " This is explained by the " high cost of ' giant-step ' development programmes, which makes it appear economically infeasible to cover less-likely possibilities. "

H. Kahn remarks in this context that the high quality level of evaluation in the Office of the US Secretary of Defense may even constitute a certain danger that ideas which cannot be properly assessed on the basis of available information—including potentially fruitful "crackpot" ideas—will inevitably fall by the wayside. With less brilliant evaluation groups there is a chance that such ideas may "sneak through."

The general picture presented by military technological forecasting today demonstrates its necessity and its great value in all areas of medium- and long-range development. It may be noted, as one example, that the change wing concept which underlies the new American multi-purpose aircraft F-111A (the former TFX) has emerged from technological forecasting in the US Air Force.

Chapter III.4

THE NATIONAL LEVEL

See also Annex A.3. for a descriptive account of technological forecasting activities identified at national level

It is always wise to look ahead, but difficult to look further than you can see.

Winston S. CHURCHILL.

III.4.1. FUNCTION-ORIENTED NATIONAL PLANNING

Only two countries have so far established a framework in which technological forecasting can be used systematically to aid national planning: France and the United States. Both approaches are strongly function-oriented, and integrate forecasting and planning; thus they happily anticipate the general development which has been pointed out with respect to industrial and military environments. However, France and the United States differ widely in other respects: whereas technological forecasting for the French Plan is mainly a centralised, concentrated effort at five-year intervals in the framework of a rigid five-year plan, the United States has recently created a structure for the continuous performance of decentralised technological forecasting and planning in the framework of a sliding five-year plan, with annual formal revisions. And France, too, now appears to be moving gradually towards more continuous technological forecasting.

The French approach establishes, within the framework of the five-year plan, long-range technological forecasting with a 20-year time-depth (counting from the time the plan goes into effect) for the purpose of aligning medium-range planning with long-range objectives, which are based upon the recognition of long-range potentialities and limitations. The famous " Groupe 1985," which functioned mainly in 1963/1964 in connection with the preparation of the Fifth Plan, constituted the first experiment in this direction. A more ambitious scheme is currently being implemented for the Sixth Plan, with the main effort in long-range forecasting apparently being delegated to an outside institution, which is jointly owned by the government and big industry.

The basic question whether long-range technological forecasting should be performed within the government, or only commissioned and synthesised by it can probably not yet be fully answered. The opinion is frequently encountered[1] that government bureaucracy is a priori not fit to deal in an unprejudiced

1. For example, in the discussions of the Year 2000 Committee of the American Academy of Arts and Sciences, and in the visionary books by Marshall McLuhan.

way with long-range social needs and implications in the context of rapidly advancing technology, and cannot assume the important functions embraced by the idea of " look-out institutions " (see Chapter III.6.). The principal argument put forward to support this view is the department-oriented structure of governmental planning; the function-oriented approaches introduced in France and the United States may be considered a first major step in adapting to the changing tasks of governments with a view to long-range planning.

The ***Planning-Programming-Budgeting System*** **(PPBS),** introduced into the civilian branches of the United States government in October, 1965, after it had been in use in the Department of Defense since 1961, is essentially a medium-range planning scheme with a five- to six-year time-depth (for a more detailed description see Annexes A.2.4. and A.3.10). Its particular features are: the upgrading of medium-range forecasting and planning to a continuous activity which shapes thinking and decision-making in the entire government area and directs them to functions relevant to national objectives and broad social goals; a systems-oriented approach, (including the evaluation of alternatives), which is quite new in government; and the use of advanced techniques, such as systems analysis, operations research, cost/effectiveness studies, and model-building. The introduction of the **PPBS** marks the first adoption of advanced management techniques for the purposes of civilian government and constitutes perhaps the greatest revolution in democratic governmental forms which our century has seen. What this scheme involves can be summarised by the two ideas of " programme analysis " and " programme budgeting. "

A more tangible effect expected of the **PPBS** is, logically, that it will lead to greater cost/effectiveness. Systems analysis will almost certainly point the way to achieving the same result with the use of fewer resources. One need think only of the transport system, which obviously has to be studied as a whole—a requirement which, surprisingly, is only gradually being recognised in governments and has thus far led to only a few preliminary announcements in this sense (for example in France, the Federal Republic of Germany, and the United Kingdom)[1].

Two aspects still remain incompletely solved by the **PPBS**: (1) The departmental structure of the government is retained, although forecasting and planning are function-oriented, While many departments and agencies in modern decentralised governments (there are still centralised governmental concepts, as **in** Switzerland) are function-oriented, this does not hold for the entire government; foreign policy, for example, increasingly includes aspects of scientific and technological advance, of which the American " Atoms for Peace " programme, technical aid to developing countries, and the problem of " disparities " (especially " technological gaps ") between countries are just a few examples. **A** complete function-oriented approach would **imply** programme analysis and budgeting across departmental boundaries—or a fully efficient " matrix management " as it is called in industry—which might present difficulties if carried out on a thorough basis.

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1. A Swedish example may illustrate this point: the big ship yards Gotaverken have taken the initiative of building liquefied cargo ships and importing natural gas to the Gothenburg region, where it is distributed in the area by trucks to industries which have indicated an interest—this regional system might have turned out to be quite different if the national system had been analysed (pipelines, etc.). Other obvious examples include the complete " system " which an air passenger encounters in his trip from and to downtown points.

(2) In the framework of PPBS, long-range forecasting is implicitly conceived in the same decentralised way as medium-range forecasting and planning. It has already been pointed out in connection with the PPBS structure in the US Department of Defense (see Chapter 111.3.) that central co-ordination and the ability to synthesise decentralised input is desirable if long-range implications are to be properly assessed in relation to current planning and if the " overall system " is to be analysed for the purpose of formulating a consistent set of national objectives.

Two different solutions for long-range technological forecasting in the framework of the US Government structure may be envisaged:

The appropriate function could be assumed by the Office of Science and Technology in the Executive Office of the President, which would then operate as the " Chief Scientist" for the government;

A new " staff function " at executive level could be created, for example the special Presidential Advisory Staff on Scientific Information Management, which US Vice-President Hubert Humphrey called for in the Senate in September, 1964, with the specific task of aiding decision-making in areas with long-range implications. A RAND Corporation proposal, " The Science Corps," (*lit. ref. 232*), " re-invents " the idea and develops it further.

The idea of a centralised long-range technological forecasting function in government (but within the framework of a Ministry) is also advanced by Alexander King, the OECD Director for Scientific Affairs, in a hypothetical look ahead at British science policy in the year 1984 (*lit. ref. 261):*

" The Council for Science Policy... which exercises control on behalf of the Minister... is served by the Central Scientific Secretariat, responsible for providing the background data and studies required for a comprehensive science policy, as well as maintaining day-to-day liaison with ' the Plan,' with industry, and with the specialist research councils. Amongst work in progress are (1) the provision of detailed statistics of research and development expenditure, (2) advanced studies in technological forecasting, (3) special surveys of selected scientific fields and of the research needs of different sectors of the economy, (4) investigations of the relationship between scientific creativity and different types of research organisation, (5) studies to elucidate more clearly the nature and economic significance of technological innovation and of the sociology of change, (6) forecasts of the impact of certain scientific developments on foreign policy, and (7) the development of electronic models of the economy and of research input-output networks.—The Secretariat consists of some 187 professionals, most of whom are natural and social scientists, economists, and operational research workers. It is difficult to see how such a small group can seriously hope to undertake the vast range of investigation and analysis required to maintain a realistic and balanced policy... "

Current activities of the British Cabinet Office seem to indicate that such a solution might eventually develop within the framework of the Cabinet Office, which would be properly located in the governmental structure for such a job.

The above-mentioned RAND proposal by Freeman (*lit. ref. 232*) enumerates the possible tasks of a " Science *Corps* " in a central staff position within government:

Provide comprehensive national research strategy and organisation;
Conduct evaluations of scientific proposals;
Perform technical scientific audits;
Develop " sensible " research control procedures;
Sponsor " Research on Research."

It may be added that this should be a clearly defined long-range function which ties in organically with the medium-range functions carried out in a decentralised structure.

Harvey Brooks[1] stresses the importance of decentralised initiative and centralised balancing, and advocates the allocation of research and development funds through mission-oriented agencies instead of broad instrumental agencies such as the National Science Foundation (whose charter is now being extended to include applied research).

An important problem, mentioned only briefly here, is that of consensus, which in some areas will have to be achieved on a wider basis than government can provide. The recent report to the US President on " Technology and American Economy " (*lit. ref. 383*) may be regarded as a first attempt to reach some consensus between widely differing opinion groups on the thorny subject of the future impact of automation.

III.4.2. OTHER INCENTIVES

Italian industry has taken a most remarkable initiative in the area of ***national co-operation in investment planning.*** Annex A.3.6. lists a number of sectoral study and development centres, set up on a private basis, which essentially look at long-range implications, although technological forecasting is so far only an implicit function. In the light of the present positive attitude of Italian industry towards the " programmazione concertata " (concerted planning), one might expect that a future network of such private industrial study and evaluation centres could co-operate (as the existing centres already do) with government to form the National Plan.

In other countries with a national plan, this opportunity has not been grasped by industry. In the United Kingdom, the advantages of such co-operation are frequently pointed out by industry, but the attitude is taken that " the hour is very late " for it. The need for long-range co-ordinated investment planning is felt primarily by the chemical and the pharmaceutical industries in many countries, but only a few partial schemes have so far resulted[2] (for example in the nitrogen products sector in the United Kingdom and also on a European basis). The project for a European co-ordination scheme among 25 chemical companies is still in the informal discussion stage and is apparently leading nowhere.

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1. In a speech given before the Conference on Technology Transfer and Innovation, 15-17 May 1966, Washington, D.C.
2. Lord Beeching of I.C.I. (Imperial Chemical Industries, Ltd.) remarks in this context that, apart from mutual distrust, the main reason for the failure to agree has to be seen in the fact that high-level negotiations ignore the conditions existing on the operational level and therefore rarely lead to implementation.

The problem of technological forecasting at national level has **also** recently come to the fore, for very different reasons, in Canada, Switzerland and Israel: whereas Canada is torn between the alternatives of comfortable dependence **and** an arduous effort towards greater technological independence40 per cent of Canadian industrial production capacity is controlled by United States companies, as compared to only ***5*** per cent of European capacity—Switzerland feels an increasing impact on its industrial programme resulting **from** limitations on foreign labour **and** capital.

Israel, entering the fourth stage of its struggle to life—the stage of industrialisation, coming after those of exploitation of natural resources, modernisation of agriculture, and formation of effective defense forces—will probably become a unique example of the importance of technological forecasting in an accelerated and ambitious industrialisation process. There will be significant lessons to be learned for developing countries which are embarking somewhat more slowly, on the same path. Existing industry almost completely lacks the necessary entrepreneurial spirit, so that government has to take the initiative, possibly by creating a national industrial construction corporation which could be aided by technological forecasting performed as, or feeding into, **a** high-level staff function attached to the Prime Minister's Office. The following criteria, tentatively formulated by S. Freier of the Weizmann Institute, exemplify imaginative and ambitious thinking with a view to boosting the country's economy:

1. Develop the exploitation of natural resources having superior economic characteristics and develop, at the same time, new applications for them. (Bromine occurs at the Dead Sea Works in a concentration 100 times greater than elsewhere in the world. 250,000 tons per year could be produced, as compared with 7,000 tons at present. The world market amounts to 150,000 tons at present, of which 100,000 tons are " not feasible " for Israel as a result of existing political patterns. **As** a consequence, the development of new applications, for example flame-proof wood and plastics, is emphasised in Israel.)
2. Choose suitable industrial sectors with a high scientific content, where a small country can compete, for example by making special and " tailored " products. (Fine chemicals and electronics instruments have proved a successful beginning here and medical electronics may be another promising option ; fertilizer development specialises in high-concentration fertilizers to avoid excessive transport costs from Israel to Europe—the added incentives for the users may enhance the success.)
3. Find entirely " open " fields for competition. (Photochemistry and applications of molecular biology to agricultural problems are **pos**sible " growth " sectors of this kind.)
4. Participate in problems of world-wide interest. (The joint study of the problem of nuclear water desalination by Israel and the United States is a striking example. The idea is to let a big country lead and subsequently to participate in a reasonable way in the industrial exploitation.)

III.4.3. THE ROLE OF PROFESSIONAL SOCIETIES

The Engineers' Joint Council (EJC) in the United States *(lit. ref. 264)*, in a highly critical statement, has very clearly enunciated the responsibility of professional societies in the area of technological forecasting:

“ Professional engineering societies have lacked the mobility to grasp the full dimensions of the rapidly changing technological needs of society. Traditionally, the engineering societies have been organised **on** a national basis around certain rather distinct, well-defined technologies, such as civil, electrical, or mechanical engineering. Their primary attention has been devoted to certain dominant fields which tend to become self-perpetuating.

... There are areas of urgent need for technological development which have been largely ignored because the engineering societies have lacked the foresight, the organization, and the mobility to identify these emergent technological needs and then to move forcefully to open up their resources to pioneer new developments. This has led to a serious unbalance in technological development. It becomes strikingly evident, for example, in the fields of transportation, urban development, environmental control, technical assistance to foreign nations, etc., where billions of dollars are being spent annually, with totally inadequate research and development and only fragmented attention by the engineering societies.

There is no forum in the engineering societies where scientists and engineers can explore scientific frontiers and their future technological applications together. Despite the fact that technology of the future will find many of its greatest innovations on the scientific frontiers, the sporadic, fragmented, shallow treatment of science has alienated the scientists and has generated technological provincialism that fails to see the larger technological potentialities in the rapidly advancing sciences. Some form of cooperative endeavor of the engineering societies will be necessary to overcome this fractionated, superficial outlook and develop a smooth and effective transition from science into technology. ”

In spite of this clarion call, made in 1962, the situation has not changed significantly in the United States, not to speak of other countries where professional societies are traditionally much slower in adapting themselves to needs.

The Engineers’ Joint Council, which itself undertook a remarkable study of “ The Nation’s Engineering Research Needs 1965-1985” (*lit.* ref. *264*), from which the above statements have been taken, has apparently lost much of its drive in this direction, although it still plans to repeat the forecasting effort periodically, This is especially unfortunate in view of the Engineers’ Joint Council representing a unique scheme of collaboration between a dozen of the most important engineering societies, and being able to count on the participation of leading people from civilian government, military administration, universities, and industry, as the impressive membership list of the committees for the above-mentioned report demonstrates.

In Europe, there is perhaps only one society comparable to the Engineers’ Joint Council in its scope and possibilities of action[1]: the Royal Swedish Academy of Engineering Sciences (IVA), which appears to possess the necessary aggressive spirit, but has not yet formulated programmes in the area of technological forecasting.

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1. EIJC, the British Engineering Institutions’ Joint Council, originally modeled after the EJC, has abandoned most of the more ambitious tasks originally envisaged.

The foremost initiative by a professional society—if this term is applicable to the present example—is to be found today in the US National Academy of Sciences with its ambitious COSPUP programme in the fields of fundamental science (see Chapter **1.4.** and Annex A.3.10.). The US National Academy of Sciences, through its intricate relationship with the National Research Council, is in a unique position to perform forecasting tasks on a national level: it has access to the research sections of the National Research Council, and ties in with all levels of government; its conclusions and recommendations go directly to the departments and agencies concerned and to the Executive Office of the President. Many people in the United Kingdom would like to see the Royal Society in a similar situation, and a number of Fellows of the Royal Society (which now also accepts " applied " scientists) advocate **a** restoration, along these lines, of the important role the Society played in public life in the 19th century.

The problem of organising the scientists and engineers of a country to make possible their well-ordered participation in the formulation and implementation of national objectives is extremely important. Satisfactory **solu**tions are still very rare, especially in Europe.

Governments may also ask industry to perform general look-out and forecasting functions in technological fields of key importance to national objectives. **An** intelligence, analysis, and forecasting centre for aircraft propulsion was recently set up in an important company in this field upon the request of the government.

Chapter III.5

INTERNATIONAL ORGANISATIONS

See also the outline of technologicalforecasting activities identijied in International Organisations, in Annex A.4.

The most powerful way to action is to state a problem.

René DUBOS.

The *tasks* for technological forecasting in an international context may be described in the following ten points:

1. The formulation of broad goals and objectives for technological development, mainly in the area of social technology.
2. Technological forecasting at the fundamental science and technology level, preferably through a strong normative approach—i.e. the systematic assessment of fundamental research potentials with a view to their contribution to pre-determined social goals (population control, health, nature conservation, nuisance control, harmful effects of technology, etc.). The exploratory approach—for example, early interpretations of future technological potentials arising from scientific discoveries—is desired in " alert " technological environments, but cannot be expected to cause substantial impact. **(UNESCO** has published one ambitious report along the line of an exploratory approach; see ***lit. ref. 251).***
3. Systems analyses of regional economies from the point of view of technological innovation, assessing alternative ways of introducing new technologies and deriving an optimum solution (for example for the large-scale introduction of nuclear energy in Europe, taking into account interdepencies between the present and future reactor generations—plutonium build-up for fast reactors, etc.—and the complete supporting system from fuel mining to reprocessing and waste disposal). The evaluation of the potential of large-scale co-operative schemes for research and development, manufacturing, application and service engineering, management and marketing, may be of particular value in connection with the numerous incentives for " integration " today. The industrialisation of developing regions (analyses of the total systems comprising urbanisation, water and power supply, transportation, raw material supply, related industries, markets, etc.) constitutes another important problem.
4. Technological forecasting in specific technological, industrial, or economic sectors for which a planning or co-ordinating function has

been entrusted to global or regional organisations. (CECA, **Euratom**, and ICAO, are already prominent in this area—see Annex A.4.).

5. Technological forecasting in broad economic sectors, taking a function-oriented systems analysis approach to determine how future technologies will fit given (or pre-determined) functions. Particular emphasis should be placed on technological and acceptance cycles and on structural changes in industrial and international patterns that may be caused by technological innovation (the "growing together" and the changing functions of industrial sectors, the "technological gap" between America and Europe, etc.). An interdisciplinary approach may be required for more ambitious tasks in this area undertaken with a view to reaching conclusions about the political, social, economic, and technological implications and to the formulation of normative guidelines.
6. Technological forecasting in specific industrial and economic sectors with the aim of providing an "early warning system" for countries which might be unfavourably affected by new technologies. This function could apply to different levels, for example to the question of the "technological gap" between America and Europe (this approach would constitute a merely defensive attitude while point (5) reflects higher ambitions), and to the problems of developing countries, especially those which depend on the export of one or a few raw materials which might be synthesised by new techniques. (Several years ago the US Senate investigated the question of the threat to raw materials markets and the implications for developing countries—see *lit. ref. 395).*
7. Technological forecasting on behalf of developing countries in technological areas which are applicable exclusively, or predominantly, to developing economies—e.g. non-conventional electricity generation in small units, water desalination, etc. (An activity along this line has been proposed for possible future inclusion among the tasks of the UN Advisory Committee on the Application of Science and Technology to Development by its Russian member, Prof. Gvishiani. The two UN conferences held in Rome 1961 and in Geneva 1963—see Annex A.4.3.—helped promote the carrying out of this task).
8. Normative technological forecasting for the purpose of promoting horizontal technology transfer—diffusion of existing technology, new ways in applications and service engineering, etc. (Numerous activities on different scales, including the tasks of the OECD Pilot Teams Project, can be found in international organisations—see Annex A.4.).
9. An active role in the development of techniques for the improvement of technological forecasting, preferably in the area of social technology.
10. Promotion, initiation, and sponsorship of "look-out institutions" (see Chapter III.6.) which would have the task of systematically evaluating alternative feasible futures in order to provide guidance to present developments, mainly in the area of social technology. This task, although it is the most important one outlined in these ten points, has been placed last, because, as one of its principal promotors has remarked *(lit. ref. 165)* " the large-scale international poli-

tical institution, of which the UN is the single-most current example, has not yet succeeded in either defining or imposing its authority in a manner that would make it practical for such work to be undertaken under its aegis." On the other hand, " this possibility appears attractive at first for the simple reason that it suggests a distribution of beliefs over the whole of mankind, and a control which being aggregated in terms of entire nations remains pluralistic." Point (2) can be regarded as a form of point (10) and may be recommended more wholeheartedly for action by international organisations.

The present situation can be summarised by stating that international organisations have as yet recognised few of these tasks and have taken action with respect to still fewer. Only points 2, 4, 6, 7, and 8 have received any attention. Among the organisations which have undertaken action in this field, only three—CECA, Euratom, and ICAO—have been found to be capable of performing valuable in-house forecasting.

International tasks have also, to some extent, been undertaken by ***foundations***, e.g. the Rockefeller Foundation examines converging developments and needs and has recently redefined its programme in line with an orientation towards social goals. Two of these goals are being pursued at national level (cultural development, and education for disadvantaged groups), and three at international level (the conquest of hunger, population control, and university development).

The initiative taken by the US Senate in line with point (6), the forecasting activity of the Israel National Physics Laboratory in the area of solar energy conversion (see Annex A.3) and a " Scientific American " series on " Technology and Economic Development " (*lit. ref. 380*), containing broad technological forecasts, have also contributed to the performance of international forecasting tasks.

The problem of ***developing economies*** obviously constitutes a salient issue in a context of technological change and forecasting. Leontief, by applying his input/output analysis, observes that the internal structures of developing economies are also largely dictated by technology (*lit. ref. 380*).

Global implications of emerging technologies are not difficult to recognise. Technologies which are international in character can be easily defined, and broad trends readily discerned. The crucial problem comprises the formulation of goals and objectives—which normally requires a consensus of countries and governments possibly differing widely in their views—and the detailed forecasting work.

In this connection CECA has found a successful formula for co-operation with the Battelle Memorial Institute. Ambitious forecasting tasks which require specialist knowledge in scientific or technical fields and the use of advanced techniques such as systems analysis, could probably be performed by such institutes and by consulting firms. International organisations are in the favourable position of being able to make use of institutes whose activities are restricted to areas of public interest (for example, the System Development Corporation in Santa Monica, California, which offers the otherwise unaavailable full intellectual background developed at the RAND Corporation). The in-house capabilities required of an international organisation making use of such institutes would then be reduced to those needed for carrrying out co-ordinating functions and, if possible, for synthesising the work done outside.

" LOOK-OUT " INSTITUTIONS

See also Annex A.5. for a descriptive account of activities identified in this area

Active advocacy, whether in the form of normative planning or in some other form, has become the intellectual and ethical duty of our age.
Hasan OZBEKHAN.

The hour is very late, and the choice of good and evil knocks at our door.
Norbert WIENER.

The idea of " look-out " institutions[1], mainly in the area of social technology, is " in the air " in many countries and on both sides of the Atlantic. It is actively promoted by a number of distinguished scientists as well as semi-professional " futurologists."

The primary aim of the "forerunner" activities which are listed in Annex A.5. (to the extent that such activities have been identified in the course of this study), is two-fold: *(a)* to create a climate of opinion, and *(b)* to search for missions. The area of social technology, although the most important, generally lags far behind military and economic technology in the attention it receives and the funds allocated to it. " Look-out " institutions, providing a " driving-force " for future-oriented work, may ultimately bring about a change in this relationship.

The main function of a full-fledged " look-out " institution will be " to conceive of possible futures; to create standards of comparison between possible futures; to define ways for getting at such possible futures by means of the physical, human, intellectual, and political resources that the current situation permits to estimate " (*lit. ref. 165).* The significance of looking at alternative feasible futures, and of effecting, by way of a feedback cycle, proper modifications of our present planning, has been outlined in Chapters I.3. and I.7. and in section II.5.1.

The main problems on which " look-out " activities concentrate today are: the dangers of random power, the impact of automation and the threats arising from unemployment and leisure, the distortion of the biological environment, population explosion (crowding), and urban living.

An important idea was recently formulated by M. Michaelis[2]. The " forerunner " activities in this area should be monitored nationally with the intention of subsequently using this experience at a national level. Monitoring might also be envisaged on an international level and could become a worthwhile activity for an international organisation.

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1. The term " look-out " institutions has been proposed by Ozbekhan as a modification of de Jouvenel's " look-out agencies."

2. In a paper presented to the Conference on Technology Transfer and Innovation, 15-17 May 1966, Washington, D.C.

ANNEXES

Annex A

TECHNOLOGICAL FORECASTING ACTIVITIES IN NON-INDUSTRIAL ENVIRONMENTS IDENTIFIED DURING THE OECD INVESTIGATION

A.I. FORECASTING INSTITUTES AND CONSULTING FIRMS

The Institute for Defense Analyses (IDA) which works exclusively for the US Department of Defense, has not been included in this list (see Annex A.2.4. for its functions).

A.I.I. *ABT* ASSOCIATES, INC.

Address: *55* wheeler street, Cambridge, Massachusetts 02138 (USA).

Founded in 1965 by Raytheon scientists, Abt Associates specialises in operations research, social science, systems engineering and computer simulation efforts. Although Abt have worked so far mainly for the US Department of State and the US Air Force, they are free to accept problems from international organisations, governments, industry and commerce.

The inter-disciplinary approach, with systems analysis in the political, social, economic, and technological areas, can be applied, in particular, to development economics. Original model-building for computers and gaming concentrates on interdisciplinary problems of this kind.

Technological forecasting up to a 15-year time-depth has been performed as an input function, e.g. for the report on " Great World Issues of 1980" *(fit.* ref. 83).

A special technique, useful for technological forecasting, has been developed to generate alternatives. It comprises five steps: *(a)* Extrapolation of trends with a probability range; (*b*) Scenario-writing; (c) Random mixing of variables; (*d*) Computer analysis; (e) Iteration and refinement of the process by relative probability analysis and improvement by incremental forecasting, thereby reducing the " noise level " of forecasting.

A.1.2. BATTELLE MEMORIAL INSTITUTE

Adresses: *505* King Avenue, Columbus, Ohio 43201 (USA);
7 route de Drize, CH-1227 Carouge-Genbve (Switzerland);
Frankfurt/Main (Federal Republic of Germany).

A non-profit organisation, mainly for research. Technological forecasting enters into Batteile's activities in three different ways:

1. *Ad hoc* forecasts in connection with corporate planning services which represent approximately **25** to 30 per cent of Battelle's total activities;
2. Development of forecasting techniques; in this area the Technical Planning Center of the Mechanical Engineering Department in Columbus is particularly active; **a** policy of publishing all techniques has been adopted. **See**, for example, *lit.* ref. ***90, 105, 138 and 179;***
3. Technological forecasting for internal purposes, especially in connection with Battelle's proposals for jointly sponsored research and development programmes.

The following details are of interest with respect to area (1): Technological forecasts fit mainly into the Advanced Corporate Thinking (ACT) activity which ranges from continuous programmes (for example, the $ 500,000 per year programme for NASA on optimum strategies for unmanned space programmes) to *ad hoc* forecasts in the **$ 10,000** to $ 50,000 range.

Approximately **100** to **150** projects per year undertaken by Battelle involve technological forecasting. These projects are handled by interdepartmental task forces which also prepare the forecasts, drawing on other specialists in-house; there is no separate forecasting group. In Geneva, technological forecasts are prepared mainly by the Applied Economics Department, with the help of specialists from other departments.

Recent ad *hoc* studies for governments and industry have included:

- Consumer market patterns for **1975** in the United States and the Common Market countries (Columbus and Geneva)—see lit. ref. **119**;
- Future patterns of industrial fuel consumption, new steel technology, and other studies for CECA (see Annex **A.4.1.**) (Geneva with aid from Columbus);
- Demand for metals (Columbus);
- Impact of new metals (Columbus);
- Demand for sulphur (Columbus and Geneva);
- Synthetic lubricants (Columbus);
- Railroads (Columbus, joint sponsorship);
- Plastics in house-building (Geneva, joint sponsorship);
- Steel in the construction industry (Geneva, joint sponsorshop);
- Numerous studies in connection with developing economics, for AID (Columbus);
- National policies, position of specific industries and firms in the framework of national policies, export boosting, etc. (planned at Geneva).

A.1.3. BUREAU D'INFORMATIONS ET DE PRÉVISIONS ÉCONOMIQUES (BIPE)

Address: **122,** avenue de Neuilly, **F-92** Neuilly-sur-Seine (France).

Founded in **1958** and owned jointly by the French Government **(50** per cent share) and approximately SO important French industrial companies, BIPE has been entrusted with the preparatory work for the technological long-range forecasts to be incorporated into the forthcoming VIth National Plan **(1971-1975).** For this purpose, a long-range forecast file in **20** product lines of particular importance to the French economy will be completed by the end of **1966** and will subsequently be continuously updated and extended. Industry (shareholders only) will be able to consult this file.

The input for the technological forecasts is obtained from the following sources: (*a*) consultants of DRME (Division de Recherches et **Matériels** of the Ministère des **Armées**); (*b*) private industry (approximately 30 of the SO founders are taking an active part in the preparation of the file); (*c*) literature (only occasionally); (*d*) as from 1968, a Washington branch office is expected to contribute.

A.2.4. CORPLAN ASSOCIATES (an affiliate of the IITRI, Illinois Institute of Technology Research Institute).

Address: **10 West** 35th Street, Chicago, Illinois 60616 **(USA)**; branch offices in New York and The Hague (Netherlands).

Technological forecasting enters into corporate planning activities in various ways including new product planning, future-oriented market research, acquisitions and mergers, etc. A series of comprehensive studies in the future development of industry in the Chicago area has been made. The scientific and technical capabilities of the Illinois Institute of Technology Research Institute (IITRI), formerly Armour Research Foundation, are at the disposal of Corplan.

A.1.5. THE DIEBOLD GROUP, INC.

Addresses: **430** Park Avenue, New York, N.Y. **10022** (USA);
Diebold Europe, Goethestrasse 3, Frankfurt/Main (Fed, Republic of Germany); and other branch offices.

Diebold is a consulting firm, specialising in information technology. Technological forecasting activities are three-fold:

1. The Diebold Research Programme, started in **1963,** a jointly sponsored project for assessing the impact of future technological developments in the information technology area (especially computer development) on business and management with emphasis on applications of potential interest to the sponsors. The first two years

of the programme were devoted mainly to 10-year forecasts in the area of information processing equipment, while the focus is now on applications, feedback problems, etc. Contacts with industry provide the input information. Participation in the programme costs $ 16,000 per year for computer manufactures and $ 9,600 per year for users. Approximately 60 American and 40 European companies participate, the latter being served by Diebold Europe in Frankfurt/Main.

2. Technological forecasts, usually with a five- to seven-year time-depth, prepared in connection with management consulting work. This activity may become integrated with (1).
3. Internal technological forecasting.

A.1.6. HUDSON INSTITUTE.

Address: Quaker Ridge Road, Croton-on-Hudson, N.Y. 10520 (USA).

A non-profit organisation, specialising in scenario-writing and the evaluation of alternative future environments in a broad political, social, economic, military, and technological context. Works mostly for the US Government, but is available occasionally for other work in the public interest.

Technological forecasting is required in the work which the Institute contributes to the Year 2000 Committee of the American Academy of Arts and Sciences *(lit. ref. 352).* Forecasting in the same broad political-social-economic-technological line has also been performed under contract with the Martin-Marietta company *(lit.* ref. 272).

Apart from work in the military area, technological forecasting in specific fields includes a recent informal report on " Technology and the Prospects for World Food Production " (lit. *ref. 288)* and a survey of techniques for technological forecasting (*lit. ref.* 89).

A.1.7. ARTHUR D. LITTLE, INC.

Address: 25 Acorn Park, Cambridge, Massachusetts 02140 (USA), with branch offices in Chicago, San Francisco, New York, Washington, Santa Monica, Edinburgh, *London,* Mexico City, Toronto, Zurich, and Brussels. Address of European head office: *2,* place du Champ-de-Mars, Brussels (Belgium).

A non-profit research organisation. Technological forecasting activities are divided *into* three parts:

1. " Service to Management " Programme, a " package " available for a $ 5,000 per year subscription fee and comprising: *(a)* 20 to 25 technological forecast reports per year in all technical areas, aiming at approximately a five-year time-depth (areas are periodically reviewed as necessary, computer technology every 18 months, etc.); *(b)* 30 to 35 letters of informal comment per year, containing some individual forecasts; (c) 10 to 12 discussion meetings in areas of particular interest; (d) management briefings and other types of consulting work. Half of the subscription fee is set aside for individual work for the participant. Parts of the programme are also available on a selective basis, under certain conditions. In 1966, more than 100 companies and government agencies from the US and five European countries participed in the programme.
2. Large-scale multi-client efforts in technological forecasting, for example the $ 300,000 project on microminiaturisation in electronics, undertaken for 12 large US companies in 1962 (when integrated circuits were imminent).
3. Ad *hoc* forecasts in connection with general management consulting in three areas: *(a)* corporate planning; (b) product and service planning; (c) market research. In addition advice is given on the creation of a proper environment for innovation *(see* also *lit. ref.* 44).

A.1.8. MCGRAW-HILL ECONOMIC DEPARTMENT

Address: 330 West 42nd Street, New York, N.Y. 10036 (USA).

The economic department of the big scientific and technical publishing house issues forecasts on the American economy viewed mainly against a background of technological change: " America in 1975 " and " The American Economy — Prospects for Growth Through

1980" (Sept. 1965, see *lit.* ref. 274). This series, which is to be continued, developed out of the intention of providing a homogeneous forecasting base for the different scientific and technical periodicals published by McGraw-Hill. The reports are available free of charge upon application.

In addition, Mc-Graw-Hill prepares three-year forecasts of research and development expenditures, rate of innovation in industrial sectors, and expectations concerning the probability of breakthroughs (see *lit. ref.* 54). For both series, input information is based on the statistical evaluation of questionnaires sent out to industry.

A.1.9. NATIONAL PLANNING ASSOCIATION

Address: 1606 New Hampshire Avenue, N.W., Washington, D.C. 20009 (USA).

A non-profit organisation, which publishes the series " National Economic Projections " (yearly subscription rate $700) on the American economy; these are basically 5- to 10-year economic projections, sometimes viewed, to a considerable extent, against a background of technological change. Recent examples: " National Economic Projections 1975" and " American Industry in 1976 and 1985—Projections of Output, Employment and Productivity " (Report 64-1).

A.1.10. THE RAND CORPORATION

Address: 1700 Main Street, Santa Monica, California 90406 (USA).

The famous non-profit organisation, working under contract for the US Air Force, and which, since 1948, has developed the systems analysis technique, the military cost/effectiveness system, the Planning-Programming-Budgeting System for the Department of Defense (*see* Annex A.2.4.), contracting systems, etc., and has rediscovered gaming.

Apart from its important work in the defence and national security as well as foreign policy areas, the RAND Corporation also maintains some activity in civilian areas of public interest, and has become a leader in forecasting in the social technology area. Typical subjects of this type of forecasting, carried out on the basis of systems analysis, are urban planning, city building, transportation and future forms of vehicles, natural resources, etc. Reports in this area are unclassified and available from the Federal Clearinghouse for Scientific and Technical Literature, but are sometimes difficult to identify.

The RAND Corporation has also been active in investigations concerning technology transfer and technological innovation in general (see for example *lit. ref. 65)* and has contributed to the development of forecasting techniques, such as " learning curves," gaming, model-building and, of course, systems analysis. The most recent addition is the " Delphi " technique (see section II.2.3.), which is being tested at present. The RAND Corporation is now becoming a leader in the development of special forecasting techniques in the area of social technology, and will probably assume a consulting role for civilian government in connection with the introduction of the PPBS (see Annex A.3.10).

A.1.11. RESOURCES FOR THE FUTURE, INC.

Address: 1755 Massachusetts Avenue, N.W., Washington, D.C. 20036 (USA).

A non-profit organisation, fully financed by the Ford Foundation, established in 1953. Not available for other tasks. Author of the volume " Resources for America's Future " *(lit.* ref. *273).* Technological forecasting is now carried out internally in the following groups: (*a*) land-use; (*b*) water; (c) energy and minerals; (*d*) regional development; (c) appraisal; (*f*) environment (pollution, etc). The appraisal programme is of particular significance: it constitutes perhaps the first systematic experimental attempt to quantify social goals in terms of cost/effectiveness.

A.1.12. SAMSON SCIENCE CORPORATION/QUANTUM SCIENCE CORPORATION (affiliates of Samson Associates, Inc.)

Addresses: 245 Park Avenue, New York, N.Y. 10017 (USA), and 851 Welch Road, Palo Alto, California 94304 (USA); branch office planned in Brussels (Belgium).

A group of senior ex-industry people specialising in selling judgment (not only data) in the applied physical sciences business area, especially electronics. Close contacts with industry constitute the main source of input information.

Samson Science Corporation is the " publishing house," putting out highly qualified and very explicit technological forecasts in the following two forms:

1. " Samson Trends," a monthly publication, begun in 1963, with a $ 150 per year subscription rate and relatively wide dissemination, aimed mainly at the science-oriented investment business. Technological forecasts in selected areas are supplemented by current technological indicators and stock averages.
2. " Samson Reports," an irregular series of thorough technological forecasts in key areas. Two reports had appeared by 1966: (a) Satellite Communications—Comsat and the Industry (Nov. 1964—see *lit. ref. 334*), price $95; and *(b)* Microelectronics—Revolutionary Impact of New Technology (1965—see fit. *ref. 333*), price $ 60.

The activities of Quantum Science Corporation are two-fold, consisting of financial and corporate consulting. The corporate consulting activity issues **MAPTEK,** a five-year technological forecast in the electronics sector in the form of an input/output table, begun in 1965 and now sponsored by approximately *50* companies at a subscription rate of $ 10,000 to 50,000 per year depending on scope (for a detailed description, see section 11.3.12. of this report). MAPTEK now comprises *500* categories, to be extended to 1000; it is planned to make MAPTEK the core of the reporting system for all technological forecasts prepared by Samson and Quantum and also to extend the input to European economics. On-line access to information is also now being planned.

In addition, Quantum Science Corporation prepares *ad hoc* forecasts, usually in the 2,000 to $ 50,000 range, advises on strategies, future competition, and future markets, and develops techniques for analysing the introduction of new products in relation to market needs and company growth policies.

A.1.13. Société d'Études et de Documentation Économiques Industrielles et Sociales (SÉDÉIS)

Address: 205, boulevard Saint-Germain, Paris 7e (France).

A non-profit organisation which publishes the " Futuribles " series; the latter was initially financed by the Ford Foundation (USA), administered by FERIS (Fondation pour l'Étude des Relations Internationales en Suisse) and directed by an international steering group.

The " Futuribles " (which means " possible futures ") investigate alternative future environments in the broad political, social and economic areas—with technology entering in a direct way only occasionally. 107 issues had appeared by the end of 1965. They were published as part of the " Bulletin SÉDÉIS " which appeared three times each month until the end on 1965. As of 1966, a monthly publication " Analyse et Prévision " is supplemented by " Chronique d'Actualité " three times a month.

" Futuribles " have also published collections of the papers in book form and sponsor the periodical " Perspectives, Studies in Social and Political Forecasting " (Supplement to the Indian Journal of Public Administration, New Delhi, India).

A.1.14. Stanford Research Institute

Address: Menlo Park, California 94025 (USA); branch offices in Washinton, New York, Detroit, Zurich and Tokyo (Japan). Address of European office: Pelikanstrasse 37, Zurich (Switzerland).

The " pioneer " among technological forecasting institutes, having.made available systematic work in this area as far back as 1958, specialises in the interactions between science, technology, and society.

Technological forecasting is offered mainly in the framework of the Long Range Planning Service (LRPS), a package comprising: (a) Long Range Planning Reports (see below); (*b*) Special Research studies, which discuss key problems in management planning areas; *(c)* Information Center (see below); (d) Inquiry Service; (e) Personal consultation; (*f*) Round Tables, held at frequent intervals each year in major cities; (g) an Annual Client Conference. Annual subscription rate is $ 4,000 for companies, and $ 3,000 for agencies wholly supported by public funds (a minimum two-year subscription is required). By the end of 1966, approximately 400 companies and agencies participated.

The " Long Range Planning Reports," which form, as has been pointed out above, an integral part of the Long Range Planning Service, were begun in 1958 and currently appear at a rate of approximately 40 reports per year, covering all areas in which technological, economic, social, or political change occurs (including such topics as The Impact of Medicare, Britain and the Common Market, Unemployment, etc.). The time-depth aimed at is generally between five and 15 years (25 for nuclear energy). The reports are prepared by the staff of the Long Range Planning Service (50 people, of whom 30 are professional) which relies partly on specialists of the institute and on outside consultants; 40 per cent of the work is done by the LRPS staff, 60 per cent outside. 600 periodicals are followed regularly by the LRPS staff, and 400 to 500 suggestions are received every year from participants, institute staff, and others. 50 projects are started every year, of which 10 are abandoned on the average. More than 300 reports had appeared by the end of 1966. Starting in 1964, the service has included each year a complex of several reports grouped together around a broad subject:

- Fall 1964 (reports 232 through 236): " The World of 1975," comprising reports on The International Prospect, Economic Trends, Governmental and Political Trends, Science and Technology, A Social and Cultural Framework;
- Fall 1965: A series of studies forecasting how different industries will respond to these 1975 environments;
- Fall 1966 (in preparation at time of writing): " A Framework for R & D Planning," composed of studies on planning methodology and techniques, including techniques related to technological forecasting, and analyses of past forecasts;
- Fall 1967 (planned): " The Management of Innovation," including a report on Methods of Forecasting Technological Change.

The Information Center (also " Planning Library ") is accessible to participants in the LRPS. It contains the complete background material for the Long Range Planning Reports, classified by report and filed, either in the original or in photocopy, together with annotated copies of the reports. Inquiries may also be made by mail and photocopies may be requested. It is planned, starting in 1967, to include the microfilmed background material with the reports.

The " SRI Journal ", appearing irregularly five to six times a year and containing in each issue " spin-off " from the LRPS in one or several fields, is available free of charge upon request.

A.1.15. STUDIENGRUPPE FUER SYSTEMFORSCHUNG

Address: Werderstrasse 35, Heidelberg (Federal Republic of Germany); planned subsidiary in Berlin " Institut fuer Automation ".

A non-profit organisation, financed by the Federal Government, but available for work in governmental or international context.

Ad *hoc* forecasts, on a joint-sponsorship basis, each representing a total effort of between $ 300,000 and $ 500,000, are undertaken in areas of rapidly advancing technologies, such as electronic components (1966) and scientific instruments (in progress in 1967). The Studiengruppe contributed to the brochure " Deutschland 1975 " (for the election campaign of the Socialist Party), and started forecasting in the field of programmed education. It is interested in the development of forecasting techniques, especially gaming and model-building.

A.1.16. SYSTEM DEVELOPMENT CORPORATION

Address: 2500 Colorado Avenue, Santa Monica, California 90406 (USA).

A non-profit organisation, originally a division of the RAND Corporation which separated in 1956. Available to national and local governments and to international organisations.

Specialising in data-based management systems, SDC applies corporate planning methods and systems analysis to the public domain and is becoming a leader in their application to social technology. It is particularly active in developing techniques for future probabilistic forecasting in the area of social technology with the use of advanced information technology (see also section 11.5.2.). Present applications of information technology by SDC concentrate on education planning.

A.1.17. TEMPO CENTER FOR ADVANCED STUDIES, GENERAL ELECTRIC CO.

Address: 816 State Street, Santa Barbara, California 93102 (USA); branch offices in Washington and Honolulu, planned in Europe.

TEMPO (Technical Military Planning Operation—now also Technical Management Planning Operation)—is formally a department of the Defense Planning Operation in General Electric's Defense and Aerospace Group; in existence since 1956. Only 20 per cent of the work is for the parent company (mainly as an advisory function to top management), the rest being for the United States and foreign governments and other industry (restricted only by the requirement that no conflict of interest exists in business areas overlapping with General Electric's activities).

TEMPO's speciality is the application of strategic techniques to business. It is probably the only consulting company which applies total systems analysis in the form first developed by the RAND Corporation and now being used in mission and weapon systems evaluation to business and civilian economic problems. Its deep roots in a large and highly diversified industrial concern on the one hand, and in military planning, on the other, make it a unique consulting group.

Technological forecasting is performed in the following areas:

- Defence (for the US Government): strategic warfare, weapon systems in future environments, cost and logistics of total weapon systems;
- Management techniques;
- Business strategies;
- Application areas, for example in developing economies (a study for the government of Algeria is in progress in 1966);
- Specific technological areas for General Electric and other companies (recent examples: fuels, information technology);
- Environmental analyses (future markets) for General Electric or other companies.

In technological forecasting TEMPO distinguishes between Complete System Studies (comprising market, supply alternatives, and cost/effectiveness aspects) and partial studies. Recent examples of Complete System Studies include: *(a)* Nuclear Merchant Shipping 1965-1985 (for General Electric); *(b)* Commercial communication satellites; *(c)* North American water and power; (*d*) Gold industry in the USA. Recent partial studies include: *(a)* Utility patterns over the next 20 to 25 years (only market aspects, for General Electric); and *(b)* Cost-resource models for programme planning (only supply alternatives).

A.1.18. OTHER CONSULTING FIRMS

Consulting firms which were frequently mentioned during the investigation for this report, but have not been visited, include:

- Dynamar, Bazainville, Seine-et-Oise (France), specialising in future social environments; owned by British Petroleum Ltd., London, but also available for outside consultation;
- Equity Research Associates, Inc., New York (USA), which make use of the reports of the Midwestern Research Institute;
- IFO Institut, Munich (Federal Republic of Germany), reported on the social impact of technical progress and forecast freight traffic, for example;
- Prognos A.G., Basle (Switzerland), specialising in economic forecasts and consulting work with considerable technological background;
- Simulatics Inc., New York (USA) reportedly working along the same lines as Quantum Science Corporation;
- Stollar Associates, Inc., New York (USA), reportedly specialising in nuclear energy.

In addition to these consulting firms, the Atomic Forum in New York has also been mentioned as a valuable source of forecasts in the nuclear energy area.

A.2. MILITARY ENVIRONMENTS

A.2.1. FRANCE

Centralised technological forecasting (by the Ministère des Armées) has been carried out since 1964 in the framework of a succession of rigid (non-sliding) five-year plans. The principal aims are (*a*) to orient defence research policy and *(b)* to point to long-range consequences of decisions. Top criterion is cost/effectiveness, introduced more as an attitude in the absence of a rigorous scheme for its assessment.

Technological forecasting has been handled, since February 1964, by the " Centre de Prospection et d'Évaluations, " a staff function directly attached to the Minister and (at the beginning of 1966) composed of 19 professional people, divided about equally among military officers, engineers, and evaluation specialists (economists and operations research specialists). It co-operates closely with the strategic functions, the military headquarters and the " Division de Recherches et Matériels " of the Ministry. In carrying out its functions, it makes extensive use of outside consultants (especially economists) and of meetings with specialists from industry at which " brainstorming " is sometimes encouraged,

A five-step normative procedure is generally followed:

1. Hypothetical broad missions, involving broad economic aspects, are postulated for a 20-year time-depth; alternatives including non-military alternatives, are defined. (Strategic functions.)
2. A detailed view of general missions is formulated and tasks are defined. (" Centre " together with military headquarters.)
3. Technological needs are defined and technological options determined for a 10-year time-depth (development time), with a view to 20-year operational effectiveness. As far as possible, alternative weapon systems are investigated. (" Centre " together with " Division de Recherches ".)
4. Technological deficiencies and development objectives are defined. (" Centre " together with " Division de Recherches ".)
5. Development objectives are ranked, by using a four-factor formula (see section II.4.4.) which, from 1967, bas been modified so as to add weights, not multiply them; as from 1967, this will be done with the help of a computer. The resulting ranking order is used as only an auxiliary means in decision-making. (" Centre ".)

At the beginning of 1966, the formal system comprised: 100 tasks, 200 functional systems (i.e. an average of two alternatives for each task), and 800 development objectives.

Ad hoc technological forecasts are commissioned occasionally, especially with industry **(CGE, CSF,** etc.).

A.2.2. SWEDEN

An integrated approach to technological forecasting and planning has been in effect since 1954 and concentrates on the preparation of a flexibile, sliding seven-year plan. In general, a time-frame of 10 years is allotted for development, and up to 40 years for operation.

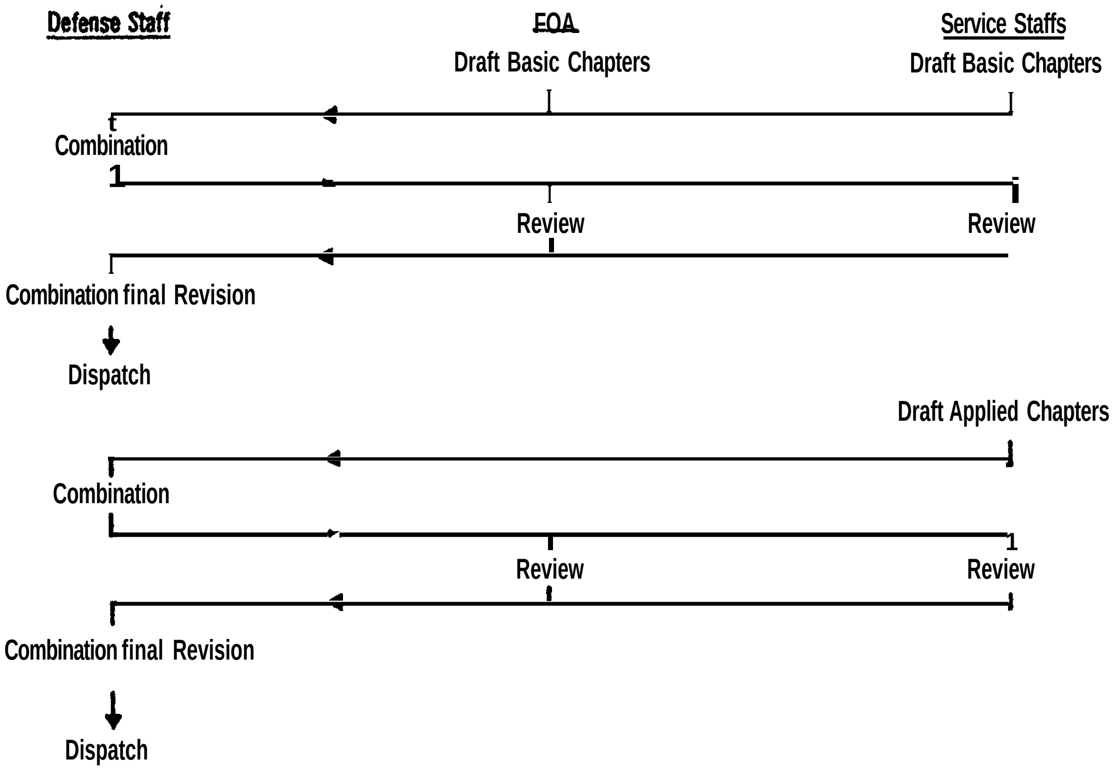
The principal functions which co-operate in this scheme are: *(a)* The Supreme Commander; (*b*) the Defence Staff, with 20 full-time people in its Planning and Studies Department, and part-time help from the operational departments; (c) **FOA,** the Research Institute of Swedish National Defense, with several full-time, and many part-time contributors, and *(d)* the Service Staffs (Army, Navy, Air Force), aided by their respective material administrations. The Defence Staff serves also in a co-ordinating function.

The basis for the assessment is total systems analysis (adapted from American developments in this field). The main criterion is cost/effectiveness adapted to the needs of a small country, i.e. the maximisation of total costs for an aggressor including " indirect " political military, and economic costs (e.g. caused by world reaction) and a preference for a broad basis of efficiency (multiple-task weapons, etc.) over higher efficiency for a single situation.

The general eight-step procedure outlined below is characterised by an early marriage between exploratory and normative technological forecasting at a stage in which only general guidelines have materialised from the normative side, and a subsequent close interaction between exploratory and normative components:

1. In accordance with the medium-range allocation framework set by Parliament, the Supreme Commander issues general directives for overlapping seven-year periods (for example, " ÖB 62 " and " ÖB 65 ") which are openly published, except for classified details;
2. " Scenarios " of possible and probable changes in the political, military, technological, economic and social areas are prepared on a global basis by the Defence Staff and **FOA.** A 10- to 15-year time frame is generally aimed at, with major trends indicated for the period beyond. Types of warfare and broad missions emerge from these " scenarios ";
3. A " Technical Study and Prognosis " (TSP) document, aiming at a 10-year time-depth and precise time estimates for the first seven years, constitutes the major input of technological forecasting. It is composed of basic chapters (including

anticipated advances in fundamental science and technology grouped in a normative way, by "fundamental applications") and applied chapters (including quantitative assessments of development costs) and is prepared in accordance with the following simplified flow scheme:



The preparation of the complete document takes approximately $1^1/_2$ years. The sixth "round" since the beginning of formal technological forecasting is now in progress (autumn 1965 to spring 1967). To supplement this, a "Scientific Prognosis", taking a broad look at advances in all fundamental sciences, is now being planned; it may be established outside FOA, on a broad national basis;

4. A "Strategic Study and Prognosis" (SSP) document, prepared by the Defence Staff with the help of the Service Staffs, adds strategic facts and estimates about Sweden's military situation and the main trends forecast for the seven-year planning period;
5. Cost/effectiveness evaluations are carried out by the Service Staffs on the basis of total systems analysis over the expected life-time of the weapon systems. FOA is responsible for evaluation techniques;
6. "Joint Studies" are carried out, mainly by the Defence Staff, to provide a basis for "contingency planning," i.e. a basis for decisions concerning the optimum deployment of resources and an optimum combination of strategies and tactical methods to achieve the best defence against various kinds of possible future attacks. The technical and strategic forecasts are matched against the "scenarios", principally by playing two-sided war games;
7. A flexible seven-year sliding plan, within the limits of the expected resources, is set up, with detailed planning for the first four years. Clear "cross sections" are defined for each year. This is a total economic plan, which is revised annually and is presented to the government;
8. Development programmes are decided upon flexibly and individually at "decision points" indicated in the plan.

Since 1965, the year in which the first 10-year forecast of 1955 could be checked, an evaluation and "feedback" step for past technological forecasts has been informally added.

A.2.3. UNITED KINGDOM

Technological forecasting is handled centrally by the Ministry of Defence, with annual formal inputs (new ideas, etc.) from the Army Department, from the Navy Department, and, until its abolition in mid-1966, from the Ministry of Aviation (now incorporated in the Ministry of Technology) as well as from numerous defence research establishments. For this task, the staff of the Defence Ministry's Chief Scientific Adviser in the two areas " Studies " and " Research " (six highly qualified scientists) is aided by the Defence Operational Analysis Establishment (DOAE) in Byfleet, Surrey, with a staff of 100. Guidance is provided mainly by three committees: (*a*) Operational Requirements Committee (military people); (*b*) Defence Research Committee (military people, defence and university scientists), and (*c*) Weapons Development Committee.

There is no sliding plan; instead, a less formal framework is now provided by the " Defence Review " which includes part of the developments for the near future and an economic estimate for approximately five years. There is no fixed time-frame for technological forecasting, but a 10-year outlook is generally adopted for the development side. The basis of the evaluation is operations research and systems analysis. A new basis for the cost/effectiveness criterion was recently created with the introduction of the " Functional Costing System " (adapted from the American Planning-Programming-Budgeting System, but less highly formalised).

Technological forecasting is organised in the form of continuous interaction between the following three areas:

1. Long-range missions and tasks, formulated principally by the Operational Requirements Committee;
2. Exploratory research, for which an operational need has not yet been precisely expressed. In this area, the Defence Research Committee is aided by temporary specialist committees (task forces) that work for approximately one year and produce reports along the lines of (partly quantitative) exploratory technological forecasting; at the beginning of 1966, there were six such committees;
3. Technological requirements for weapon systems to meet the missions and tasks formulated in (1). Extensive studies to assess cost/effectiveness for alternative strategies and weapon systems are mainly carried out by DOAE with the use of operations research (systems analysis) and gaming. A quantitative ranking system for development projects will be introduced shortly by DOAE.

A typical form of interaction between these three areas may be illustrated by the example of the laser: it was kept in area (2) until a range-finding task had been formulated in area (1), and it was moved subsequently to area (3).

A.2.4. UNITED STATES OF AMERICA

Before 1961, military planning in a 5- to 10-year time-frame was oriented towards military services and major weapon systems, whereas budgeting was based on functional categories (but did not focus sufficiently on key decision areas). However, technological forecasting *between 1947 and 1953* was function-oriented and was handled centrally by the Research and Development Board of the Department of Defense (the *forerunner* of today's ODDRE—Office of the Director of Defense Research and Engineering). A part-time supporting staff of 20 people co-ordinated the input from approximately 2,000 part-time contributors (half military, half civilian). An in-house document was prepared in 1947, no final document was turned out for 1348, but comprehensive formal documents appeared annually from 1949 through 1952. The technological forecasting effort died in 1953, when many planning functions were cut under the Eisenhower administration due to budget reductions.

Since the beginning of the McNamara era in 1961, technological forecasting has been feeding into the strongly normative *Planning-Programming-Budgeting* System *(PPBS)*, which ties all facets of the Department of Defense (DOD) effort together. The main PPBS objectives are: (*a*) plan programmes around missions rather than services; *(b)* relate resource requirements to the programmes; (c) provide capability for making cost/effectiveness studies of alternative force structures; (*d*) appraise programmes on a continuous basis; *(e)* co–ordinate long-range planning with budgeting[1]. The main result is a sliding five-year plan.

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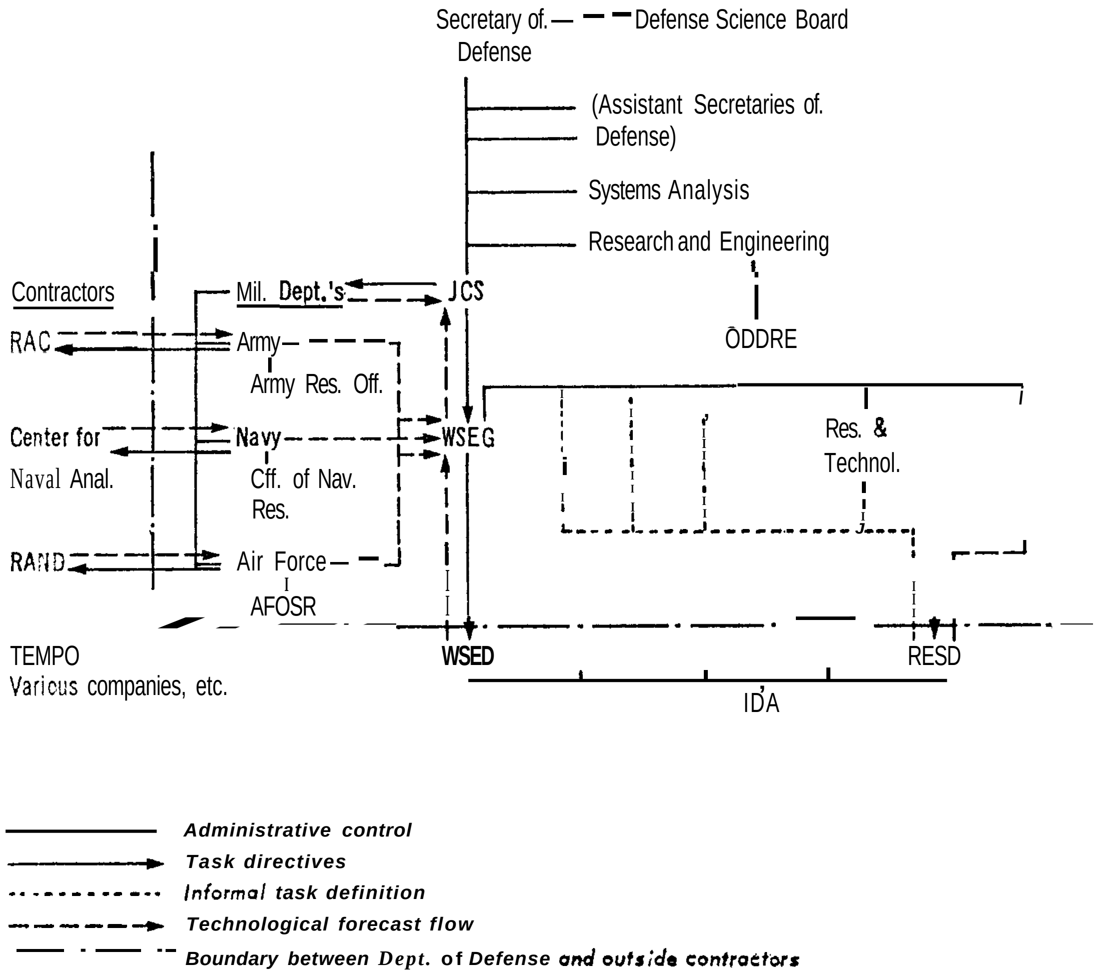
1. In DOD language, the team " services" refers to Army, Navy, and Air Force, whereas "forces " denote armed forces grouped by functional missions or tasks, for example " strategic retaliatory forces ", " missile forces ", etc.—see also the decision tree explained below.

Technological forecasting enters in the first and second phase—planning and programming—mainly through inter-actions occurring within the following organisational structure:



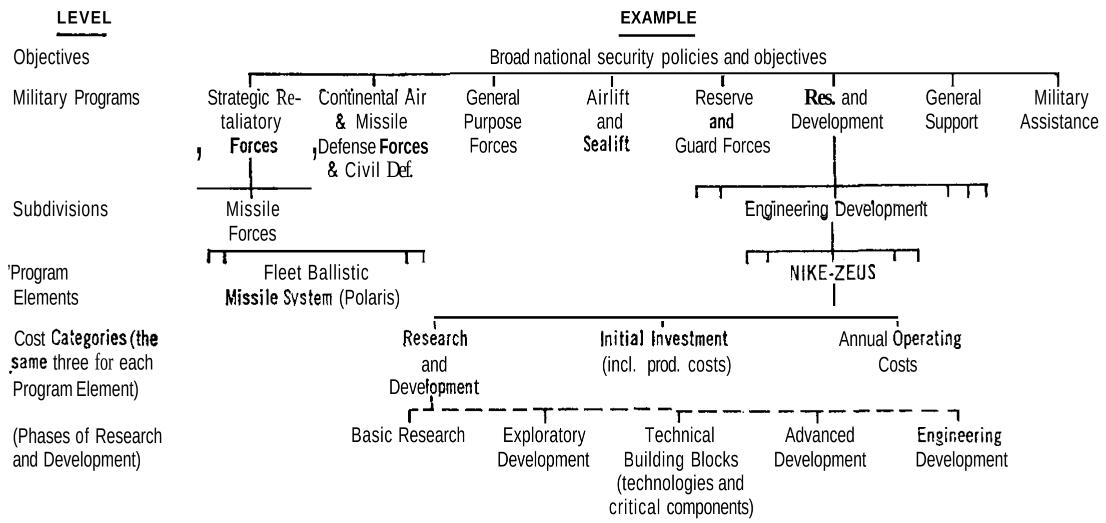
AFOSR = Air Force Office of Scientific Research
ARPA = Advanced Research Planning Agency
IDA = Institute for Defense Analyses
JCS = Joint Chiefs of Staff
ODDRE = Office of the Director for Defense Research and Eng.
RAC = Research Analysis Corporation
RAND = RAND Corporation, Santa Monica, California
RESD = Reseaich and Engineering Support Division of IDA
TEMPO = TEMPO Center for Advanced Studies, General Electric Co. Santa Barbara, California
WSED = Weapon Systems Evaluation Division of IDA
WSEG = Weapon Systems Evaluation Group

WSEG is composed of approximately 50 officers of the three services, whose average rank is that of colonel. IDA, the Institute for Defense Analyses, located next to the Pentagon, is a non-profit civilian organisation under exclusive contract with the Department of Defense. Its RESD represents the highest scientific level in the entire complex, with a staff composed of PhD-level scientists, a third of whom are on loan from university faculties.

A decentralised approach characterises long-range and exploratory technological forecasting, whereas co-ordinated effort and central control are ensured for medium-range forecasting which enters into the costing and cost/effectiveness estimates phase. Long-range technological forecasting originates mainly in the three services (its internal organisation in the services will be described following the description of PPBS). Only very informal co-ordination exists between them, and there is no centralised attempt at a synthesis.

The bulk of the weapon systems evaluations, cost/effectiveness studies and systems analysis work in a medium-range time-frame is carried out for the Joint Chiefs of Staff by WSEG/WSED in co-operation with the military departments (where AFOSR, in particular, assumes a key role). ODDRE is normally not active in long-range technological forecasting, except for certain *ad hoc* efforts. Equally, RESD is only occasionally asked for contributions to the forecasting effort. The Systems Analysis Group is responsible for the evaluation techniques, technical guidance to other groups, and the final synthesis for the Secretary of Defense, but participates only occasionally (for inter-service tasks) in the evaluation work itself.

The " ***decision tree*** " (or relevance tree) underlying the ***Planning-Programming-Budgeting System*** may be represented as follows



The Research and Development Programme includes all the research and development projects not directly associated with Programme Elements in the mission-oriented programmes, especially weapon systems not yet approved for production and deployment (such as the anti-ballistic missile missile NIKE-ZEUS).

The ***decision-making process*** of the Planning-Programming-Budgeting System, which starts from the broad national policies and objectives defined by the White House, is broken up into three major phases :

1. ***Military planning and requirements determination.*** Once every year a " Joint Strategic Objectives Plan " (JSOP) is prepared by the Joint Chiefs of Staff together with the planners in the Military Departments to relate force requirements to major missions. The formal conclusions for a five-year time-frame take into account long-range points of view and exploratory forecasting. The Office of the Secretary of Defense (OSD) then makes a detailed assessment of resource implications of the JSOP and of requirements studies initiated elsewhere in the Department of Defense. Systems analysis and cost/effectiveness studies are carried out principally by the Joint Chiefs of Staff, by WSEG/WSED (whereby the three services exert an influence since in WSEG every weapon system evaluation job is handled by a tri-service group), by other supporting organisations on a contractual basis, and, in special cases, across services lines, by the Systems Analysis Group as well. These studies have the purpose of aiding (not substituting for) decision-making. JSOP goes down to the " sub-division " level of the decision tree and contains formal proposals for changes over the forthcoming five-year period. These proposals are reflected in the programme changes which are effected. The Secretary of Defense makes his force decisions on the basis of JSOP, after detailed review.
2. ***Formulation and review of programmes.*** In this phase the PPBS objectives ***(a)*** through ***(e)*** listed above are implemented for a five-year time-frame for development (eight years for operational use). In particular, a cost assessment is made of the Program Elements in order to provide input data to the cost/effectiveness studies. Out of the three cost categories for each Programme Element (see decision tree), the annual operating costs can usually be related to present cost factors and the initial investment costs estimated on the basis of past experience, " learning curves," etc. The cost assessment for the Research and Development category is mainly made

on a simple " level-of-effort " basis (rough percentage of effort believed to be a justified proportion, etc.) for the first three research and development phases (basic research, exploratory development, and technical building blocks); for advanced development and engineering development phases, project costs are assessed with the auxiliary use of simple techniques and attitudes. Costs are assessed for every fiscal year up to five years beyond the current year, forces (operation) are projected eight years ahead. The detailed cost structure, together with " peripheral costs," is represented on a " Program Element Summary Data " sheet, all the data being programmed on computers. The totality of these sheets represents the " Five-Year Force Structure and Financial Programme " which is approved by the Secretary of Defense.

Since 1965, cost assessment has been aided by a Cost and Economic Information System (CEIS) whose purpose is to improve the collection and analysis of cost data. As from 1966, computerised " cost models " are expected to become available; these will be capable of rapidly providing cost estimates as well as the underlying resource implications of such considerations as alternative force structures, changes in logistics, procurement or deployment schedules, etc.

PPBS is kept flexible *so* that changes can be introduced whenever necessary. The " Programme Change Control System " ensures that there is only one main channel for decisions about changes. Most changes are proposed at the time a new JSOP is presented in April of each year.

3. ***Preparation of the annual budget estimates*** consists simply of taking the next one-year increment of the " Five-Year Force Structure and Financial Programme " and using it as the basis for the budget request.

Long-range technological forecasting in the Army

Since 1963, annual classified " Army Long Range Technological Forecasts " (LRTF) have been prepared by a special full-time group (Technical and Objectives Branch of the Research and Development Directorate) in the Army Material Command, comprising approximately 10 to 12 technical people. Close co-operation with the Army Research Office is ensured. The fourth formal document has been issued for 1966. The LRTF is composed of three volumes: " Scientific Opportunities " (basic opportunities and limitations); " Technological Capabilities " (chiefly exploratory forecasting in areas of broadly defined missions); and " Advanced Systems Concepts " (chiefly normative forecasting which assumes the feasibility of attaining the functional capabilities outlined in the second volume). The basic approach is that of iteration of exploratory and normative technological forecasting, however, without taking feedback from actual research and development continuously into account. The LRTF is published by the Chief of Research and Development of the Department of the Army and constitutes a major input for the " Basic Army Strategic Estimate " which, in turn, forms the basis for the Army Department's " Five Year Plan RDT & E." LRTF is also used in the preparation of the " Army Strategic Plan ", the Army input to JSOP (see description of PPBS above), and the 20-year " Army Force Development Plan ".

In addition to the periodic LRTF, the Army also conducts a series of " Forecasts-in-Depth " (FID). This represents an attempt at a comprehensive exploration of selected fields, including in each case a state-of-the-art description, a 10- to 20-year forecast of the pertinent technological environment, an analysis of the research effort required to attain feasible goals, and an extensive bibliography. The FID series is published by the Technical Forecasting and Objectives Branch, Research and Development Directorate, Army Material Command, and also includes unclassified reports, e.g. H. T. Darracott, " Forecasting in Depth—Information Processing Systems for the Field Army " (1965).

Another series, " Scientific and Technical Application Forecasts, " is published by the Office of the Chief of Research and Development, Department of the Army. It includes both classified reports (for example on laser applications) and unclassified reports, e.g. two by R. Isenson on excavation (1964 - the most ambitious evaluation of a single field so far) and non-clinical applications of electromiography (1965, DDC accession number AD-607077).

Long-range technological forecasting in the Navy

Starting in 1967 (work actually began in 1965), the first issue of an annual classified " Navy Technological Forecast " will be prepared by a full-time Technological Forecasting Group in the Advanced Concepts Branch of the Navy Material Command. It will comprise three volumes: " Scientific Opportunities, " " Technological Capabilities," and " Advanced Systems Concepts (Probable Systems Options). " The basic approach, as indicated by this sub-division, will be similar to that of the Army, but will supplement the iteration between exploratory and normative forecasting by continuous feedback from research and development operations. Close co-operation with the various Navy laboratories will be ensured by assigning the preparation of the input information in specific technological areas to one laboratory for each such area. The Naval Technological Forecast will serve purposes analogous to those outlined for the Army LRTF above.

A complementary series of " Technology Needs Identification Studies," to be prepared within the same organisation, is envisaged to study in depth specific technologies and to suggest planning strategies (the latter purpose giving these studies greater scope than that of the Army FID series). The studies are intended to continue, on a smaller scale but on a continuous basis, the concentrated effort which was first made by the Navy in " Project SEABED " (Advanced Sea-Based Deterrence Summer Study, carried out in Monterey, California, in 1964).

The Chief of Naval Development issues " Goals for Technology in Exploratory Development " providing guidelines for normative forecasting in areas outside recognised missions for the forces.

Individual technological forecasts are also issued irregularly by some of the Navy laboratories, and may be classified or unclassified. An example of an unclassified report is, W. S. Pellini, " Status and Projections of Developments in Hull Structural Materials for Deep Ocean Vehicles and Fixed Bottom Installations," report 6167, Naval Research Laboratory, Washington, D.C., 4 November 1964.

Technological forecasts are also prepared by industry under contract with the Office of Naval Research; for example, Lockheed Aircraft's report, " Research on Oceanic Forecasting " 1964).

The *Marine* Corps, with one foot in Army and the other in Navy areas, has so far adapted the Army LRTF to its own purposes. In addition, it has commissioned from the Syracuse University Research Corporation an unclassified comprehensive study on " The United States and the World in the 1985 Era " *(lit. ref. 281).* In future, the Army and the Navy will prepare (perhaps jointly) a version of their long-range forecasts for the Marine Corps.

Long-range technological forecasting in the Air Force

The pioneering effort dates back to 1944: Von Kármán's famous report (" Towards New Horizons, " or simply " the Von Kármán report ") to the Scientific Advisory Board, the result of a concentrated group effort which laid the foundation for aircraft propulsion developments over the following years. A permanent technological forecasting group operated only between 1958 and 1960, and was then disbanded. It is tentatively planned to establish a new permanent group in the Air Force Material Command in 1967.

The major input to Air Force forecasting has been provided by two concentrated efforts spaced five years apart from each other:

1. The " Woods Hole Study " of 1958, conducted in 1957/58, under the supervision of Von Kármán, by approximately 100 people representing in the main a combination of existing independent Air Force groups in the following areas: Aircraft and Missiles, Propulsion, Space Problems, Medicine, Materials, and Behavioural Sciences; the study derives its name from Woods Hole, Massachusetts, where the final meetings were held.
2. " Project Forecast " of 1963, an ambitious study conducted in 1962/63 and involving approximately 100 (according to some sources, 300) Air Force and industry people full-time for periods ranging from three to six months. They were grouped in task-force type capability panels (exploratory approach) and technology panels (normative approach), supported by panels for threat definition, cost and analysis, evaluation and synthesis. In its general scope, this project sought to combine current and potential technology in alternative ways and to assess the desirability of developments towards feasible technological goals, all within a time-frame of 15 to 20 years. Simple techniques, such as time-series and envelope curve extrapolation, vertical decision matrices, and simple numerical ranking procedures for missions as well as for multi-mission weapon systems, were employed in a strictly auxiliary function. " Brainstorming " played a relatively important role in the preliminary phases of the work.

The full Air Force framework for technological forecasting is at present composed of five elements (all classified):

- Missions and tasks, related to technological requirements, are outlined in the annual " Office of Aerospace Research Five-Year Plan, " which includes a long-range outlook and a detailed plan of action for the next five years; it constitutes the main Air Force input to JSOP (see description of PPBS above).

— Technological warfare goals are laid down in the " AFSC Technological War Plan " which is prepared by the Air Force Systems Command, and discusses environments, threats, systems, technologies, and resources.
— " Project Forecast, " outlined above, assessed technological and broad systems options over the next 15 to **20** years.
— Technology deficiencies are pointed out by the irregularly published " Technical Objectives Documents, " which are prepared by the Research and Technology Division, Air Force Systems Command, and screen **36** different technical areas.
— Resource allocation to research and development in a 10-year time-frame, as planned in line with the recommendations formulated by " Project Forecast " and assuming the attainability of technological goals identified by it, is set forth in the " RTD Technological War Plan/Long Range Plan," prepared by the Research and Technology Division, Air Force Systems Command.

A complementary classified study, " Technology for Tomorrow," was prepared periodically (5th and last edition 1962/63, published in December **1962)** by the Aeronautical Systems Division, Air Force Systems Command, and it may be reinstated by the Research 2nd Technology Division of the Air Force Systems Command. Its objective was the presentation of motivational concepts outlining the approach to an optimum plan and providing guidelines for the selective application of resources and capabilities in order to produce aggressive support for long-range technological missions. The contents reflected advanced informal thinking in scientific and technical Air Force circles and reportedly seemed to indicate that " a cohesive detailed plan exists collectively in the minds of engineers, scientists, and management personnel. "

In addition to these publications, contributions to technological forecasting are also made by contracting organisations such as the RAND Corporation and industry. Examples of participation by industry are the classified Lockheed Aircraft study by H.A. Linstone: " Mirage 75 " : Military Requirements Analysis Generation **1970-75** ; the RCA study, " Applied Defense Electronic Products — Future Astro-Communication Techniques "; and the study on " Projected International Patterns " by General Electric's TEMPO Center.

In **1966,** the Air Force began an experimental assessment of political environments 50 years in the future, carried out with the use of the " Delphi " technique (see section **II.2.3.).**

Inter-service forecasting

Informal and friendly contacts exist between the promotors of permanent technological forecasting in the three services. These contacts are responsible for the coherence in the Army and Navy forecasting schemes, with the Air Force expected to fit in once a permanent group has been re-established. The basic approach will in each case be the three-fold scheme: " Scientific Opportunities, " " Technological Capabilities, " and " Systems Concepts. " The prerequisites for formal co-ordination would thus be met.

A.2.5. NORTH ATLANTIC TREATY ORGANIZATION (NATO)

NATO has no comprehensive technological forecasting. However, a series of " ***Long-Term Scientific Studies*** " was initiated in **1961** by the Von Kármán Committee, dealing with **15** to 20 selected military and scientific topics. The first " round " was completed in **1963,** and it was decided subsequently to update the series at intervals of five to six years by tackling several topics each year. A 20-year outlook is generally aimed at.

A small staff under the Assistant Secretary General for Scientific Affairs co-ordinates this activity, which follows two different procedures: ***(a)*** a member country prepares a working paper on a specific topic, which is then submitted to two weeks of thorough discussion by **an *ad hoc*** expert group of approximately 50 people and is considerably modified to arrive at an " agreed report " (only **25** to 30 per cent usually remains unchanged); ***(b)*** mixed expert groups with participants from different countries prepare a topic report. " Brainstorming," and simple techniques such as trend extrapolation, etc., are employed.

The ***Advisory Group for Aerospace Research and Development (AGARD)***, since its formation in **1952,** has published a loose series of reports on expert panel meetings, containing technological forecasting in specific areas and aimed at a time-depth of about **10** years. The areas are identified by the AGARD Steering Group (chaired by NATO's Assistant Secretary General for Scientific Affairs, thus ensuring co-ordination with the Long-Term Scientific Studies). The expert panels, composed of military and industry people, meet approximately three times a year; **a** number of the panels have only three or four members, while more substantial and concentrated efforts are sometimes undertaken in key areas (gas turbines, **VTOL**, etc.) in which large symposia are occasionally held. The main purpose of the AGARD series of forecasts so far was to advise the **NATO** Standing Group in Washington (disbanded in the summer of **1966).**

All technological forecasts by **NATO** and AGARD are classified.

A.3. NATIONAL **LEVEL**

For military technological forecasting see Annex A.2.

A.3.1. **AUSTRIA**

" Aktion 20," a broad 20-year normative forecast, was drawn up for the nation by the People's Party (Österreichische Volkspartei) in January **1966** for the election campaign (lit. ***ref. 376***), and now—the People's Party having formed the government—has been extended to become a national programme. It is subdivided into six areas: society in a process of change, education and science policy, public health, legislation, international position, and national economy.

A.3.2. CANADA

Technological forecasting plays a certain role in the activities of AECL (Atomic Energy of Canada, Ltd.) and of the Paper and Pulp Research Institute of Canada.

It is tentatively planned to establish a technological forecasting function in government, possibly through collaboration between the Department of Industry and the Economic Council.

A.3.3. **FEDERAL REPUBLIC OF** GERMANY

The German Federal Railways (DBB - Deutsche Bundesbahn) in **1964** published preliminary ideas on long-range technological potentials (lit. ***ref. 298***), and a 20-year traffic forecast is currently **(1966)** under preparation for the Federal Ministry of Transport; an economic study of future ultra-rapid railway traffic was evaluated by a committee between **1961** and **1965.** The IFO Institute in Munich has prepared, for the Federal Ministry of Transport, **a** freight traffic forecast for all transport sectors.

The two biggest political parties used broad national forecasts for their election campaign in **1965** : the Socialist Party (SPD) published a brochure, "Deutschland **1975,**" containing sections on education, transport, automation (including hospital management), and nuclear energy; the Christian Democratic Union (CDU) replied with a counter-brochure.

A.3.4. FRANCE

France was the first country to introduce the use of long-range technological focerasting for purposes of formal national planning. A **"** ***Groupe 1985*** **"** under the aegis of the Délégation Générale à la Recherche Scientifique et Technique took part in the preparation of the Fifth Plan for the period **1966-1970.** Approximately **35** technological forecasts in different fields, formulated mainly in broad terms and containing quantitative estimates to **a** limited degree only, were commissioned from research institutes or specialists in the relevant fields (a summary of their findings has been published under the title **"** Réflexions pour **1985 ")** see ***lit. ref. 278).*** The individual forecasts were processed in three steps: ***(a)*** they were reviewed by **"** Groupe **1985 "; (*b*)** meetings of young and dynamic scientists and science policy people —the so-called " Jeunes Turques " (" Young Turks ")—discussed them and tried to formulate the " ideal Plan "; ***(c)*** the official working groups of the Commission de la Recherche Scientifique, attached to the Commissariat Général du Plan reviewed the forecasts and took their findings into account for the five-year planning exercise. Some of the sub-panels of " Groupe **1985** " now subsist within the framework of ministries, e.g. the Ministry of Transport.

For the Sixth ***Plan,*** which is being prepared for the period **1971-1975,** technological forecasting has already begun within the framework of the BIPE (see Annex **A.1.3.).** It will be much more systematic and comprehensive than the experiment for the Fifth Plan.

Since **1961,** the concept of **"** ***actions concertés*** **"** has been implemented by the Délégation Générale à la Recherche Scientifique et Technique. Only one such " action "—space— **has been** transformed into an **"** option," i.e. into an operational scheme. (The terms " action " **and** " option " exchange their usual meanings here.)

The " *Groupe Saint-Geours* " which adopted the name of its chairman, the head of economic and financial planning in the Ministry of Finance, was composed of four members representing civilian government, military administration, and nationalised and private enterprise. It functioned from 1965 to 1966 and broadly scrutinised national objectives and technological missions, applying both an exploratory and a nomative approach.

ONERA (Office National d'Études et de Recherche Aéronautique) carries out technological forecasting which reportedly provides considerable stimulus to the French aerospace industry and is instrumental in initiating research and development programmes.

A.3.5. ISRAEL

The National Council for Research and Development, attached to the Prime Minister's Office, in 1965 sponsored a number of committees which defined broad options for the nation: oceanics, photochemistry, bromine applications, and electronics. A permanent, ambitious technological forecasting function at the national level is under consideration in connection with the plans for Israel's industrialisation. It might tie in with the work of a proposed National Industrial Development Corporation (no definite name yet).

In the vitally important area of *water resources,* a National Review Board (also called the " Sporn Committee " after its chairman, the Austro-American Philip Sporn) meets once a year and tries to evaluate the broad potentialities of new technologies, such as water desalination by nuclear energy, etc. The Water Planning Corporation, a public company for water conservation and uses, has a 1965-1980 Development Programme and stimulates research and development in this area.

The Ministry of Agriculture assesses research priorities through committees which perform some exploratory technological forecasting.

Technological forecasting on solar energy conversion began in 1954 and has since been pursued by the National Physics Laboratory at the Hebrew University in Jerusalem. While, in general, applications have proved uneconomic for Israel, the forecasting and development activity is maintained for the benefit of developing countries with more favourable conditions for the use of solar energy (i.e. in a more unfavourable situation as far as conventional energy conversion is concerned).

A.3.6. ITALY

Italian industry has taken the initiative in technological forecasting in several areas, with a future possible input function for the nascent National Plan:

Confindustria, the association of Italian industry, publishes broad annual four-year technological forecasts—for example, in 1965, " Le Prospettive dell'Industria Italiana nel quadrennio 1965-68 "—with input from industry.

National study and development centres on a private basis existed at the end of 1965 in four industrial sectors:

- Centro Studi Sviluppi Industria Chimica, in Milan (chemical industry);
- Associazione Tecnica del Cimento (cement industry);
- Centro Sviluppi Applicazioni Vetro (glass industry);
- Centro di Ricerche Macchine Utensile (machine tool industry, in co-operation with the Consiglio Nazionale delle Ricerche, the Italian National Research Council).

A mixed nationalised/private steel industry centre was in a planning stage, and interest was shown by the automobile industry. These centres, although established primariliy for the purpose of national co-operation in investment planning, are also gradually becoming active in technological forecasting to be able to assess medium- and long-range needs and potentialities. Confindustria might act as clearing and publishing house for their forecasts.

The national electricity holding company, *ENEL,* puts considerable emphasis on technological forecasting (see *lit. ref.* 303). Consumption forecasts are based on detailed assessments of technological change in industrial sectors and in the household (for example, the expected impact of the introduction of air-conditioning, the future electronic kitchen, automation in industry, etc.).

STET, the national telephone holding company, is also active in forecasting.

A.3.7. NETHERLANDS

The ***PTT,*** the national post and telecommunication services in The Hague, is the most active European PTT in the area of technological forecasting. In 1949, a first technological (not only traffic) forecast was prepared for 1970, and produced many surprises. Since 1959 formal technological forecasting has been established, and since **1963** an adviser for long-term planning in the office of the Director-in-Chief for Financial Planning has been in charge of this function. The Laboratory Governing Board, which meets four times a year, contributes ad hoc forecasts. The need for even more formalised technological forecasting is felt. It is believed that technological forecasting, by clearly outlining long-range goals and applying normative stimulus, has resulted in the allocation of more funds to PTT developments.

The newly formed Science Policy Council, set up by the government, is giving much attention to the possibility of a technological forecasting function at national level.

A.3.8. SWITZERLAND

An informal study group of leaders in industry, mainly from the French-speaking part of the country, started in **1965** to discuss broad national objectives and the needs for a national industrial research policy.

The national postal and telecommunication services, PTT, are active in technological forecasting.

A.3.9. UNITED KINGDOM

The present governmental structure offers excellent possibilities for the establishment of **a** technological forecasting finction (e.g. Ministry of Technology, National Economic Development Council = " NEDDY," " little Neddies " under the Ministry of Economic Affairs, NRDC—National Research Development Corporation, IRC—Industrial Reorganisation Corporation), but such activity is not yet under way.

In **1963,** the DSIR (Departement of Scientific and Industrial Research) began a study of the obstacles to growth over the next 20 years on the basis of an input/output analysis for **31** industrial sectors. The simple assumption was made that the average technological level in **1980** would correspond to the best level in **1963.** When the DSIR was absorbed by the Ministry of Technology in **1965,** the study was discontinued.

Following a recommendation of the First OECD Ministerial Meeting on Science in October **1963,** the NRDC (National Research Development Corporation) undertook in **1964/65,** on behalf of the DSIR and subsequently the Ministry of Technology, a study on **"** The Implications for Economic Growth of Research on New Materials **"** ***(lit. ref. 344).*** Planned as a technological forecast, this study became primarily a national survey of new materials currently under development. It may not be declassified due to certain inadequacies.

The ***Cabinet Office*** attempts to formulate uniform " criteria for the appraisal of civil technological projects " to be used in connection with government funding.. It is also interested in scrutinising the implications of broad national objectives for research under government contract, and seeks to fill an " educational " role for the entire government in this respect.

CEGB, the Central Electricity Generating Board, has five committees, includiog a Long Range Problems Committee which undertakes some technological forecasting.

A.3.10. **UNITED** STATES *OF* AMERICA

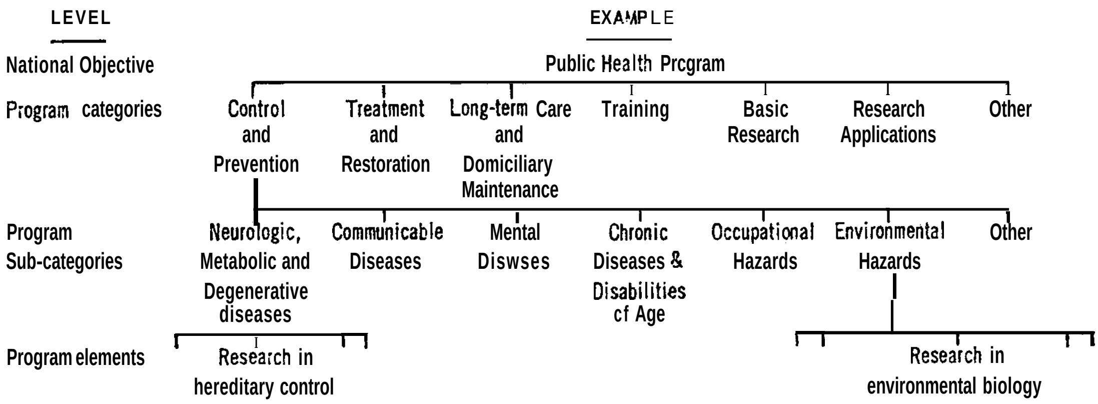
An early effort by the ***National Resources Committee*** in **1937** produced a remarkable document **: "** Technological Trends and National Policy—Including the Social Implications of New Inventions **"** ***(fit. ref. 184).*** In the following years, several ad hoc forecasts were made by various committees, for example the Harding Committee which forecast supersonic commercial air traffic in **1954.**

The ***Senate*** in **1960** commissioned **a** study of the consequences of new technologies for American foreign policy. Such matters as nuclear energy and the substitution of synthetic for natural materials (with the consequences for developing countries) were investigated in this report ***(fit.ref.*** 395).

In March **1967,** hearings were begun on a bill to create a Select Committee of the Senate on Technology and the Human Environment.

In October, **1965,** the ***Planning-Programming-Budgeting*** System (PPBS), in use at the Department of Defense since **1961,** (for a detailed outline see Annex A.2.4.), was introduced to civilian government. In the first PPBS preview all executive departments (directly under the President) and 22 government agencies were included, while an additional **17** agencies are encouraged to adopt PPBS. By spring **1967** not less than **31** agencies had adopted the PPBS. The PPBS (see Annex A.2.4. and, for a discussion of its importance in the civilian sectors, Chapter 111.4.) is a function-oriented framework for decision-making and quantitative five-year planning which involves medium- and long-range evaluations with the use of cost/effectiveness studies, systems analysis, operations research, operational models, and other advanced techniques. Its introduction into civilian government establishes integrated forecasting and planning, oriented towards common long-range goals, on a national level.

PPBS as set up in the civilian sectors is similar to its military version, and functions essentially in the framework of a four-level decision tree (the example is hypothetical):

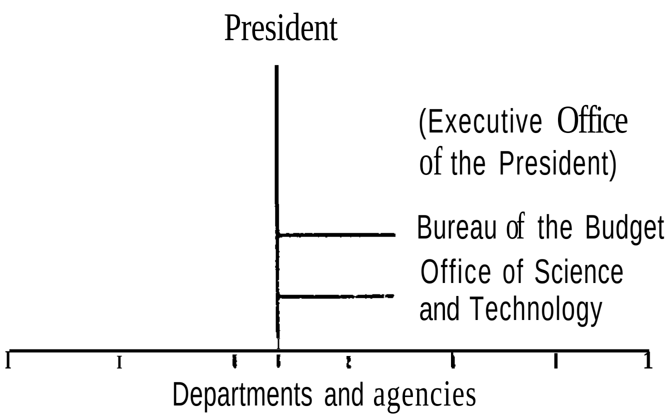


Before the introduction of PPBS, the planning and budgeting structure of the Health Services was mainly instrumental, not function-oriented: National Institutes of Health; Community Health; Hospital Construction; Environmental Health and Consumer Protection; Maternal and Child Health; Other. This scheme did not bring to the foreground the basic choices in research and in the application of research.

Research and development which contribute to the specified functions (programmes) are planned and budgeted under the headings designating the relevant functions, whereas " non-functional research " for which no specific use is yet envisaged (for example, in the health field, research in psychedelic drugs, etc.) come under the separate heading " Research and Development. " The five-year programming and budgeting procedure is analogous to that described for the PPBS in Annex A.2.4. The evaluation is generally envisaged as an in-house function carried out by systems analysis or other full-time supporting groups. In the Department of Health, Education and Welfare for example, a post of Assistant Secretary for Systems Analysis—equal in rank to the corresponding position in the Department of Defense—has been created.

The Bureau of the Budget in the Executive Office of the President provides guidance to the other executive branches and the agencies.

The research and development forecasting and planning structure of the government will be similar to that of a decentralised company:



The departments and agencies will develop their " businesses " like decentralised operating divisions of a company and will do their own forecasting and planning. There will be no master plan. However, the Office of Science and Technology will act as " Chief Scientist " of the " corporation "—with corresponding functions in relation to long-range implications (technological forecasting has not yet been considered among them)—while the Bureau of the Budget acts as " General Management Consultant " to the President and " educates " the departments and agencies. The allocation of funds is decided by the President and by Congress, who also provide the broad national objectives for each department.

NASA (National Aeronautics and Space Administration) operates a very efficient long-range technological forecasting scheme, generally within a 20-year time-frame, but, in its broad lines, extending up to **1990** and **2000** at the present time. It is based on decentralised input, mainly from NASA laboratories, and is synthesised and integrated in two places: NASA headquarters in Washington and the Mission Analysis Division of the Ames Research Center. Judgment, not intuition, is the general aim. For the ranking of projects, a decision theory/option theory technique of NASA's own has been developed, and the PATTERN relevance tree technique is also used for specific tasks. Although NASA contractors have no great influence on its forecasting, they are asked for their views on long-range potentialities, for example at present on the definition of the post-Apollo programme. Another input source consists of NASA's Scientific Committees. NASA has an explicit statutory obligation to promote spin-off, so that technological forecasting also takes the direction of application engineering (for example solar energy conversion). A " Conference on Space, Science, and Urban Life, " sponsored by NASA in Oakland in **1963,** explored the future " Space-Age City " and the application of space and other new technologies to urban living.

The ***Atomic Energy Commission (AEC)*** uses much input from industry for its technological forecasting function. The report to the President, " Civilian Nuclear Power " ***(lit. ref. 347),*** in **1962** with projections up to 2000 and beyond made **a** deep impact around the world and marked a turning point by forecasting the imminent economic potential of nuclear energy. The large-scale introduction of nuclear energy which followed—and which surpassed the AEC forecast—was greatly stimulated by this report.

Partly in response to this unilateral encouragement of research investment in nuclear energy, the ***Executive Office*** of the President agencies—the Bureau of the Budget, the Office of Science and Technology, and the Council of Economic Advisers—undertook from **1964** to **1966** a review of Federal energy resource programmes and policies, involving a good deal of technological forecasting throughout the energy field. The review was published at the end of **1966** under the title " Energy, Research and Development, and National Progress. "

The ***Federal Power Commission*** has made projections of power demand up to the **1980's,** involving only little technological forecasting.

A ***Federal Task Force on Supersonic Transport*** was set up for assessing the technical as well as the economic aspects of **SST** development which is supported by the government ***(lit. ref.*** 183).

The ***Bureau of Labor Statistics,*** on the basis of technological coefficients derived from a comparaison of the **1958** and **1963** input/output tables of the American economy, completed in **1966 a** forecast for **1970** ("Technological Trends in **36** Major American Industries") and is preparing another forecast for **1975.** These forecasts are used to study manpower needs, shifts between industrial sectors, the impact of automation, etc.

The ***Department of Labor*** has completed three studies in **1966,** concerning technology and manpower in the period **1965-1975** in the following areas: the health service sector, design and drafting, and the telephone industry.

The Office of Science and Technology of the ***Department of Commerce*** has established a " Commerce Technical Advisory Board, " comprising leading people from industry and research, and meeting monthly to study impediments to technological innovation, etc.

Ad hoc efforts by temporary Presidential commissions contribute to technological forecasting and to the definition of goals and objectives. The conclusions formulated by the ***President's Commission on National Goals*** in **1960 *(lit. ref.* 384)** included broad statements with respect to technology and its relevance to social goals. The ***National Commission*** on ***Technology, Automation, and Economic Progress,*** which published its findings in **1966** in the report " Technology and American Economy " ***(lit. ref. 383),*** constituted a remarkable attempt to achieve consensus between widely differing groups, such as industrialists and union leaders, on the subject of the future implications of automation. Most of the technological forecasting that contributed to this investigation is contained in the input reports (Volume II).

The ***National Academy of Sciences—National Research Council,*** which also contributes to the definition of national and social goals for fundamental science (see ***lit. ref.*** 20; an effort in the applied research area is planned for **1967),** has undertaken a most important task with its Committee on Science and Public Policy (COSPUP). The COSPUP reports (see also a detailed discussion in Chapter I.4.) attempt to scrutinise the potential contribution of fundamental research to social and national goals by systematically assessing the internal and external values of scientific fields.

Among professional societies, the ***Institute of Radio Engineers*** collected 50-year forecasts from many leading scientists and engineers in the communication field. The results, published in the volume " Communications and Electronics—2012 AD " *(lit. ref. 316)*, constitute an imaginative, but not very systematic, undertaking in intuitive thinking.

The Engineering Research Committee of the ***Engineers' Joint Council*** in 1962 began a major effort to forecast and define engineering research requirements in 12 areas in which existing programmes were considered inadequate; this involved mainly engineering tasks in the area of social technology (see also Chapter 1.7.). The results of the painstaking committee work are published in the report, "The Nation's Engineering Research Needs 1965-1985" *(lit. ref. 264)*. It is intended that such forecasting efforts will be repeated at intervals of several years.

Meetings involving a considerable degree of technological forecasting are also held by ***NSZA***, the ***National Security Industrial Association***, which comprises a few hundred of the most important government contractors in the defense and space areas. Regular future-oriented meetings are arranged by NSIA's Research and Development Committee (for example, on " Applications of Microelectronics Technology " in 1965, and a planned meeting in autumn, 1967, on " Research in the 1970's ", which will also include a ssesion on technological forecasting as such).

The activity of the ***Solar Energy Society*** may also be mentioned in connection with professional societies. It has recently penetrated more deeply into the area of social and economic impact (Solar Energy Conference in Boston, March 1966). This area is obviously of importance primarily to developing countries.

The forecasting activities of the National Planning Association and of Resources for the Future, which, to some extent, also belong to the national level, have been outlined in Annex A.1.9. and A.1.11, respectively.

A.4. INTERNATIONAL ORGANISATIONS

The North Atlantic Treaty Organisution, NATO, is listed under Annex A.2.5.

A.4.1. THE THREE EUROPEAN COMMUNITIES (EEC - EUROPEAN ECONOMIC COMMUNITY, BRUSSELS; EURATOM - EUROPEAN ATOMIC COMMUNITY, BRUSSELS; AND CECA - EUROPEAN COAL AND STEEL COMMUNITY, LUXEMBOURG)

The obligation to carry out long-range technological forecasting has its source in the statues of Euratom (article 40) and CECA.

In the ***energy*** field, ambitious technological forecasting for the EEC region is performed jointly by the three communities (thus anticipating their official merger which may soon become effective). The tasks are shared in the following way:

- Euratom forecasts nuclear energy and overall electricity generation developments: a first report *(lit. ref. 305)*, has been published, accompanied by documentation *(lit. ref. 304)*, and extending to the year 2000 with emphasis on the period 1970-1980. The report also constitutes guidelines for research and development in the nuclear energy field.
- CECA undertakes 10-year forecasts of fuel consumption (cement, brick, ceramics, paper and pulp, textiles, sugar, and chemistry sectors-covering 50 to 60 per cent of total fuel consumption outside steel and electricity production) ; the technological changes in these sectors are evaluated in detail by a three-step procedure: *(a)* the Battelle Memorial Institute, Geneva, studies the technical and the broad economic aspects; (*b*) five economic institutes, one in each of the EEC countries except Luxembourg, add the aspects which are particular to the the individual countries; (c) CECA co-ordinates the work, refines it by iteration, and writes the synthesis *(lit. ref. 291* for one sector, the complete series was published by the end of 1966).
- The European Economic Community combines the results obtained by Euratom and CECA.

The three communities jointly publish comprehensive 10-year forecasts in the energy field for the EEC countries. The latest published report is for the period 1965-1970 *(lit. ref. 292)*, and a report for 1970-1980 is in preparation. In future, detailed technological forecasting, as outlined above, will underly these demand forecasts.

CECA, in addition to the above-mentioned work in the field of fuel consumption, undertakes technological forecasting in the following areas:

1. Comprehensive forecasts of steel demand and steel technology, with considerable technological forecasting (automation, etc.), undertaken at five-year intervals with a five-year time-depth. In 1961 a study extending up to 1965 was carried out (*lit. ref. 293*), with a subsequent check on the fulfilment of the forecasts during the

first three years of the forecast period (*lit. ref.* 294); a study extending up to 1970 was in progress in 1965/66;

2. Steel in house-building, with the Battelle Memorial Institute, Geneva, investigating the technical aspects (30 types of housing are distinguished), and CECA drawing the conclusions. In progress in 1965/66;
3. Steel in industrial construction and civil engineering (only partly technological forecasting). Planned in 1966;
4. A 10-year forecast on technological change in the field of machinery and equipment for the ultimate purpose of permitting better steel and energy demand forecasts. In an experimental state in 1965/66;
5. A study of the horizontal diffusion of steel technology. Started in 1966.

The " Comité de Politique Economique à Moyen Terme " (Comité Langer), aided by the " Groupe d'Étude des Perspectives Économiques à Moyen Terme " (Groupe Kervyn de Lettenhove) and a Division de Prévision a Moyen Terme, has instituted a medium-range economic programme for the EEC region, not yet explicitly taking into account technological change, but constituting a first attempt to formulate broad goals. A first programme, for the period 1966-1970, was published in 1966.

A.4.2. INTERNATIONAL CIVIL AVIATION ORGANIZATION **(ICAO),** in Montreal (Canada). (Affiliated to United Nations).

ICAO issues the most explicit and most imaginative technological forecasting found **in** any international organisation. The forecasting which is prepared by technically qualified in-house staff on the basis of information collected from national authorities, airlines, and, where possible, the aerospace industry, has been carried out on the following principal subjects:

1. Economic implications of the introduction of commercial jet aircraft (*lit. ref. 311*), forecasts made in 1957/58—before large-scale introduction—with quantitative projections up to 1961, and a qualitative outlook beyond that date. This study has been instrumental in overcoming much initial hesitation (due to economic uncertainties) and has become a " self-fulfilling prophecy ";
2. Technical, economic, and social implications of commercial supersonic air traffic ***(lit. ref. 314)*****,** studied back in 1959/60 when supersonic aircraft development was in an early planning stage with manufacturers. Due to proprietary considerations, the technical information received from industry, was not complete, and the economic assessments which existed at that stage in the United States (inexistent as yet in France and the United Kingdom) were not revealed. In 1962, an addendum was published containing the comments of **ICAO** member countries;
3. **An** air freight forecast in quantitative terms, extending up to the year 1975, pubiished in 1962 ***(lit. ref. 310);***
4. Periodic passenger, cargo, and air-mail traffic forecasts, in detailed quantitative terms, over a 10-year period. Recent examples, in which to a large extent, technological change was taken into account, include forecasts for the North Atlantic region, published in 1966 ***(lit. ref. 312)*****,** and for the European region (1966);
5. Technological forecasting relating to the exploration and use of outer space is under consideration ***(lit. ref. 33.3).***

A.4.3. OCCASIONAL EFFORTS BY OTHER ORGANISATIONS

Economic Commission for Europe (ECE), In Geneva (affiliated to United Nations). Economic forecasts with little technological forecasting content; Economic Advisers Group (fifth meeting in 1967 will deal with acceleration of technical progress, background study prepared by **ECE** in 1966); clearinghouse for national planning methodologies.

Food and Agricultural Organization (FAO) of the United Nations in Rome. Mainly promotion **of** horizontal technology transfer, i.e. diffusion of existing technology, planning its gradual introduction, special applications.

Organisation for Economic Co-operation and Development (OECD) in Paris. Global and regional energy forecasts with 15-year time-depth, prepared at intervals of five years (" Hartley Report " 1957 - forecasting up to 1970; " Robinson Report, " 1960 - up to 1975; " Energy Policy Problems and Objectives, " 1966 ***(lit. ref. 328)*** up to 1980, for nuclear energy 1985) with assumed aggregated rates of technological change; economic and social implications of automation (conference in Zurich, 1-4 February 1966); Pilot Teams Project for the assessment of technological needs of developing economies; two pilot forecasts in the energy and materials fields *(lit. ref. 317,318)*; Development Centre for developing countries outside the OECD region, not yet active in the area of technological forecasting.

Union Internationale de Télécommunications (UIT) in Geneva, General UIT Plan up to the year 2000, including technological forecasting in aggregated terms; five study groups (committees) to assist developing countries in the introduction and development of communication services, among them group GAS 5 which advises on optimum economic approaches to the development of telecommunications in developing countries.

United Nations, New York. UN Advisory Committee on the Application of Science and Technology to Development, so far mainly definition of technological needs, concentrating on the areas of proteins, population control, water, desalination, and breeding of salt-resistant plants *(lit. ref. 392,393);* Center for Industrial Development, at the end of 1966 transformed to UNIDO—UN Industrial Development Organisation, moving to Vienna in 1967, mainly promoting horizontal technology transfer; conferences in the following areas: peaceful uses of atomic energy (1955, 1958, and 1964, in Geneva), application of science and technology for the benefit of the less developed areas (Feb. 1963, Geneva, *lit. ref. 394*), new sources of energy and energy development (Aug. 1961, Rome, *lit. ref. 345);* report on water desalination in developing countries (1964, *lit. ref.* 346).

United Nations Educational, Scientific and Cultural Organization (UNESCO) in Paris: Report on current trends in scientific research (1961, *lit. ref. 251).*

A.5. "FORERUNNER" ACTIVITIES IN "LOOK-OUT" INSTITUTIONS

Permanent, temporary, and occasional activities are combined in one alphabetical list.

The following research institutes, listed in Annex A.1., are also particularly active in promoting the idea and performing preliminary functions of "look-out" institutions in the area of social technology:

- Hudson Institute, Croton-on-Hudson, N.Y. (USA);
- The RAND Corporation, Santa Monica, California (USA);
- SÉDÉIS - Futuribles, Paris (France);
- System Development Corporation, Santa Monica, California (USA);
- TEMPO Center for Advanced Studies, General Electric Co., Santa Barbara, California (USA).

A.5.1. AMERICAN ACADEMY OF ARTS AND SCIENCES, Brookline (Boston), Massachusetts (USA)

The "Commission on the Year 2000," under the chairmanship of Daniel Bell, functioned during the academic year 1965/66. It was composed of some 30 persons and met three times; a 10-member working party prepared the meetings and will summarise the discussions. The Hudson Institute contributed a comprehensive study on alternative world futures. Five papers outlined the methodology and the kind of data and knowledge needed; the paper on technological forecasting was prepared by Donald Schon. Five broad problems of the year 2000 provided the framework for the discussions and were studied in greater detail by working parties: the adequacy of the political structure; the realm of values: the individual, equality, rights; the intellectual institutions of the post-industrial society; the life cycle and its variations; the international system—Papers and transcripts of the discussions *(lit. ref. 352)* were privately circulated and the publication of the synthesis in book form is expected.

The Academy also has a 1975 Committee (chaired by Carl Kaysen and Jerome Wiesner), publishes "Daedalus," and sponsored the first attempt to apply historical analogy to a new technology: "The Railroad and the Space Programme" *(lit. ref. 373).*

A.5.2. AMERICAN INSTITUTE OF PLANNERS, Washington, D.C. (USA)

Two conferences are being sponsored under the general heading "The Next Fifty Years 1967 - 2017": Part I, "Optimum Environment with Man as the Measure," held 14-18 August 1966 in Portland, Oregon; and Part II "The Future Environment of a Democracy," scheduled for 1-6 October 1967 in Washington, D.C. The principal question is: If we had the technology and the economy which are said to be imminent, what kind of environment would we build? The first conference concentrated on urban living and biological environments.

A.5.3. CENTER FOR CULTURE AND TECHNOLOGY, UNIVERSITY OF TORONTO, Toronto, Ontario (Canada)

The Center is made up of volunteers among the University faculty and graduate students under the leadership of Marshall McLuhan. The principal research activity in 1966 is a programme on " A Sensory Profile of the Entire Ontario Population "—a study of changes in the sensory profile over the past 30 years, resulting from new technologies (see also section II.2.5.).

A.5.4. THE CENTER FOR THE STUDY OF DEMOCRATIC INSTITUTIONS, Santa Barbara, California (USA)

A " Symposium on the Technological Society " was sponsored in Santa Barbara, 19-23 December 1965.

A.5.5. CENTRE INTERNATIONAL D'ÉTUDES DE PROSPECTIVE, Par s (France)

Founded in 1957 by Gaston Berger, the Centre is now composed of 45 persons prominent in public life under the leadership of Pierre **Massé.** Following the two latest general efforts in the area of science and technology, published in No. 5 and No. 12 of the series " Prospective " (lit. ref. 78, 79), a research programme has now been proposed to the Centre, in which international panels would be set up on the basis of the " Delphi " or a related technique, in order to determine communalities and differences in social goals and desires for the future in different regions of the world.

A.5.6. CIBA FOUNDATION, London (United Kingdom)

The Foundation organised the symposium " Man and his Future " (lit. ref. 350), and takes an active part in the " Mankind 2000 " enterprise (see Annex A.6.9. below).

A.5.7. HARVARD UNIVERSITY PROGRAM ON TECHNOLOGY AND SOCIETY, Cambridge, Massachusetts (USA)

This 10-year programme, funded by a $ 5 million grant from the IBM Company, and directed by Emmanuel G. Mesthene and Jurgen Schmandt, started in June 1964. During the first year, proposals were received and 15 smaller studies were financed. Weekly " Think Seminars " began in 1966, and out of these seminars " Research Groups " crystallise, The first two " Research Groups, " composed of Harvard and other university faculty members (part-time) and graduate students, started in the autumn of 1966; their themes are " Education and Information Technology " (concerning problems at the secondary school level) and " Biomedical Sciences and Society " (artificial organs, manipulation of genetic information, etc.). Additional research groups are tentatively planned on " The City " and on " Socially Desirable New Jobs " (should automation abolish the old jobs).—The working procedure consists of, first, the formulation of a hypothetical synthesis on the basis of the " Think Seminar, " next the performance of research in the respective groups, and then the preparation of a final synthesis.

A.5.8. INSTITUT FUER ZUKUNFTSFRAGEN, Vienna (Austria)

Founded in February, 1965, and directed by Robert Jungk and Ernst F. Winter, the institute is at present preparing to set up a " Documentation Centre on the Future " and to publish a quarterly bibliography. Research programmes are intended for the future.

A.5.9. MANKIND 2000, Boekelo (Netherlands)/London (United Kingdom)

Following an idea put forward by Robert Jungk, an international foundation " Stichting Mankind 2000 International, " chaired by Fred Polak, has been founded in the Netherlands. The Foundation is particularly active in the United Kingdom, where it is administered by James Wellesley-Wesley and where it enjoys the moral support of the CIBA Foundation. The general aim is to set up an international research institute for the coordination and integration of long-range forecasting carried out in different countries.

A.5.10. SWEDISH PARLIAMENT, Stockholm (Sweden)

In **1964,** the Swedish National **Bank** presented the Parliament with 500 million Swedish crowns (nearly **$ 100** million), leading to the creation of a permanent " look-out" effort concerned with " The Human Being in a Changing Society ". Studies will be commissioned and will be financed by the interest from the foundation **(25** to **30** million Swedish crowns per year). The initial phase **(1** million crowns was spent in **1965,** and 2 to 3 million crowns are expected to be spent in **1966)** has not thus far included technology but which will soon be brought in. The foundation is administered by a mixed committee composed of members of Parliament, the National Research Council and the Royal Swedish Academy of Engineering Sciences.

A.5.11. STATE OF CALIFORNIA (USA)

In **1964,** the State of California commissioned four studies, along the general lines of a " look-out " endeavour in social technology from the aerospace industry: Transportation (North American Aviation); Information Handling (Lockheed); Crime Prevention (Space General); Waste Management (Aerojet).—The basic aim was to define possible future areas of activity for the Californian aerospace industry—which constitutes a factor of economic and social importance to the State—in the event of a decline of aerospace business activities as such.

A.5.12. WORLD FUTURE SOCIETY, Washington, DC (USA)

Formed in **1966** under the leadership of Edward S. Cornish, the World Future Society publishes " The Futurist " (lit. ref. *395B*) and sponsors lectures on all topics with which future-planning is concerned.

A.5.13. WORLD RESOURCES INVENTORY, at the Southern Illinois University, Carbondale Illinois (USA)

This centre, sponsored by the Southern Illinois University and directed by R. Buckminster Fuller and John McHale, concentrates on the continuous research programme " The World Design Science Decade **1965-1975,"** proposed by R. B. Fuller to the International Union of Architects in **1961.** The principal aim of this ten-year programme is to investigate " how to redesign the world's prime tool networks and environment facilities so as to make the world's total resources, now serving only **44** per cent of humanity, serve 100 per cent through competent scientific design and anticipatory planning. " Four documents were published during the first five years of the programme (see *lit.* ref. **3634).** The next five years will be devoted to the study of such topics as world literacy, prime movers and prime metals, tool evolution, the service industries, and will thus go more deeply into technological forecasting proper.

A.5.14. PLANNED " LOOK-OUT " INSTITUTIONS

The following plans for permanent institutes have recently become known:

An international research centre in France, announced by Minister of State Louis Joxe *(lit.* ref. 379);

A centre to be established at Columbia University, New York, due mainly to the initiative of André Cournand and Christopher Wright; the centre is reportedly in an advanced planning stage as of late **1966;**

An Institute for the Future planned to be located near the RAND Corporation in Santa Monica, California;

OSTI (Organization for Social and Technological Innovation.), set up in **1966** in Cambridge, Mass. (USA), under the direction of Donald A. Schon;

Another American centre, similar to OSTI, but still in an embryonic state in late **1966.**

A symposium on " The Patterns of the Future, " planned by Prof. C. H. Waddington, President of the International Union of Biological Sciences and sponsored by that Union, is to be held in spring **1968.** It will concentrate on the biological future, and include such topics as population, food, health, urbanisation, education, deepening understanding, and others. It is to be hoped that this symposium will lead to a continuous " look-out " function for the biological sciences.

Annex B

AN ANNOTATED BIBLIOGRAPHY

The following selective annotated bibliography comprises, in general, the literature references used in connection with this report. The titles of a few publications not consulted have also been included and concern literature references pointed out to the author as directly pertinent. Similarly, a few references concern books not yet published at the time the bibliography was prepared but were expected to be published late in 1966 or in 1967.

A relatively large portion of the literature references concern publications which are not easily available or freely accessible. They are included here because they constituted valuable sources for this report, and because a considerable number of readers might be in a position to procure them. A number of classified military publications, and subscription series published by forecasting institutes and consulting firms, have been mentioned in Annex A.l. and A.2.; they are not included in the bibliography.

The author wishes to express his gratitude to all who made available to him informal papers, manuscripts, restricted reports, etc., and in particular the following organisations which contributed to this bibliography by putting their libraries or special bibliographies at his disposal: Brown Boveri, Mannheim (Germany); British Museum (United Kingdom); American Management Association, Lockheed, McGraw-Hill, Stanford Research Institute, System Development Corporation, US Navy (all United States); United Nations. Among the public libraries the following (all in the United States), proved to be of particular value for the compilation of the bibliography: Chicago Public Library, Chicago, Ill; Engineering Library, New York; Library of Congress, Washington, DC; New York Public Library.

THE BIBLIOGRAPHY IS DIVIDED INTO THE FOLLOWING BROAD SUBJECT CATEGORIES

An author index is added at the end

***

B.I. FUNDAMENTAL SCIENCE AND TECHNOLOGY (General)

1. Berkner, Lloyd V., ***The Scientific Age - The Impact of Science on Society,*** Yale University Press, New Haven, **1964. 137** p.
(Mainly a discussion of the relationship between science and government.)

2. Bridgman, P.W., ***Reflections of*** a ***Physicist,*** Philosophical Library, **1950.**
(Proposes the application of pragmatic operational analysis to physical concepts. An idea can be substantiated only when the conditions of use have been made clear.)

3. Bronowski, J., ***Science and* Human *Values,*** Hutchinson, London, **1956** and **1961.**
(Not reviewed.)

4. Conant, James B., ***Science and Common Sense,*** Yale University Press, New Haven, 1952, Yale Paperbound (tenth printing) July 1964. 344 p.

(A study-in-depth of the history of scientific discovery, stressing the importance of conceptual schemes which provide focus to research. The conclusions drawn from the investigation of a very rich fund of material are somewhat vague and amorphous.)

5. De Solla Price, Derek J., A ***Calculus of Science,*** International Science and Technology, No. 15, March 1963.

(A synthesis of the author's books " Science since Babylon," 1961, and " Little Science, Big Science"—for the latter see lit. ref. 6.)

6. De Solla Price, Derek J., ***Little Science, Big Science,*** Columbia University Press, New York, 1963, Columbia Paperback edition, 1965. 118 p.

(General growth problems in science—number of scientists, publications, degrees, etc., and a discussion of the extrapolation of their growth curves. A highly original approach which has had a very stimulating effect on technological forecasting in general.)

7. Green, E.I., ***Creative Thinking in Scientific Work,*** Electrical Engineering, Vol. LXXIII, June 1954; reprinted in condensed form, lit ref. 32, pp. 118-127.

(Includes three attempts to systematise: 1. a list of 10 basic capabilities - knowledge, capacity for self-instruction, curiosity, observation, memory, intellectual integrity, scepticism, imagination, enthusiasm, persistence; 2. a most interesting relevance tree of creative thinking; 3. Processes of creative thought.)

8. Heitler, W., ***Man and Science,*** Oliver and Boyd, Edinburgh and London, 1963.

(Science is too mechanistic today; its effects are therefore inimical to man. A sense of reality beyond the boundaries of our science is missing in our society.)

9. Holton, Gerard (ed.), ***Science and Culture - A Study of Cohesive and Disjunctive Forces,*** The Deadalus Library, Vol. 4, Houghton Mifflin Co., Boston, Mass. 1965.

(Especially significant are the articles by René Dubos, " Science and Man's Nature," pp. 251-272, and Harvey Brooks, " Scientific Concepts and Cultural Change," pp. 70-87, the latter discussing feedback and information in the physical and biological sciences.)

10. Kuhn, Thomas S., ***The Structure of Scientific Revolutions,*** Phœnix Books (also Vol. II, No. 2, International Encyclopaedia of Unified Science), both at The University of Chicago Press, Chicago, Ill., 1962. 172 p. (Phœnix edition 1964.)

(Kuhn's basic position is that fundamental science can only deteriorate by contact with society and social needs. He distinguishes between " normal science" which develops around paradigms—intellectual concepts—and revolutions which emerge from crises caused by anomalies and take the form of competition between different new paradigms, until the victorious is instituted and gives rise to new " normal science." Any attempt to introduce stimulation or focus from outside can be only harmful according to the author. Purpose-free science will substitute for evolution-toward-what-we-wish-to-know the better alternative, evolution-from-what-we-do-know. Kuhn's brilliant essay, which has made considerable impact, is partly at the root of the widesperad belief that fundamental science is not amenable to forecasting, choice, and planning.)

11. Lapp, Ralph E., ***The New Priesthood - The Scientific Elite and the Uses of Power,*** Harper & Row, New York, 1965.

(The role of the scientist in formulating and pursuing social goals on a national level.)

12. Pyke, Magnus, ***The Boundaries of Science,*** Pelican Book A *593,* Penguin Books, Harmondsworth, Middlesex, 1963. 208 p.

(A general discussion of limitations to current fundamental research.)

13. Quinn, J.B., and Cavanaugh, R.M., ***Fundamental research can be planned,*** Harvard Business Review, Vol. 42, Jan./Feb. 1964, p. 111-124.

(Fundamental research can be related to corporate long-term objectives and planned in an optimum way.)

14. Ridenour, Louis N., ***Physical Science and the Future,*** in: Lyman Bryson (ed.) ***Facing the Future's Risks - Studies Toward Predicting the Unforeseen,*** Harper & Brothers, New York 1953, pp. 60-89.

(Selective thoughts on forecasting in the physical sciences, stressing thinking in fundamental principles, and on the interaction of science, engineering and industry, especially on the merger of different technologies to bring about innovation.)

15. Scientific American, a ***symposium*** comprising the following articles: J. Bronowski, ***The Creative Process;*** Paul R. Halmos, ***Innovation in Mathematics;*** Freeman J. Dyson, ***Innovation in Physics;*** George Wald, ***Innovation in Biology;*** John R. Pierce, ***Innovation in Technology;*** John C. Eccles, ***The Physiology of Imagination;*** Frank Barron, ***The Psychology of Imagination;*** Warren Weaver, ***The Encouragement of Science;*** Scientific American, Sept. 1958.

16. Siu, R.G.H., ***The Tao of Science,*** an essay on Western knowledge and Eastern wisdom, MIT Press, Cambridge, Mass., 1957, MIT Press Paperback Edition, August 1964. 180 p.

(A very important, though not very widely known essay advocating the integration of fundamental science and society and a link between fundamental research and social goals by the introduction of a little Eastern wisdom. Three types of knowledge are distinguished: rational knowledge, intuitive knowledge, and no-knowledge. The last type is the key to the introduction of " intrinsic values "—goodness, truth, and beauty—in science and to the desired integration. Written in a very pointed and explicit language, this essay merits wide attention in connection with the present attempts to effect the integration between science and society.)

17. Snow, C.P., ***The Two Cultures: and a Second Look,*** (an expanded version of: The Two Cultures and the Scientific Revolution), Cambridge University Press, Cambridge, Mass., 1959 and 1963, Mentor Book, The New American Library, New York, 1964, 92 p.

(The well-known book on the fatal split between natural and humanistic sciences.)

18. Taton, R., ***Reason and Chance in Scientific Discovery,*** translated from French (original title unknown), Science Editions, New York, 1962, 171 p.

(A study of past scientific discovery showing that " systematic discovery " apparently played a larger role than is generally assumed, and that some great scientists in the 19th century felt their responsibility towards society and consciously chose research topics which contributed to social goals and external scientific values.)

19. Lord Todd, ***Science and Society,*** The Sir Henry Tizard Memorial Lecture, given at Westminster School, London, 5 March 1964. 10 p.

(Advocates the integration of fundamental science and society.)

20. US National Academy of Sciences, ***Basic Research and National Goals,*** a report to the Committee on Science and Astronautics, US House of Representatives; National Academy of Sciences, Washington, DC., March 1965.

(A collection of articles by prominent scientists, such as Kistiakowsky, Teller, Weinberg and many others.)

21. US National Academy of Sciences - National Research Council, ***Chemistry: Opportunities and Needs,*** publication No. 1292, Academy of Sciences—National Research Council, Washington, DC., 1965.

(The " Westheimer report," the most complete report of the COSPUP series.)

22. US National Academy of Sciences—National Research Council, ***Physics: Survey and Outlook : Reports on the Subfields of Physics,*** National Academy of Sciences—National Research Council, Washington, DC, 1966. 165 p.

(The eight sub-field reports, constituting the input to the Survey of Physics—the " Pake Report "—in the framework of COSPUP.)

23. US National Academy of Sciences—National Research Council, ***Theoretical Chemistry - A Current Review,*** Publication No. 1292-D, National Academy of Sciences—National Research Council, Washington, DC, 1966. 44 p.

(The input report on theoretical chemistry to the Survey of Chemistry—the " Westheimer Report "—in the framework of COSPUP.)

24. Weinberg, Alvin M., ***Criteria for Scientific Choice,*** Minerva, 1963, p. 159-171.

(The director of the US-AEC's Oak Ridge National Laboratory maintains that criteria for making scientific choice are identifiable. He distinguishes between internal and external criteria. Internal criteria include ripeness of a field and availability of good research people. External criteria include scientific merit, technological merit, and social merit. Scientific merit also covers relevance to, or impact on, related fields of science.)

B.2. Technological Invention, Innovation and Diffusion (General)

25. Abraham, J.P., Blœmer, K.H., Tavernier, K., ***Progrès Techniques, Croissance Économique et Consommation d'Énergie,*** Revue d'Économie Politique, Paris 1965, p. 350-384.

(A correlation based on data from the electricity-and fuel-consuming industries of the Common Market countries.)

26. Audoin, ***Situation de l'Industrie Electronique,*** Secrétaire Général de la Commission Permanente de l'Électronique du Commissariat Général du Plan, Paris (France), manuscript Dec. 1965.

(A comparison between US and European developments in the electronics sector, recognising two important factors: the role of strongly mission-oriented development in accelerating innovation and raising the technological level in the US, and the forthcoming structural changes in the electronics sector due to technological change, especially microminiaturisation. A " coalition " approach is suggested for the European countries in order to keep pace with US developments. This paper represents one of the rare attempts in Europe to understand the roots of the US-Europe technological gap in an important sector and to stress the necessity of a strategy for the future.)

27. Aujac, H., ***Le Passage de l'Invention d la Production,*** paper presented at the Congrès des Économistes de Langue Française, Orléans (France), May 1966. 85 p.

(A general treatise on technological innovation on the basis of French and American experience, and an outline of BIPE's study programme, by the director of BIPE. Different aspects and examples of technological forecasting are included in the discussion.)

28. Barnett, H.G., ***Innovation: The Basis of Cultural Change,*** McGraw-Hill, New York, 1953.

(Develops a working hypothesis on the process of invention and innovation from the point of view of the setting, the incentives to innovation, the nature of innovative process and acceptance/rejection. The working hypothesis is tested on the basis of six main cultures, among them the European.)

29. Bickner, Robert E., ***The Changing Relationship between the Air Force and the Aerospace Industry,*** Memorandum RM-4101-PR, prepared for the US Air Force Project RAND, The RAND Corporation, Santa Monica, California, July 1964. 79 p.

(The chapter " Pressing against technological frontiers " argues for a slight relief from the extreme pressure of requirements on technological capabilities. It is suggested that the extreme system complexity often encountered today may be the consequence of " squeezing " capability from a temporarily overtaxed state of the arts, whether because of an emergency need to " over-stretch " or because of an irrepressible optimistic temptation to do so.)

30. Blackett, P.M.S., ***Tizard and the Science of War,*** Nature, March 1960.

(Includes an interesting analysis of the research and development'strategy for radar.)

31. Bright, James R., ***Opportunity and Threat in Technological Change,*** Harvard Business Review, Nov./Dec. **1963,**

(Seven important technological areas of change are discerned: transportation, energy, organic and inorganic products, characteristics of materials—" molecular engineering," sensory capabilities, mechanisation: physical, mechanisation: intellectual. A number of general economic consequences are pointed out, such as: competition from distant areas and from non-traditional fields, opportunities of marketing, technological obsolescence leading to shorter competitive life span, increasing risk for business decisions, etc. Technological forecasting is recognised as a valuable contribution to management in the light of these consequences.)

32. Bright, James R. (ed.), ***Research, Development, and Technological Innovation,*** Richard D. Irwin, Homewood, Ill. **1964. 783** p.

(This very useful anthology, conceived for the benefit of students at the Harvard Graduate School of Business Administration, contains original and reprinted articles as well as short quotations from various sources, papers and discussions from a Harvard Seminar, and direct contributions by the editor. Section V on " Technological Planning and Forecasting " is of particular relevance to problems of technological forecasting, but closey related problems are also discussed in articles that appear in Section I " The Process of Technological Innovation," and Section III " Finding and Evaluating Significant Technological Opportunities." The following references in this bibliography are reprinted in Bright's anthology: lit, ref. **7, 40, 55, 70, 87, 199,217.)**

33. Brown, Murray, ***On the Theory and Measurement of Technological Change,*** Cambridge University Press, London, **1966.**

(Not reviewed.)

34. Brozen, Yale, ***Determination of the Direction of Technological Change,*** American Economic Review, **Vol. 43,** May **1953,** pp. **288-302.** Discussion by M.C. Urquhart, I.H. Siegel, and W.N. Leonard, pp. **303-312.**

(Brozen maintains that technological change is primarily an endogenous variable within the economic system, so that the directions of technological change are entirely determined by market-orientation. Urquhart insists on the importance of exogenous factors—which since **1953,** have become quite obvious—and Siegel tries to compromise between the extreme positions.)

35. **Bruce,** Robert D., ***The Dimensions of Change,*** paper presented at the First National Joint Meeting, Operations Research Society of America and The Institute of Management Sciences, San Francisco, Calif., **9** Nov. **1961.**

(A useful discussion of different types of environmental change and its measurement, outlining important aspects of technological forecasting, by the then Manager of the Stanford Research Institute's Long Range Planning Service.)

36. Carter, C.F., ***The Characteristics of Technically Progressive Firms,*** Journal of Industrial Economics, Vol. **7,** No. **1,** March **1959,** pp. **87-104.**

(Not reviewed.)

37. Carter, C.F **,** and Williams, B.R., ***Industry and Technical Progress : Factors Governing the Speed of Application of Science,*** London 1957, **244** p.

(Not reviewed.)

38. Emme, Eugene M., A ***History of Space Flight,*** Holt, Rinehart, and Winston, Inc., New York **1965.**

(An interesting historical account of a technology which started in **350** B.C. when the ancient Greeks fired their first rocket, the important principles of which had generally been known long before they could be technically applied. This is the story of a long technological development in which opportunities pointing towards the future were clearly recognised in many cases, but had to await the maturing of discrete technologies and the creation of strong missions.)

39. **Enos,** John L., ***Invention and Innovation in the Petroleum Refining Industry,*** in: ***The Rate and Direction of Inventive Activity,*** lit. ref. **65,** pp. **299-321.**

(Derives a time lag between invention and innovation—meaning commercial operation—of **3** to **24** years for **9** cracking processes applied between **1913** and **1950.** The mean value of **13** years is approximately the same as for **35** major innovations outside the petroleum field between **1711** and **1950.)**

40. Gilfillan, **S.** Colum, ***The Prediction of Technical Change,*** The Review of Economics and Statistics, Vol. XXXIV, Nov. **1952,** pp. **368-385.** Reprinted in lit. ref. **32,** pp. **738-754.**

(Primarily " hindsight " applied to examples such as television—which is traced back to a satirical prediction in **1847—and** an investigation of the **19** most useful inventions introduced in the quarter century before **1913,** during which very long time lags occurred between the first idea and the further stages of invention, innovation, and diffusion. For these **19** inventions the mean time lag between first idea and first working model or patent is **176** years. The time lag between the first working model and commercial success is generally found to vary between **33** and **38** years, **on** the average, for different statistical evaluations of more than **200** important inventions between **1787** and **1935.** Based **on** this past history, Gilfillan discusses the recognition of future causality—mainly from an opportunity-oriented position— and **makes** the interesting observation that inventions come in functionally equivalent groups, thus making the effects easier to predict—a still essentially unconscious recognition of the strong forces of mission-oriented innovative processes.)

41. Gilman, William, ***Science: USA,*** The Viking Press, New York, **1965.**

(A popular account of how important scientific and technical breakthroughs have occurred in the **US,** with a look towards the future in a number of prominent fields. Sometimes lacking thorough scientific understanding.)

42. Griliches, Zvi, ***Hybrid Corn: An Exploration in the Economics of Technological Change,*** Econometrica (Journal of the Econometric Society), Vol. **25,** No. **4,** October **1957,** p. **501-522.**

(A study in the diffusion of an important new technology. Logistic growth functions are fitted to the data, and differences in the slopes and ceilings explained. The conclusion drawn is that the pattern and rate of diffusion are amenable to economic analysis.)

43. Griliches, Zvi, ***Research Costs and Social Returns: Hybrid Corn and Related Innovation,*** The Journal of Political Economy, Vol. LXVI, No, **5,** October **1958,** p. **419-431.**

(An outgrowth of the study lit. ref. **42.** The analysis leads to the estimate of earnings of at least **700** per cent per year on the investment in hybrid-corn research, based on **1955** data.)

43a. Isenson, Raymond, ***et al., Project Hindsight,*** First Interim Report, Clearinghouse for Federal Scientific and Technical Literature, Springfield, Virginia **22151,** October, **1966.**

(An evaluation of **835** " events "—generation of knowledge—in the development of 20 major weapon systems. The conclusions stress the great importance of normative thinking and show that undirected research contributes very little.)

44. Little, Arthur **D.,** Inc., ***Management Factors Affecting Research and Exploratory Development,*** report for the Director of Defense Research and Engineering, contract No. **SD-235,** Arthur **D.** Little, Inc., Cambridge, Mass., April **1965. 180** p. Clearinghouse for Federal Scientific and Technical Literature number **AD-618, 321.**

(An evaluation of **63** research and exploratory development " events " in the development history of six complex weapon systems. The main findings are that new weapon systems depend on many small inventions—only two major inventions contributed to the development of the evaluated systems—and that " adaptive " environment, in contrast to " authoritarian " environment, is probably an absolute prerequisite for successful development.)

45. Little, Arthur **D.,** Inc., ***Patterns and Problems of Technical Innovation in American Industry,*** report PB **181573** to National Science Foundation, Arthur D. Little, Inc., Cambridge, Mass., **1963.**

(The importance of migration of scientists and engineers, and of " invasions " of static by dynamic industrial sectors, is illustrated by brilliant case studies in four industrial sectors including the dramatic story of the diffusion of semiconductor technology,)

46. Mansfield, Edwin, ***Econometric Studies in Industrial Research and Technological Innovation***, ***W. W.*** Norton ***& Co.***, New York, for the Cowles Foundation, **1966.**
(Not reviewed.)

47. Mansfield, Edwin, ***Intrafirm Rates of Diffusion of an Innovation***, Review of Economics and Statistics, November, **1963.**
(The displacement of the steam locomotive by the Diesel locomotive in the **US** between the wars is studied, and **an** econometric model is constructed to help explain the differences in the rate of acceptance.)

48. Mansfield, Edwin, ***An Introduction to the Economics of Technological Change***, ***W. W.*** Norton & Co., New York, **1966.**
(Intended for non-experts in the field.)

49. Mansfield, Edwin, ***Research*** and ***Technological Change***, Industrial Research, Vol. **6,** No. **2,** Febr. **1964,** pp. **25-28.**
(Summary of findings reported in lit. ref. **50.)**

50. Mansfield, Edwin, ***The Speed of Response of Firms to New Techniques***, The Quarterly Journal of Economics, Vol. **77,** May **1963,** pp. **290-311.**
(Preliminary results of a continuing study of the diffusion of technological innovation, with an attempt to correlate them. The following conclusion is of particular relevance to forecasting technological innovation which depends on the maturing of different technologies: In most industries, only a weak tendency exists for the same firms to be consistently the earliest to introduce different innovations. The leaders in one innovation are often followers in another, especially if large time lags exist between two innovations.)

51. Mansfield, Edwin, ***Technical Change and the Rate of Imitation***, Econometrica, Oct. **1961.**
(Models trying to explain the rate at which other firms imitate an innovator are tested empirically in the iron and steel, bituminous coal, railroad, and brewing industries of the United States. The results appear encouraging.)

52. Marschak, Thomas **A.,** ***Strategy and Organisation in a System Development Project***, in: ***The Rate and Direction of Inventive Activity***, lit. ref. **65, pp. 509-548.**
(A case study of the development of the TH System, **a** long-distance microwave relay system, at Bell Telephone Laboratories, from the start in **1952** to manufacturing in **1958.** The value of estimates made in **1954,** the time at which the choice between alternative major systems characteristics was made and detailed systems planning was started, turned out to be well in line with the pre-established planning priorities: **1.** Objectives, production and operating costs came out close to prediction. **2.** Development time slippages occurred only for some components and could be kept below **six** months in every case. **3.** Total development effort estimates were over-optimistic —between **1954** and **1958 401** man-years were needed instead of an estimated **236.** Technological forecasting studies were made at two stages by the Systems Engineering people: in **1962,** including economic demand; in **1954,** including costs, time, system objectives, development schedule.)

53. Marschak, Thomas A.; Glennan; Summers, Robert (editors), ***Studies in the Microeconomics of Development***, published in **1966** in the **USA.**
(A reprint of lit. ref. **250** is included.)

54. McGraw-Hill, ***Research*** and ***Development in American Industry***, Department of **Eco**nomics, McGraw-Hill Publications, New York, **6** May **1966.**
(The results of a survey of **US** industry concerning estimates for the amount and structure of industrial R & D in **1966** and **1969,** for **15** industrial sectors and total industry, and evaluating expected impact.)

55. Mueller, Willard F., ***The Origins of the Basic Inventions Underlying Du Pont's Major Product and Process Innovations, I920 to 1950***, **in:** ***The Rate and Direction of Inventive Activity***, lit. ref. **65, pp. 323-346,** comment by **Z.** Griliches, pp. **346-358.** Reprinted in lit. ref. **32.**

(Some inventions were due to a strong mission-oriented approach. Others were more "accidental." However, in some cases, e.g. "accidental" nylon, broad missions were given, for example through the recognition of polymerisation as an important field. A study in greater depth would probably show a structure analogous to that of the invention of the transistor—see lit. ref. 57—but the paper missed this opportunity.)

56. Myers, Sumner, ***Industrial Innovations - Their Characteristics and Their Scientific and Technical Information Bases,*** a special report to the National Science Foundation; National Planning Association, Washington, D.C. April 1966, 24 p.

(A first progress report on a continuing investigation by NPA, using a series of case studies of innovations in US civilian industry.)

57. Nelson, Richard A., ***The Link Between Science and Invention: The Case of the Transistor,*** in: ***The Rate*** and ***Direction of Inventive Activity,*** lit. ref. 65, pp. 549-583.

(An excellent account of this famous invention. The approach in Shockley's group at the Bell Telephone Laboratories was strongly mission-oriented in a broad sense, but the direction of research was changed dramatically through "learning." The general feeling that solid-state work had advanced sufficiently to make a significant contribution to communication technology, Bell's primary field of interest, first determined a direction of research towards a solid-state amplifier. In 1947-48, Bardeen's and Brattain's experiments, aimed at the development of a field effect amplifier, resulted in finding an amplifier working on different principles: the point contact transistor. Recognising the importance of minority carriers, Shockley subsequently, in 1951, first predicted on theoretical grounds, and then demonstrated, the junction transistor. Nelson stresses the importance of three factors: "learning," interaction of people, goals set in broad terms.)

58. Page, Robert Morris, ***The Origin of Radar,*** Science Study Series, Anchor Books, Doubleday & Co., Garden City, N.Y., 1962, 198 p.

(This booklet, by one of the principal contributors to radar development in the US, not only gives a good historical account including premature ideas since 1900, but also tries to explain explicitly why the fruitful idea of pulse radar died in 1930, and was taken up again and developed to a mature status after 1934.)

59. Peck, Merton J., ***Inventions in the Postwar American Aluminium Industry,*** in: ***The Rate*** and ***Direction of Inventive Activity,*** lit. ref. 65, pp. 279-298.

(Concludes that oligopoly is more inducive to innovation than monopoly, as one would have expected.)

60. Rogers, Everett M., ***Diffusion of Innovations,*** Free Press, New York 1962, 367 p.

(Considered one of the best books on this subject.)

61. Schumpeter, J.A., ***Business Cycles,*** Vol. I, McGraw-Hill, New York, 1939.

(A central concept in Schumpeter's theory of economic development is the "clustering" around innovations—the succession of related innovations and imitations following a major innovation.)

62. Siegel, Irving H., ***Scientific Discovery and the Rate of Invention,*** in: ***The Rate and Direction of Inventive Activity,*** lit. ref. 65: pp. 451-540.

(The relations between scientific discovery and invention are considered as concepts and phenomena. These two entities are connected with the generation, treatment, and use of information, which is increasingly recognised as fundamental economic and technological "stuff" comparable to energy and matter.)

63. Standard Oil Development Co., ***The Future of Industrial Research,*** Proceedings of the Forum on the Future of Industrial Research on the occasion of Standard Oil Development Company's Silver Anniversary in October, 1944; Standard Oil Development Company, New York, 1945.

(A wide cross-section of qualified opinion expressed by some of the most distinguished personalities from American government, industry, and universities. A certain consensus favours such concepts as: no planning of research, co-operative research, small science-based industry which would not " plan " but " try out " new products, etc. This concept for the future—which essentially expressed a desire to go back to pre-war habits—has changed drastically in the United States in the tws decades following its formulation in **1944.)**

64. US Agricultural Research Service, ***Agricultural Innovations - Foundation for a Modern Economy,*** Agricultural Research Service, US Department of Agriculture, Washington, DC, April **1965, 43** p. Reprinted in lit. ref. **238.**
(Contains, among other things, two interesting case studies of important innovations: Hybrid corn technology, and broiler technology.)

65. US National Bureau of Economic Research, ***The Rate and Direction of Inventive Activity - Economic and Social Factors.*** A Conference of the Universities—National Bureau Committee for Economic Research, Princeton University Press, Princeton **1962.**
(Papers presented by **24** outstanding economists, and discussions held at a conference at the University of Minnoseta, in **1960,** giving the results and conclusions of a continuing research programme through the **1950's.** References **39, 52, 55, 57, 59, 62, 244, 246** appear in this volume.

See also reference **15.**

B.3. SOCIAL TECHNOLOGY (GENERAL)

66. Aron, Raymond (ed.), ***World Technology and Human Destiny,*** The University of Michigan Press, Ann Arbor, Michigan, **1963.**
(An account of the " Basel-Rheinfelden Conference," with rather general and vague contributions by philosophers and social thinkers.)

67. Dubos, René, ***Environmental Biology,*** BioScience, Vol. **14,** No. **1, 1964,** p. **11-14.**
(Biology in a framework of social goals.)

68. Dubos, Rend, ***Social Determinants of Medical Knowledge,*** Journal of the American Medical Association, Vol. **194, 27** Dec. **1965, p. 1371-1373.**
(Medical science in the framework of social goals.)

69. Ellul, Jacques, ***La Technique,*** English translation ***The Technological Society,*** Alfred A. Knopf, New York, **1964.**
(A fundamental treatise of problems in the area of social technology, taking a fatalistic outlook.)

70. Gilfillan, **S.** Colum, ***The Sociology of Invention,*** Follett Publishing Co., Chicago, Ill., **1935.** Chapter " The Social Principles of Invention, " pp. **5-13** is reprinted in lit. ref. **32.**
(The first chapter is an attempted systematic approach to structuring the field in accordance with **38** principles.)

71. Ginzberg, Eli (ed.), ***Technology and Social Change,*** Columbia Press, New York, **1964.**
(Volume **1** of **a** series of publications based on a continuous Columbia University seminar on " Technology and Social Change, " containing original papers and discussions. **See** also lit. refs. 81 and 81a.)

72. McLuhan, Marshall, ***From Cliché to Archetype,*** The Viking Press, New York, expected date of publication **1967.**
(Clichés and archetypes are viewed as processes, not as fixed patterns.)

73. McLuhan, Marshall, ***Culture is Our Business,*** McGraw Hill, New York, expected date of publication **1967.**
(The big decisions of the future are everybody's business. " Sensory profiles " will become an indispensable means of setting goals for the world. In a transitory stage sensory control—the programming of human environments for sensory profiles—can be achieved. Governments are too old-fashioned for this task.)

74. McLuhan, Marshall, A ***Message to the Fish,*** Harcourt Press, expected date of publication 1967.
(About environments which people never see—as the fish does not see the water.)

75. McLuhan, Marshall, ***Space in Poetry and Painting,*** Harper & Row, New York, expected date of publication 1967.
(Space properties of the different senses, in the framework of research on the " sensory profile" of man.)

76. Ozbekhan, Hasan, ***Technology and Man's Future,*** report SP-2494, System Development Corporation, Santa Monica, California, 27 May 1966. 41 p.
(A visionary outline of the role of technological forecasting in the broad framework of social technology.)

77. Paloczi-Horvath, George, ***Jugend - Schicksal der Welt,*** Schweizer Verlagshaus AG., Zurich, (Switzerland), 1965.
(Not reviewed.)

77a. Polak, Fred A. ***The Image of the Future,*** 2 volumes, Oceana, New York, 1961 Abridged paperback to be published in the United States early in 1967.
(Contains a new theory of culture dynamics and of cultural forecasting.)

78. Prospective, ***Le Progrès Scientifique et Technique et la Condition de l'Homme,*** Prospective No. 5, Publication du Centre d'Études Prospectives (Association Gaston-Berger), Presses Universitaires de France, Paris, 1960.
(The first approach of the Centre to the problem of change by scientific and technical progress, seen from a somewhat philosophical point of view.)

79. Prospective, ***La Recherche Scientifique, L'État et la Société,*** Prospective No. 12, Publication du Centre d'Études Prospectives (Association Gaston-Berger), Presses Universitaires de France, Paris, Jan. 1965. 217 p.
(The distillate of bi-monthly meetings of a working group of the Centre during 18 months, enriched by contacts with USA, Austria and Belgium. An introduction by P. Piganiol, followed by an " Exposé Général " and a number of papers by R. Jungk, L. Massart, E.G. Mesthene, L. Villecourt, C. Wright and others, deal with general social and political consequences of scientific and technological progress, and constitute the basis for a future science policy.)

80. Teilhard de Chardin, Pierre, ***L'Avenir de l'Homme,*** Editions du Seuil, Paris 1959, English translation: ***The Future of Man,*** Collins, London 1964.
(The social and intellectual evolution of man, his place and reponsilibility in the universe as the basis for the determination of objectives towards which our striving should be directed—the " Grand Option " for man in the 20th century. " The whole future of the Earth and of religion seems to depend on the awakening of our faith in the future ".)

81. Warner, Aaron W.; Morse, Dean; and Eichner, Alfred S., (editors), ***The Impact of Science on Technology,*** Columbia University Press, New York, 1965.
(Volume 2 of a series of publications based on a continuous Columbia University seminar on " Technology and Social Change, " see also lit. ref. 71 and 81a.)

81a. Warner, Aaron W., and Morse, Dean (editors), ***Technological Innovation and Society,*** Columbia University Press, New York, 1966.
(Volume 3 of a series of publications based on a continuous Columbia University seminar on " Technology and Social Change. " See also lit. ref. 71 and 81.)

82. Wiener, Norbert, ***The*** Human ***Use of Human Beings,*** Houghton Mifflin Co., Boston, 1950, Second Revised Edition Anchor Book A 34, Doubleday, Garden City, N.Y. 1954, 199 p.
(A popular version of Wiener's principal book—' Cybernetics,' 1948—which points out clearly the social implications of communication and information theory, in whose development the author had a very important share. This book constitutes one of the fundamental essays on social technology and is brilliantly written.)

See also reference 165.

83. Abt Associates, Inc., ***Great World Issues of 1980***, a proposal for a study submitted to US Air Force Office of Scientific Research, Abt Associates, Inc., Cambridge, Mass., 24 April 1965. 101 p. (Restricted.)
(An imaginative broad discussion of forecasting techniques, including the following topics: a comprehensive table of quantitative, qualitative, and mixed prediction methods, with a discussion of their characteristics; an outline of four mathematical forecasting (extrapolation) techniques: classical regression technique, classical statistics, Bayesian statistics, linear system techniques: model simulation for long-range prediction of processes by evaluating qualitative and quantitative ranges for the input elements and data and arriving at the relative probability of aggregated classes of possibilities: a first attempt to introduce probabilistic input evaluation in big systems models: experimental forecasting by gaming: the role of technological forecasting in planning on a political, economic, technological, and military level. A bibliography of about 50 items is added.)

84. Abt Associates, Inc., ***Survey of the State of the Art: Social, Political, and Economic Models and Simulations***, report prepared for the National Commission on Technology, Automation, and Economic Progress. A separate summary volume exists for this report. Abt Associates, Inc., Cambridge, Mass., 26 Nov. 1965, 83 p. plus appendices. (To be published in the further volumes of " Technology and American Economy.")
(One of the input reports of The Report to the President on " Technology and American Economy, " lit. ref. 383; 57 models currently used or under development are reviewed, their typology is developed and characteristics and limitations are discussed. Recommendations for the application of current modelling activities in government areas include applications to technology forecasting, resource allocation optimisation, programme requirements identification and forecasting, cost/effectiveness evaluation, and social change forecasting.)

85. Alexander, Thomas, ***The Wild Birds Find a Corporate Roost,*** Fortune Magazine, Vol. LXX, Aug. 1964, p. 130 ff.
(A case for imaginative thinking, with evidence of the success of " science fiction " thinking.)

86. Allen, D.H., ***Assessing Industrial Research Projects,*** Science Journal, Dec. 1965, p. 79-83.
(A review of discounted cash flow methods, with proposals for some refinements.)

87. Ansoff, H. Igor, ***Evaluation of Applied Research in a Business Firm,*** in: ***Technological Planning at the Corporate Level,*** lit. ref. 195, pp. 209-224, reprinted in lit. ref. 32.
(In a decision theory approach, 13 factors are combined into a figure of merit roughly proportional to the return on investment. Multi-dimensional considerations, such as " probability of success ", or " probability of successful market penetration, " are reduced to single probability indices.)

88. Asher, D.T., ***A Linear Programming Model for the Allocation of R and D Efforts,*** in: " Special Section on Project Selection and Budgeting in R & D, " IRE Transactions on Engineering Management, Vol. EM-9, No. 4, Dec. 1962, pp. 154-157.
(An operations research approach, developed for a pharmaceutical company. Discounted net values and probabilities of success are estimated for projects. Ranking criterion is the maximum expected discounted net value, taking into account availability of man-hours and chemicals. This model suits the specific situation of the pharmaceutical sector in which technological forecasting generally does not provide a possibility of improving the " target-finding " for research. According to the 1958 US figures—115,000 compounds tested, but only 40 new chemical entities produced—a 0.0003 probability of success is assumed and a Poisson distribution for random events is proposed.)

89. Ayres, Robert U., ***On Technological Forecasting,*** Report HI-484-DP, 10 Feb., 1965, revised (and considerably improved) version HI-484-DP (Rev.) 17 Jan., 1966. Hudson Institute, Harmon-on-Hudson, N.Y. (Restricted).
(A thorough discussion of aspects and techniques of technological forecasting. Particular emphasis is placed on the discussion of extrapolation techniques in connection

with times-series, and the envelope technique is recognised as a major advance in this field. The introductory discussion of potential pit-falls in technological forecasting, illustrated by examples from earlier forecasts, is of special interest, A bibliography is added.)

90. Bagby, F.L. ; Farrar, D.L.; James, G.W. ; Badertscher, R.F. ; and Cross, H.C., *A Fesability Study of Techniques for Measuring and Predicting the State of the Art,* report HqARDC-TR-59-78, prepared for the Plans and Programs Office, Headquarters Air Research and Development Command, US Air Force, Andrews Air Force Base, Washington D.C., by Battelle Memorial Institute, Columbus, Ohio, July 1959. 32 p. plus 148 p. appendices. Former ASTIA number AD 233,350 (same number for Clearinghouse for Federal Scientific and Technical Literature.).

(An early review of the applicability of technological forecasting based on the example of delta wing aerodynamics and high-temperature metallurgy, supported by a general study of the research and development process in the United States. Exploratory technological forecasting techniques were found insufficient for the prediction of the state of the art, but the potential of normative forecasting is recognised in a general way—although the importance of normative forecasting was not fully grasped at that time.)

91. Baker, M.R., and Pound, W.H., *R and D Project Selection: Where We Stand,* IEEE Transactions on Engineering Management, Vol. EM-11, No. 4, Dec. 1964, p. 124-134.

(A review of the literature on R & D project selection, with a critical discussion of 10 published ranking procedures and an account of testing that has been done. A case for more testing is made, and implications for future research are presented. A bibliography of 119 items on project selection will be of particular value.)

92. Beckwith, R.E., A *Stochastic Regression Model for Proposal Success Evaluation,* IEEE Transactions on Engineering Management, Vol. EM-12, No. 2, June 1965, pp. 59-62.

(A decision theory approach to evaluate the probability of a given proposal to " capture " a job contract award. The identity of probable competition factors influencing a contract award, and an ability to rank one's own organisation are taken into account. This model is useful only for evaluation in a closed cycle, for example within a pre-established defence research programme.)

93. Bell, Daniel, *Twelve Modes of Prediction - a Preliminary Sorting of Approaches in the Social Sciences,* Daedalus, Summer 1964, p. 865.

(Not reviewed.)

94. Beller, William S., *Technique Ranks Space Objectives,* Missiles and Rockets, 7 Febr. 1966, 3 p.

(The application of Honeywell's PATTERN scheme, a relevance tree approach to decision-making, to NASA's Apollo Payload Evaluation Project at the Marshal1 Space Flight Center in Huntsville, Alabama.)

95. Bellman, Richard; Clark, C.E.; Malcolm, D.G.G.; Draft, C.J.; Ricciardi, F.M., *On the Construction of a Multi-Stage, Multi-Person Business Game,* Operations Research, Vol. V, No. 4, Aug. 1957, pp. 469-503.

(The American Management Association's AMA game, which includes management decisions on technical innovation.)

96. BIPE, *Les Voies de Développement Techniquement Possibles et la Prkvision Économique à Long Terme,* Bureau d'Informations et de Prévisions Économiques, Paris, June 1964.

(Discusses the plans for setting up—in the framework of preparatory work for the 6th French National Plan—a file of technically possible ways to innovation and new products, and their probable economic consequences. The graphic representation of inter-industrial relations for each expected innovation is particularly interesting.)

97. Brandenburg, Richard G., *Quantitative Techniques in R & D Planning (A survey of the State of the Art),* unpublished paper, Carnegie Institute of Technology, Pittsburgh, Pa., July 1964.

(A comprehensive and critical literature study of techniques in the following five **areas:** **1.** setting total R & D budget. **2.** determining when to commit R & D resources. **3.** evaluating and selecting R & D projects. **4.** scheduling resources on projects selected for implementation. **5.** deciding to introduce new products. The principal features of each technique are briefly described and critically discussed.)

98. Bratt, Elmer C., ***Methodology in Long-Range Forecasting,*** The Commercial and Financial Chronicle, Vol. **191,** No. **5922, 4** Feb. **1960,** pp. **10-11.**

(A brief discussion of three approaches- secular trends, input/output analysis, and end-use analysis. The third approach is best suited to deal with today's problems.)

99. Brech, Ronald, ***Planning Prosperity - A Synoptic Model for Growth,*** Darton, Longman & Todd, London **1964.**

(Chapter **3** on " A Dynamic Economic Model, " pp. **45-64,** presents the techniques used for the author's book " Britain **1984,** " lit. ref. **256,** although not in very great detail. The synoptic model is the combination, by iteration, of six different pre-established models: demographic, psychological, sociological, technological, political, economic. The goal was to use economic principles and statistical techniques, on an aggregate level, to predict a route for approximately 25 years. The technological model is set up more from the point of view of diffusing existing knowledge than of forecasting innovations,)

100. Brown, Bernice; and Helmer, Olaf, ***Improving the Reliability of Estimates Obtained from a Consensus of Experts,*** report **P-2986,** The RAND Corporation, Santa Monica, California, **1964.**

(Some details of the " Delphi " technique.)

101. Brown, J.H.; and Cheaney, E.S., ***Report*** on ***a Study of Future Research Activity*** *and* ***Pertinent Forecasting Techniques for Battelle's Trends in Research Study,*** Battelle Memorial Institute, Columbus, Ohio, **1965. 51** p.

(A review and discussion of the state of the art and the methodology of technological forecasting. A bibliography with 70 entries is added, mainly on various specific forecasts and methodology.)

102. Bush, G.A., ***Prudent-manager forecasting;*** new approach to long-range planning, Harvard Business Review, Vol. **39,** May/June **1961,** p. **57-64.**

(An original approach to brainstorming developed by Lockheed Aircraft Corporation: Experts from different areas, such as research, engineering, marketing, finance, etc., are asked to assume the role of decision-making managers of a customer firm and to evaluate from this point of view alternative long-range plans.)

103, Carter, Anne ***P., The Economy of Technological Change,*** Scientific American, Vol. **124,** No. **4,** April **1966,** pp. **25-31.**

(Reports on work done at the Harvard Economic Project to derive characteristics of technological change on the aggregate level by comparing the input/output tables for the **US** economy **1947** and **1958.)**

104. Cetron, Marvin J., ***PROFILE - Programmed Functional Indices for Laboratory Evaluation,*** Dissertation, American University, Washington, D.C., in preparation; summary paper of **US** Navy Marine Engineering Laboratory, Annapolis, Maryland, dated 9 August **1965,** presented at the 16th Military Operations Research Symposium, **12** Oct. **1965, 17** p.

(A brief description of the numerial analysis scheme proposed for the ranking ***of*** R & D projects in the **US** Navy's technological forecasting.)

104*a*. Cetron, Marvin J.; Martino, Joseph; and Roepcke, L., ***The Selection of R and D Program Content - Survey of Quantitative Methods,*** IEEE Transactions on **Engi**neering Management, Vol. EM-14, No. **1,** March **1967.**

(A survey of **30** quantitative techniques actually in use, and a comparison of their features, ease of use, and areas of applicability. A bibliography with **220** references is added.)

105. Cheaney, E.S., ***Technical Forecasting as a Basis for Planning,*** with an appendix " A Technique for Forecasting the Attainability of Technical Concepts " by **R.J.** McCrory, ASME paper **66-MD-67,** presented at the Design Engineering Conference, Chicago, Ill., **9-12** May **1966,** ASME (American Society of Mechanical Engineers), New York.
(A brief survey of techniques for technological forecasting, following Lenz's typology —see lit. ref. **151**—is followed by the outline of techniques developed and used at the Battelle Memorial Institute: a relevance tree for normative forecasting and critical path evaluation and a corresponding forecasting matrix, and a concept for probabilistic exploratory forecasting by mathematical formulation of the propagation of variance.)

106. Churchman, C.W.; Ackoff, R.L.: Arnoff, E.L., ***Introduction to Operations Research,*** John Wiley & Sons, New York, **1957.**
(A standard book on operations research, including basic discussions of the decision or relevance tree principle, which has become important in normative technological forecasting.)

107. Clark, Charles H., ***Brainstorming - the Dynamic New Way to Create Successful Ideas,*** Doubleday & Co, Inc., Garden City, N.Y. **1958, 262** p.
(An eloquent account of the advantages of systematic brainstorming, mainly along the lines promoted in the **1950's** by the big advertising firm BBDO, Buffalo. The main value of the book consists of a number of practical examples from American industry. Refinements of brainstorming, such as analysis by supporting staff, iterative series of sessions, etc., were not foreseen at that time.)

108. Combs, Cecil E., ***Decision Theory and Engineering Management,*** IRE Transactions on Engineering Management, Vol. EM-9, No. **4.** Dec. **1962,** pp. **149-154.**
(A general discussion of possible applications.)

109. Cornell Aeronautical Laboratory, ***LRTP Mathematical Model Brochure,*** report CAL number **VQ-2044-H-3,** prepared for the US Army Material Command, Cornell Aeronautical Laboratory, Inc., 30 Oct. **1965.**
(An analytical choice model, programmed for an IBM **7090** computer, to aid in the synthesis of information generated by the planning process to determine priorities for long-range technological planning tasks.)

110. Cramer, R.H., and Smith, B.E., ***Decision Models for the Selection of Research Projects,*** The Engineering Economist, Vol. 9, No. **2,** Jan./Feb. **1964,** pp. **1-20.**
(Abstract from lit. ref. **91:** an economic analysis and operations research approach. An application of portfolio selection and utility theory to the problem of research project selection. For each alternative project, estimates are made of net values and probabilities of occurrence. Utility curves are also obtained. Projects may be ranked on the basis of expected value or expected utility. Lack of project independence is also mentioned.)

111. Cress, H.A., and Cheaney, E.S., ***Determining Design Feasibility,*** ASME paper **63-MD-4,** presented at the Design Engineering Conference, May **1963, ASME** (American Society of Mechanical Engineers), New York.
(Technological forecasting fitting into the Design Method, developed at Battelle Memorial Institute—see also lit. ref. **214.)**

112. Dal Monte, Giorgio, ***Leggi naturali di sviluppo delle communicazioni: traffici ed utenze,*** presented at the **XII** Convegno Internazionale delle Communicazioni, **8-12** Oct. **1964,** Genova, **27** p.
(The growth of telephone subscriptions is fitted to a mathematical formulation based on a correlation of national per capita income by means of a Gompertz law, so that " phase shifts " in the development of different countries are introduced. The telephone growth curve of an individual country can then be described by this general function and a second function which is particular to the country.)

113. Dean, B.V., and Sengupta, *S.S.*, ***Research Budgeting and Project Selection,*** in: " Special Section on Project Selection and Budgeting in R & D, " IRE Transactions on Engineering Management, Vol. EM-9, No. **4,** Dec. **1962,** pp. **148-169.**

(An approach combining economic analysis and operations research. Economic analysis of a company's past experience in product and process research leads to empirical expressions for the effect of overall research budget size—permitting one to fix the overall research budget—and for different classes of research projects. New projects are then classified into groups with different probabilities of success. Following empirically established patterns, the discounted net value is estimated for each project. The criterion for selection is the maximum expected discounted net value subject to a budget constraint. Linear programming formulation, based on empirical analysis, is suggested.)

114. Disman, Solomon, ***Selecting R & D Projects for Profit,*** Chemical Engineering, Vol. 69, 24 Dec. 1962, pp. 87-90.

(An economic analysis approach. An estimate of the expected rate of return on R & D expenditure is used to determine the maximum expenditure justified for a project. The results, modified by multiplication by one risk factor for technical and one for commercial success, are used for the ranking of the projects.)

115. Economic Commission for Africa, ***Methods of Forecasting Future Demand for Electric Energy,*** United Nations Economic and Social Council, New York, report E/CN. 14/EP/20, 12 June 1963. Addendum " Long-term forecasts of development of demand and production of electric power, " report E/CN. 14/EP/20/Add.2, 22 October 1963, 16 + 11 p.

(A review of techniques based on trend extrapolation, regression analysis, and total systems planning.)

116. Economic Commission for Europe, ***Methods and Principles for Projecting Future Energy Requirements,*** report ST/ECE/ENERGY/2, United Nations, New York, 1964, 88 p., plus annexes. Sales number: 64.II.E/Mim. 13.

(A comprehensive survey and critical discussion. In the methods reviewed, technical progress is reflected in smooth changes of efficiency figures, capital and operating cost reductions, and indices expressing changes in output relative to change in labour employed. A bibliography of 88 items is included.)

117. Esch, Maurice E., ***Planning Assistance Through Technical Evaluation of Relevance Numbers,*** Proceedings of the 17th National Aerospace Electronics Conference, held at Dayton, Ohio, 10-12 May 1965, pp. 346-351, IEEE—Institute of Electronics and Electrotechnical Engineers, New York, 1965.

(A description of Honeywell's PATTERN, a relevance tree approach to decision-making, by the Director of Honeywell's Military and Space Sciences Department, the home of PATTERN.)

118. Fange, Eugene K. von, ***Professional Creativity***

(Reviewed in lit. ref. 137. Develops basic rules for brainstorming sessions.)

119. Fontela E.; Gabus, A.; and Velay, C. ***Forecasting Socio-Economic Change,*** Science Journal, Sept. 1965, p. 81-88.

(An outline of the study carried out by the Battelle Memorial Institute, Geneva., to determine the socioeconomic patterns of several European countries for 1975. Forecasts of population and its structural characteristics, particularly employment, education and income patterns, are used to forecast consumer consumption patterns. New technology was not taken into account explicitly but the results may have significant bearings on planning for future technologies.)

120. Forrester, Jay W., ***Industrial Dynamics - A Major Breakthrough for Decision Makers,*** Harvard Business Review, Vol. 36, No. 4, July/Aug. 1958, p. 37-66.

(Develops a feedback model of industrial dynamics which can also be used for the development of dynamic technological forecasting models—see also Lenz, lit. ref. 151, where such an approach is attempted.)

121. Freeman, Raoul J., ***R & D Management Research,*** Memorandum P-3216, The RAND Corporation, Santa Monica, Calif., Aug. 1965, 8 p.

(A brief review of quantitative research in the research management area, and new ideas for the development of decision patterns by the use of numerical analysis, etc.)

122. Freeman, Raoul J., ***A Stochastic Model for Determining the Size and Allocation of the Research Budget,*** **IRE** Transactions of Engineering Management, Vol. EM-7, No. **1,** March **1960,** p. **2-7.**

(An operations research approach, using a linear programming formulation, for determining the size of the research budget and allocating it among competing projects for which estimates are made of the probability distribution of the net value. A hypothetical example illustrates the method.)

123. Fucks, Wilhelm, ***Formeln zur Macht,*** Deutsche Verlagsanstalt, Stuttgart, **1965.**

(The well-known Professor for Plasma Physics at the Technical University, Aachen, attempts to forecast future patterns of political power on the basis of three parameters only : population, steel production, and energy consumption. Different combinations are empirically tested against the actual pattern and a " plausible " future. The chosen formula reads: Power is equivalent to the sum of steel production plus the product of energy consumption and the cubic root of population number. Based on rather doubtful assumptions on the future of steel and energy in different countries, the result sees China soaring Within a few years, overtaking Russia in **1970,** leaving behind the US plus the Western European Union in **1980,** and equalling the Western alliance plus Russia in **1985. An** astonishing example of forecasting on as indiscriminate a basis as one can possibly imagine.)

124. Gargiulo, G.R.; Hannock, J.; Hortz, D.B.; Zang, T., ***Developing Systematic Procedures for Directing Research Programs,*** IRE Transactions on Engineering Management, Vol. **EM-8,** No. 1, March **1961,** pp. **24-29.**

(**A** decision theory approach. Two system are proposed: ***a)*** a Data Presentation System to record status, progress, and plans in terms of allocation of resources, in matrix form: *b*) An Evaluation System which considers technical, economic, and timing aspects. Eleven factors of assumed equal importance—including some interesting refinements such as " assessed enthusiasm of the project supervisor "—are assessed and recorded on " project rating worksheets " in three value categories : favourable, no opinion, unfavourable. No numerical analysis is suggested because no distinction is seen in the importance of these factors. Finally, technical and economic factors are grouped to give scores which are expressed in a numerical range **1** to **10.)**

125. General Electric Co., ***Today's Decisions... Tomorrow's Results - Dollar Planning Model,*** General Electric, Light Military Electronics Department, Utica, N.Y. **31** Aug. **1960.**

(New business opportunities are assessed by Product Teams on three levels of estimate : minimum, probable, maximum. The model also comprises the actual planning of R **&** D.)

126. Goddard, F.E., Jr., et al., ***A Technique for Estimating Funding and Manpower Requirements for Research and Development Long-Range Planning,*** JPL Planning report **35-6** Rev. **1,** NASA **CR-53571,** Jet Propulsion Laboratory, Pasadena, California, 8 Nov. **1962.** NASA Scientific and Technical Information facility number N **64-18450.**

(Not reviewed.)

127. Gordon, William J.J., ***Qperational Approach to Creativity,*** Harvard Business Review, Vol. **34,** No. **6,** Nov./Dec. **1956,** p. **51.**

(In a brainstorming session, only the group leader knows the exact nature of the problem, and structures the discussion to arrive at it.)

128. Granger, Charles H., ***The Hierarchy of Objectives,*** Harvard Business Review, Vol. 42, No. 3, May/June **1964,** p. **63-74.**

(**A** decision theory approach based on the relevance tree principle.)

129, Green, Paul E., ***Bayesian Statistics and Product Decisions,*** Business Horizons, Fall **1962,** pp. **101** ff.

(Decision making under conditions of uncertainty, especially concerning the introduction of new or improved products. Optimum timing and other aspects can be analysed.)

130. Griliches, Zvi, ***Production Functions in Manufacturing: Some Preliminary Results,*** presented at the Conference on Research in Income and Wealth, **15-16** October **1965,** National Bureau of Economic Research, Inc., New York; Report **6509,** Center for Mathematical Studies in Business and Economics, University of Chicago, Chicago, Illinois, **15** December **1965.**

(A first progress report on a research programme on major sources of productivity growth in US manufacturing industries after World War 11. The analysis aims at deriving a production relation based on man-hours, capital services, various measures of labour and capital quality, coefficients of industry and state dummy variables, and random disturbances. The implications for the measurement of technical change in manufacturing are discussed. It is intended to test the estimated production functions on the basis of the **1963** Census.)

131. Haase, **R.H.,** and Holden, W.H.T., ***Performances of Land Transportation Vehicles,*** Memorandum **RM-3966-RC,** The RAND Corporation, Santa Monica, California, Jan. **1964., 138** p.

(A detailed account of a systems analysis approach intended to lead to the construction of possible transportation systems of the future. Physical " building blocks " of a generalised transportation system are found in the following five categories: vehicles, propulsion systems, right-of-way and allied structures, storage and maintenance facilities, and control systems. Each component is described in terms of existent and developing technological and economic pressures, and mathematical formulations are derived. Each component is reshaped into the form it will probably have in the foreseeable future. The performance of land transportation systems and the derived equations of motion are based on **an** analysis of vehicle-propulsion system combinations.)

132. Hart, Hornell, ***Predicting Future Trends,*** in Allen, Hart, et al. (eds.), ***Technology and Social Change,*** Appleton-Century-Crofts, New York, **1957.**

(Not reviewed.)

133. Hartman, Lawton M., paper on technological forecasting, presented at the Multi-National Corporate Planning Seminar, Institut Europeen d'Administration des Affaires, Fontainebleau-Avon (France), Sept. **1964,** to be published in: Steiner, George A., and Cannon, Warren (editors), ***Multinational Corporate Planning,*** Crowell-Collier/Macmillan, **1966.**

(Develops a mathematical model for information growth by analogy with a physical reaction process in a gas which may become useful for a deeper understanding of trend evaluation in specific technologies and for influencing factors.)

133a. Heinlien, Robert A., ***The Worlds of Robert A. Heinlien,*** Ace **Books,** New York, **1966.**

(The philosophy of trend extrapolation.)

134. Helmer, Olaf, ***Social Technology,*** report **P-3063,** The RAND Corporation, Santa Monica, California, February **1965.** French translation ***Technologie sociale,*** in Analyse et Prévision, Tome **1,** No. **1,** Paris, January **1966.** Partly reprinted in lit. ref. 134a.

(A broad outline of forecasting techniques such as operational model-building, scenario-writing, the systematic use of expertise, etc. applicable to social technology.)

134a. Helmer, Olaf, ***Social Technology,*** Basic Books, New York and London, **1966.**

(A condensation, in book form, of the reports lit. refs. **134** and **269,** and a new formulation of the basic framework for forecasting in the field of social technology.)

135. Hess, Sidney **W.,** ***A Dynamic Programming Approach to R and D Budgeting and Project Selection,*** in: " Special Section on Project Selection and Budgeting in R & D, " IRE Transactions on Engineering Management, Vol. EM-9, No. **4,** Dec. **1962,** pp. **170-179.**

(An operations research approach. The sequential decision characteristics, i.e. reappraisals at different stages of a project, are taken into account. Discounted gross value and probability of success are estimated. The criterion for selection is the maximisation of total expected net value, either without or with initial budget restraints. Optimal project expenditures are determined for each phase. A dynamic programming formulation is used. This model has apparently been developed for the drug industry where projects are generally started without specific target, so as to benefit from the results of screening at different project stages.)

136. Hetrick, J.C., and Kimball, G.E., ***A Model for the Discovery and Application of Knowledge,*** in: ***Basic Research in the Navy, Vol. II, US*** Department of Commerce, Washington, **D.C. 1959,** pp. **5-29.**
(Knowledge is broken up into unknown facts, known but unapplied facts, and applied facts. Levels of effort and rates of transition are assumed. The model intends to assist in an analysis with the aim of balancing the effort.)

137. Hinrichs, John R., ***Creativity in Industrial Scientific Research: A Critical Survey of Current Opinion, Theory, and Knowledge.*** AMA Management Bulletin No. **12,** American Management Association, New York, **1961.**
(Discusses, among other things, different concepts of brainstorming, and the related " buzz group " technique and " operational activity " approach.)

138. Hoess, Joseph A., ***A Discipline for Both Obtaining and Evaluating Alternative Product Concepts,*** ASME paper 66-MD-87, presented at the Design Engineering Conference, Chicago, Ill., **9-12** May **1966,** ASME (American Society of Mechanical Engineers), New York.
(Two techniques developed at the Battelle Memorial Institute and used in the framework of the " Design Method " there: a decision-theory approach to derive a " needs profile ", and an economic analysis approach considering utility for the customer and risk evaluation.)

139. Horowitz, Ira, ***Evaluation of the Results of Research and Development: Where We Stand,*** IEEE Transactions on Engineering Management, Vol. EM-10, No. **2,** June **1963,** pp. **42-51.**
(Current efforts are discussed at three levels: broad macrolevel, company level, individual project level. The conclusion is drawn that the whole field is still in bad shape.)

140. Imperial Chemical Industries, ***Mathematical Trend Curves - An Aid to Forecasting,*** ICI Monograph No. 1, London, **1964.**
(Empirical trend-fitting **on** the basis of statistical techniques.)

141. Isenson, Raymond *S.*, ***Technological Forecasting: A Planning Tool,*** paper presented at the Multi-National Corporate Planning Seminar, (Institut Européen d'Administration des Affaires), Fontainebleau-Avon (France), **9** Sept. 1964, published in: Steiner, George A., and Cannon, Warren (editors), ***Multinational Corporate Planning,*** Crowell-Collier/Macmillan, **1966.**
(Discusses chiefly trend evaluation of technological parameters.)

142. Isenson, Raymond *S.*, ***Technological Forecasting in Perspective,*** manuscript, Feb. **1966, 24** p. will be published in Management Science.
(After a brief discussion of a few published approaches to technological forecasting a Technological Forecast Equation is suggested by analogy with the growth of scientific literature. Semi-empirical formulae are derived, which are supposed to provide a basis for the judgment of information growth in specific technologies and for the understanding of influencing factors, like funding, number of scientists, communication, etc.)

143. Jestice, Aaron L., ***Project PATTERN - Planning Assistance Through Technical Evaluation of Relevance Numbers,*** paper presented to the Joint National Meeting Operations Research Society of American and The Institute of Management Sciences, Minneapolis, Minnesota, **7-9** October **1964.** Pamphlet, Honeywell Inc., Washington D.C., **25** p.
(The most comprehensive available description of Honeywell's relevance tree approach to decision-making.)

144. Jouvenel, Bertrand de, ***L'Art de la Conjecture,*** in the " Futuribles " series, Edition du Rocher, Monaco, **1964, 369** pp. plus index. English translation, ***The Art of Conjecture,*** Basic Books Inc., New York, **1967.**
(The classic on the philosophy of forecasting in general, on attitudes and quantitive techniques, mainly in the areas of economic and social forecasting. A chapter on

" The Forecasting Forum," which advances ideas in line with the concepts of look-out institutions, includes an attempt to explore the interaction between technological and social forecasting. The numerous literature references, which include a large proportion of English language publications, makes this book a synthesis of current thought on the serious explanation of, and planning for the future.)

145. Kaplan, A.; Skogstad, A.L.; and Ginshick, M.A., ***The Prediction of Scientific and Technological Events,*** Public Opinion Quarterly, Spring 1950.
(Not reviewed.)

146. Kiefer, David M., ***Winds of Change in Industrial Chemical Research,*** Chemical and Engineering News, Vol. 42, issue of 23 March 1964, pp. 88-109.
(A survey of attitudes and techniques related to technological forecasting as practised by the US Chemical industry. Reviewed techniques include check lists, a variety of economic analysis approaches, and business models. Utilisation and experience are reviewed.)

147. Klass, Philip J., Part I: ***New Approach Pinpoints Vital R & D Needs,*** Aviation Week and Space Technology, 28 Dec. 1964; Part II: ***Rating System Gives Planning Priorities,*** Aviation Week and Space Technology, 4 January 1965.
(Honeywell's PATTERN, a multi-level relevance tree approach to decision-making.)

148. Kotler, P., ***Marketing Mix Decisions for New Products,*** Journal of Marketing Research, Vol. I, No. 1, Feb. 1964.
(Includes the proposal of a method for risk evaluation, involving the development of corporate indifference curves for expected profit versus risk that are unique to any given company.)

149. Lancoud, Ch., and Trachsel, R., ***Nouvelle étude du développement probable du telephone en Suisse/Neue Studie über die wahrscheinliche Entwicklung des Telephons in der Schweiz,*** Bulletin Technique PTT/Technische Mitteilungen PTT (in French and German language), PTT Berne (Switzerland), No. 12, 1963, p. 1-31.
(A study regarded as a " classic " in its field. A probabilistic forecast on the basis of Bernoulli's equation, made in 1956, had already led to considerable discrepancies on the pessimistic side in 1962. The authors introduce a new factor which takes care of the " attraction " produced by a rise in total or regional telephone numbers—the higher the number, the higher the advantages for an individual telephone subscriber. Such an " attraction " or " value " factor may be applied to technology acceptance in other fields too.)

150. Larsen, Finn J., ***Long-Range Programming at Honeywell,*** in Working Document DAS/RS/65.121 " European/North American Conference on Research Management Monte Carlo, 22nd-24th February 1965," pp. 52-74, OECD, Paris, 28 June 1965 (Restricted; publication envisaged by " Research Management " in 1967, and eventually also by OECD.)
(A description of PATTERN, Honeywell's multi-level relevance tree approach to decision-making by the then Vice-President for Research of Honeywell.)

151. Lenz, Ralph Charles, Jr., ***Technological Forecasting,*** Second Edition, Report ASD-TDR-62-414, Aeronautical Systems Division, Air Force Systems Command, US Air Force, Wright-Patterson Air Force Base, Ohio, June 1962. Clearinghouse for Federal Scientific and Technical Literature number AD-408,085. 106 p.
(Part of author's abstract: This study presents several methods of forecasting rates of technological advance. The methods include forecasting by extrapolation of existing rates; by analogies to biological growth processes; by precursive events; by derivation from primary trends; by interpretation of trend characteristics; and by dynamic simulation of the process of technological improvement. The investigation included a search of the literature for references to principles of technological progress and for methods which have been used for predictive purposes.)

152. Leontief, Wassily, Input ***Output Economics,*** Oxford University Press, New York, 1966.
(The latest state of the art of input/output analysis, by its " rediscoverer.")

153. Lilley, **S.,** ***Can Prediction Become a Science?,*** Discovery, Nov. **1946,** reprinted in B. Barber and W. Hirsch (eds.), The Sociology of Science, The Free Press, Glencoe, **1962.**
(Not reviewed.)

154. Lovewell, P.J., and Bruce, R.D., How ***We Predict Technological Change,*** New Scientist, Vol. **13, (1963)** p. **370-373.**
(A short discussion of the strategy used for the Stanford Research Institute's Long-Range Planning Service, stressing the importance of a synoptic view of many factors and dividing the task into three phases of forecasting: levels of achievement, applications and outlook, impact of technological change,)

155. Maestre, ***Note sur quelques elements methodologiques d'une strategie nationale de la recherche,*** unpublished paper, Délégation Générale à la Recherche Scientifique et Technique, Paris, **1965. 45** p.
(Research/production and research/research matrices are developed for the representation of the French national economy. Their potential use for normative technological forecasting on the aggregate level is discussed.)

156. Magee, John F., ***Decision trees for decision making,*** Harvard Business Review, Vol. **42, July/August 1964,** p. **126-138.**
(A general discussion of the decision tree technique, which is becoming of great importance for normative technological forecasting at the present time.)

157, Mansfield, Edwin, and Hensley, Carlton, ***The Logistic Process: Tables of the Stochastic Epidemic Curve and Applications,*** The Journal of the Royal Statistical Society, **1960,** pp. **332-337;** Reprint No. **60,** Graduate School **of** Industrial Administration, Carnegie Institute of Technology, Pittsburgh, Pennsylvania, **1960.**
(Logistic growth, taking probability distributions into account, is treated mathematically. Extensive calculated tables are given. This formulation is applicable to technological change over time—for example, the diffusion of new technologies.)

158. Mansfield, Edwin, ***Razes of Return from Industrial Research and Development,*** The American Economic Review, Vol. LV, No. **2,** May **1965,** pp. **310-322.**
(Preliminary and tentative results of research aiming at a method for estimating the marginal rate of return from R & D expenditures, assuming that a simple model of production holds and that all technical change is either organisational or capital-embodied. Estimates derived on this basis are tested numerically for a number of US firms.)

159. McCrory, R.J., ***The Development of a Methodology for Evaluating Potential Weapons Concepts,*** proposal prepared for the US Army Material Command, Battelle Memorial Institute, Columbus, Ohio, **17** Dec. **1963.**
(A concept for the evaluation of the probability of a given weapon concept being developed by a given future date or, ultimately, a likely target date by which it **could** become operational. The envisaged techniques are those discussed in lit. ref. **105.)**

160. Meadow, Arnold; and Parnes, Sidney J., ***Evaluation of Training in Creative Problem Solving,*** Journal of Applied Psychology, Vol. **43,** No. **3,** June **1959,** pp. **189-194.**
(Brainstorming experience can increase the score of participants.)

161. Meadow, Arnold; Parnes, Sidney J; and Reese, Hayne, ***Influence of Brainstorming and Problem Sequence on a Creative Problem Solving Test,*** Journal of Applied Psychology, Vol. **43, No.** 6, Dec. **1959,** p. **314.**
(More " good " ideas accrue if any remote idea is admitted than if only " good " ideas were asked for.)

162. Mitchell, **R.S.,** ***On the Theory of Value,*** Report No. **TN-1579,** CARDE **-** Canadian Armament Research and Development Establishment, June **1964.** 20 p. **US** Defense Documentation Center number AD-448,078.
(Evaluating activities in relation to an R & D goal, and evaluating the goal itself. A formal expression for goal evaluation is suggested.)

163. Mottley, C.M., and Newton, R.D., ***The Selection of Projects for Industrial Research,*** Operations Research, Vol. 7, Nov./Dec. **1959,** pp. **740-751.**

(A decision theory approach, developed for the pharmaceutical company Chas. Pfizer & Co., Inc., New York. For each project, ratings from 1 to 3—roughly corresponding to such expectations as " unforeseeable," " fair," " high "—are estimated for five criteria: promise of success, time to completion, cost of project, strategic need, market gain. The project score is the product of these five ratings.)

164. Neumann, John von; and Morgenstern, Oskar, ***Theory of Games and Economic Behaviour,*** revised edition, Princeton University Press, Princeton, **1955.**

(The original book on game theory for application in an economic or business context.)

165. Ozbekhan, Hasan, ***The Zdea of a " Look-Out " Institution,*** System Development Corporation, Santa Monica, Calif., March **1965. 20** p.

(The idea of " look-out " institutions is advanced, whose function is to conceive of possible futures, create standards of comparison between them and define ways of arriving at them by means of the physical, human, intellectual, and political resources estimated on the basis of the current situation. An interesting discussion of possible methods, in the framework of modern information technology, is added.)

166. Pardee, **F.S.,** ***State-of-the-Art Projection and Long-Range Planning of Applied Research,*** report P-3181, The RAND Corporation, Santa Monica, California, July **1965. 24** p. Will also be published in the proceedings of the Second Conference on Research Program Effectiveness, sponsored by the Office of Naval Research, **28-29** July **1965,** Washington, D.C.

(A brief discussion of a few concepts for aiding probabilistic forecasting: ranges of estimates, check-lists with numerical rating, etc. A proposal is added for a simple recording scheme to follow progress during the development time.)

167. Pound, William **H.,** ***Research Project Selection: Testing a Model in the Field,*** IEEE Transactions on Engineering Management, Vol. EM-11, No. **1,** March **1964,** pp. **16-22.**

(An " expected value model," based on a decision theory approach, attributes numerical weights to objectives and multiplies them by estimated contributions to objectives for each specific project. The project score is the sum of these products. Suggested objectives include profit-making, gaming knowledge, etc. This model goes back to a general model developed in lit. ref. **106** for problems in an industrial context. Testing of the model showed good results.)

167a. Prehoda, Robert **W.,** ***Technological Forecasting Methodology,*** report, Electro-Optical Systems, Inc., Pasadena, California. **1966, 56** p.

(A review of: trend extrapolation techniques; methods to improve intuitive thinking; scenario-writing; and morphological research.)

168. Putnam, A., ***State of the Art - A Mathematical Treatment,*** unpublished paper, Battelle Memorial Institute, Columbus, Ohio, **1964.**

(Described in lit. ref. **101,** as being " based on the concept of dynamic modelling of the technological growth process. Equations of the classical growth curves are derived as well as an expression for the rate of change of state-of-the-art with effort. Effort is also characterised mathematically in terms of man effort, group size, individual interplay, and concept cross-fertilization. A mathematical model of the breakthrough process is also postulated. ")

169. Raiffa, Howard, and Schlaifer, Robert, ***Applied Statistical Decision Theory,*** Harvard Graduate School of Business Administration, Boston, Mass., **1961.**

(An advanced version of lit. ref. **175** discussing Bayesian statistics in decision-making.)

170. Reitman, Walter R., ***Heuristic Decision Procedures, Open Constraints, and the Structure of Ill-Defined Problems,*** in Shelly, Bryan (ed.), ***Human Judgments and Optimality,*** J. Wiley & Sons, **1964.**

(Not reviewed.)

171. Richman, B.M., A *Rating Scale for Product Innovation,* Business Horizons, Summer **1962.**

(A decision theory approach to the ranking of new product alternatives.)

172. Rosen, E.M., and Sonder, **W.E.,** A *Method for Allocating R & D Expenditures,* IEEE Transactions on Engineering Management, Vol. EM-12, No. **3,** Sept. **1965,** pp. **87-92.**

(A slight modification of Hess' operations research approach based on dynamic programming—see lit. ref. **135.** Different criteria for optimum expenditure patterns are discussed: a) Maximise expected profit; *b)* Maximise the " Total Expected Output, " i.e. the expected research success; *c)* Achieve at least a 55-fold return on non-discounted expenditure ; *d)* Optimise " Life Expected Output," i.e. the integrated expected success over the expected life-time of the product.)

173. Rosenbloom, Richard **S.,** *Notes* on *the Development of Network Models for Resource Allocation in R & D Projects,* IEEE Transactions on Engineering Management, Vol. **EM-11,** No. 2, June **1964,** pp. **58-63.**

(A discussion of the possible application of PERT and CPM techniques to the analysis of cost time trade-offs and resource allocation. Ideas for future research are presented.)

174. Rostow, Walt **W.,** *The Process of Economic Growth,* W.W. Norton, New York, **1952.**

(Rostow's model incorporates " propensities " to develop fundamental science, to apply science to economic industry, and to accept innovations. These " propensities," in Siegel's critical reference to them, are cultural complexes devoid of operational significance.)

175. Schlaifer, Robert, *Probability and Statistics for Business Decisions,* McGraw-Hill, New *York,* **1959.**

(The original book which introduced the important concept of Bayesian statistics into business decision-making. Bayesian statistics involve the explicit use of " prior probability distributions " for each parameter in a statistical problem. *An* advanced version is given in lit. ref. **169.)**

176. Siegel, Irving H., *Technological Change* and *Long-Run Forecasting,* The Journal of Business of the University *of* Chicago, Vol. XXVI, No. **3,** July **1953,** pp. **141-156.**

(A " classic " on the subject of technological forecasting at an aggregate level with conclusions that are still valid. It is particularly concerned with breaking up aggregated systems by detailed analysis so as to give them true operational significance. Siegel's proposal of detailed studies of inter-industry relations in the framework of an input/output table is followed today in such forecasting schemes as MAPTEK.)

177. Sigford, **J.V.,** and Parvin, **R.H.,** *Project PATTERN: A Methodology for Determining Relevance in Complex Decision-Making,* IEEE Transactions on Engineering Management, Vol. EM-12, No. **1,** March **1965,** pp. **9-13.**

(A description of Honeywell's numerial analysis scheme in which present-day deficiencies in technology are ultimately related to national objectives, and priorities are established for ranking development projects.)

178. Smalter, Donald **J.,** *The Influence of Department of Defense Practices on Corporate Planning,* Proceedings of the 7th Annual Symposium on Planning, May **1964,** College of Planning, The Institute of Management Sciences, Pleasantville, N.Y. **1965.** Also published as Management Technology, Vol. **4,** No. 2, **Dec. 1964.**

(Includes a discussion of three-dimensional matrix thinking with the dimensions resources-time-market, P-E-P or Project Exploratory Planning and its modification " Management by Prority of Challenge " developed by International Minerals and Chemicals, Skokie, Ill.)

179. Swager, William **L.,** *Technological Forecasting and Practical Business Plans for Petroleum Management,* Battelle Memorial Institute, Columbus, Ohio, **18** Nov. **1965.** **18** p. **Will** be published in Petroleum Management.

(" What. " *is* more important than " how. " in forecasting. " Environmental networks " and " objectives networks " help to clarify the structure of problem complexes and alternative technologies in a technical sector. A qualitative horizontal relevance tree model has been developed for the petroleum industry.)

180. Sweezy, Eldon E., ***Technological Forecasting - Principles and Techniques,*** paper presented at the Fourth Symposium of the Engineering Economy Division, The American Society for Engineering Education, 19 June 1965, Chicago, Illinois.
(Considers mainly trend extrapolation and contextual mapping.)

181. Thomas, and McCrory, ***The Selection of Military Concepts for Long-Range Research and Development,*** proposal prepared for the US Army Material Command, Battelle Memorial Institute, Columbus, Ohio, 25 Feb. 1964.
(Further developments in the concept discussed in lit. ref. 159, including an evaluation as to which of several alternative weapon concepts has the highest probability of being developed by a given future date. The decision space can be represented on an analog computer. An original method for synthesising expert opinion and testing the sensitivity to deviation by a given expert is proposed.)

182. US Army, ***Guidebook - Technological Forecasting,*** Research Planning Division, US Army Research Office, Arlington, Virginia, July 1962 (Unclassified).
(Not reviewed.)

183. US Interagency Task Group on Technological Forecasting in the US Federal Government, ***The Role of the Federal Government in Technological Forecasting,*** Report to the President's Committee on Manpower and to the National Commission on Technology, Automation and Economic Progress. Jan. 1966. 89 p. plus appendices. One of the input reports to the Report to the President on "Technology and American Economy," lit. ref. 383, which will be published in the Annex volumes to this report.
Mainly concerned with manpower forecasting and problems of education and training in the light of technological change. Part I on " The Problem : Forecasting and Technological Forecasting " and Appendix 6 on " Methodology," giving a rather sketchy account in 42 pages as weel as a table of seven technological forecasting activities with their characteristics, will be of more general interest. Appendix 2 gives a " Partial Bibliography of Technology-Related Forecasting," comprising 90 items.)

184. US Navy Technological Forecasting Group, ***Proposed Naval Technological Forecast,*** Final Report (unclassified version), 29 April 1966. 174 p.
(The basis for the implementation of the US Naval Technological Forecast featuring two complementary approaches : Basic Forecasts—scientific opportunities, technological capabilities, probable systems options—and Technology Needs Identification Studies. In other words, opportunity- and mission-oriented approaches are combined in one system. The report also includes a chapter on methodology and a bibliography of 49 items on military technological forecasting, most of which are classified.)

185. Wagle, B., ***Some Recent Developments in Forecasting Techniques,*** Esso Petroleum *Co.* Ltd., London, published 1966 in the Journal of the Inst. of Petroleum.
(A review of forecasting techniques, mainly for marketing, covering: *a*) very short range, i.e. less than 6 months: exponential smoothing; *b*) short range, i.e. up to 2 years: survey analysis, iteration, econometric approach; *c*) middle and long range, i.e. over 2 years: econometric approach, mathematical curve fitting.)

186. Wagle, B., ***Some Statistical Aids in Forecasting,*** internal report Esso Petroleum Co. Ltd., London; introduction published under the title ***A Review of Two Statistical Aids in Forecasting,*** The Statistician, Vol. 15, No. 2, (1965).
(A synthesis of developments in multiple regression analysis, suitable for long-range forecasting, and in exponential smoothing and related techniques, suitable for short-range forecasting.)

187. Wagle, B., ***A Statistical Analysis of Risk in Capital Investment Projects,*** Esso Petroleum *Co.* Ltd., London; expected to be published in Operational Research Quarterly in 1966.
(A review of mathematical techniques to obtain the probability distributions of two widely used profitability criteria—net present value, and internal rate of return—on the basis of the means and variances of individual factors which make up the cash flows.)

187a. Zwicky, Fritz, ***Entdecken, Erfinden, Forschen im morphologische Weltbild,*** Droemer-Knaur, Munich and Zurich, **1966, 268** pp.
(Not reviewed.)

188. Zwicky, Fritz, ***Morphological Astronomy,*** Springer Verlag, Berlin, 1957. 299 p.
(After a discussion of the fundamental aspects of the author's " morphological method, " numerous applications to problems in astronomy are discussed. The methods of dimensionless, phenomenological and dimensional absolute morphology furnish successively more powerful methods of exploration, construction of instruments and reduction of the data.)

189. Zwicky, Fritz, ***Morphologische Forschung,*** Buchdruckerei Winterthur A.G., Winterthur, Switzerland, 111 p.—Available in the US from the Bookstore of the California Institute of Technology, Pasadena, Calif.
(A general treatise on the author's " morphological method," discussing applications to sociological, scientific, technical and military problems.)

190. Zwicky, Fritz, ***Morphology of Propulsive Power,*** Monographs on Morphological Research No. **1,** Society for Morphological Research, Pasadena, Calif., **1962. 382** p. Available from the Bookstore of the California Institute of Technology, Pasadena, Calif.
(The bulk of the volume consists of reprint of articles written by the author in the context of his work in the jet propulsion field. **A** few sections, however, deal with the methods of " Morphological Research " which the author has developed and applied. This is a systematic investigation of all the possible solutions to a given problem, without any prejudice, using matrix representations in as many dimensions **as** there are basic parameters. According to the author, this book is the best published account of his " morphological method. " The book is also interesting for its numerous applications of morphological thinking and for the bold outlook derived from it in the field of space travelling and ultimate "planetary engineering" up to the possibility of changing planetary orbits to render other planets habitable by man.)

See also the following references: **199,212, 213,** 214, **257, 269,** 280A, **373, 378, 379.**

B.5. ORGANISATION OF TECHNOLOGICAL FORECASTING AND PLANNING IN INDUSTRY

191. American Management Association, ***New Products - New Profits,*** American Management Association, New York, **1964.**
(Includes, for example, a description of Du Pont's scheme of matching " profiles " for research, production, market, patent situation etc.).

192. **Ansoff, H.** Igor, ***Corporate Strategy; An Analytic Approach to Business Policy for Growth and Expansion,*** McGraw-Hill, New York **1965.**
(Excellent book concerning the background against which technological forecasting has to be seen in companies. **A** special feature is the concept of synergy, also referred to **as** the **" 2 + 2 = 5** effect. **"** Operations research is not wholly applicable to the strategic problem.)

193. Baker, H.D., and Thompson, G. Clark, ***Executives Find: Long-Range Planning Pays Off,*** NICB - National Industrial Conference Board, Business Record, Vol. XIII, No. 10, ***Oct.*** **1956,** pp. **435-443.**
(Of **142 US** companies surveyed in **1956, 32** were already making formal plans for **10** *years* or more, almost half were making formal **5-year** plans, and **25** were making **formal** plans for fewer than **5,** but more than **1** year; a few were planning **12** to **20** years into the future.)

194. Bowman, Dean O., ***Organisation and Steps in Long-Range Planning***, in: ***Managerial Long-Range Planning,*** lit. ref. *222,* **1963,** p. **141-162.**
(An account of the long-range planning with integrated technological forecasting in **North** American Aviation's Autonetics Division.)

195. Bright, James R. (ed.), ***Technological Planning*** on ***the Corporate Level,*** Division of Research, Harvard Business School, Boston, Mass. 1961.
(A seminar held at the Harvard Business School in September, 1961. Includes lit. ref. 87, 206, 282.)

196. Ewing, David W., (ed.), ***Long-Range Planning for Management,*** Harper & Brothers, New York 1958.
(A collection of reprinted articles, among which the following are of marginal interest for technological forecasting: Morton M. Hunt, Bell Lab's 230 Long-Range Planners—see lit. ref. 207; Robert K. Stolz, Steps in Research Planning; Harry L. Hansen, Timing of New Product Introduction.)

197. Faltermayer, Edmund K., ***Corporate Horizons: More Companies Peer Into Distant Future, Try to Prepare For It,*** The Wall Street Journal, 25 Oct. 1961.
(The trend in US companies of looking 10 to 20 years into the future, and preparing detailed 5-year plans, exemplified by a number of big companies. Special examples include a General Electric consumer buying pattern forecast for 1980, and US Steel's steel demand forecast for 2000.)

198. Forrester, Jay, ***Industrial Dynamics,*** MIT Press, Cambridge, Massachusetts, 1961.
(A basic concept for the decision-making process in industry which became very fruitful for model-building.)

199. Gibson, R.E., ***A Systems Approach to Research Management.*** Research Management, Vol. V (1962), pp. 215-423, and Vol. VI (1963), p. 15; reproduced in condensed form in lit. ref. 32.
(Feedback schemes for different types of research and development, including interactions with environmental and social factors.)

200. Gloskey, Carl R., ***Research*** on ***a Research Department: An Analysis of Economic Decisions on Projects,*** IRE Transactions on Engineering Management, Vol. EM-7, No. 4, Dec. 1960, pp. 166-172.
(A case study of a research department in a medium-sized chemical company, in which every project is analysed beforehand. Different levels contribute to the appraisal of the research programme which is made by a Corporate Research Committee.)

201. Hafstad, Lawrence R., ***Making Research Pay: One Corporation's Approach,*** Research Management, Vol. VIII, No. 5, 1965, pp. 331-341.
(A description of General Motors' research by its Vice President in charge of the Research Laboratories, who is applying technological forecasting in a refined, though not very formalised, way.)

202. Haggerty, Patrick E., ***Highlighting Breakthrough Strategies,*** Texas Instruments Inc. First Quarter and Shareholders Meeting Report, 22 April 1965, and First Quarter and Shareholders Meeting Report, 20 April 1966, Dallas, Texas. 25 p.—resp. 15 p.
(The 1965 address of Texas Instruments' President outlines the company's long-range technological forward planning and, in particular, the concept of research strategies and tactical action programs—perhaps the best example today of technological forecasting fully integrated in long-range corporate planning. The 1966 address updates key figures in this framework. An abridged version of the 1965 address is given in lit. ref. 204.)

203. Haggerty, Patrick E., ***Research Manageemnt - Survival Issue,*** IEEE Transactions on Engineering Management, Vol. EM-11, No. 1, March 1964, pp. 3-15.
(Stresses the needs for research strategies by evoking the analogy of the strategy for the development of radar.)

204. Haggerty, Patrick E., ***Strategies, Tactics and Research,*** in Working Document DAS/RS/65.121, "European/North American Conference on Research Management, Monte Carlo, 22nd-24th February 1965," pp. 89-110, OECD, Paris, 28 June 1964 (Restricted); (publication envisaged by "Research Management" in 1967, and eventually also by OECD).

(A breathtaking description, by Texas Instruments' President, of that company's success story, including elements from the April **1965** address to the shareholders, " Highlighting Breakthrough Strategies," lit. ref. 202, in particular an account of TI's concept of research strategies and tactical action programmes.)

205. Hertz, D.B., ***The Management of Innovation,*** Management Review, April **1965,** pp. **49-52.**

(A review of the conclusions of an investigation conducted by the well-known consultant firm McKinsey & Co. Half the good research ideas in the chemical, electric, and drug industries were originally suggested by top management. A direct contact between management and R & D is favoured over committee structures. A matrix approach is briefly described which permits a close exchange of information between project and functional organisation; assignments are made from various functional groups to teams which do the technological forecasting.)

206. Herwald, S.W., ***Appraising the Effects of the Technological State of the Art on the Corporate Future,*** in: ***Technological Planning at the Corporate Level,*** lit. ref. **195, 1962,** p. **52-69.**

(An approach is suggested for choosing areas of technology bearing on a particular functional capability, and for watching technologies such as might bring about structural changes.)

207. Hunt, Morton M., ***Bell Lab's*** 230 ***Long-Range Planners,*** Fortune, May **1954,** reprinted in lit ref. **196.**

(A description of the functions of the Systems Engineering Department of the Bell Telephone Laboratories which comprise technological forecasting.)

208. Isenson, Raymond S., ***Allowed Degrees and Type of Intellectual Freedom in Research and Development,*** IEEE Transactions on Engineering Management, Vol. EM-12, No. 3, Sept. **1965,** pp. **113-115.**

(An account of an investigation carried out in the more famous US Laboratories. The conclusions reached are: that laboratories with a high reputation allow a great deal of freedom to individuals in selecting a technical path towards a stated objective, that the laboratories have a high degree of freedom in establishing their own research programmes, that there is no correlation between the reputation of a laboratory and its freedom to generate internally its own development programme.)

209. Jantsch, Erich, A ***Study of Information Problems in the Electrotechnical Sector,*** report DAS/RS/64.250 (restricted), OECD, Paris, **22** March **1965, 437** p.

(Includes a chapter on information flow in large companies which is pertinent to the communication problem encountered in industrial technological forecasting.)

210. Kast, Fremont; and Rosenzweig, James **R.** (editors), ***Science, Technology and Management,*** Proceedings of the National Advanced Technology Management Conference, **4-7** Sept. **1962,** Seattle, Washington; McGraw-Hill, New York, **1963.**

(Discussion is centred on systems engineerings and network techniques, and PERT/Cost.)

211. Krzyczkowski, Roman, ***Comprehensive Comparisons and Business Decisions,*** IRE Transactions on Engineering Management, Vol. EM-5, Sept. **1958,** pp. **65-71.**

(An outline of " The Comprehensive Comparison Method," an operations research approach for the quantitative evaluation of alternative technical solutions of a given problem. The example of a comparison between transatlantic communication by radio, coaxial cable, and multipaired cable, carried out by the author in **1954** before the laying of the first transatlantic telephone cable, illustrates the method. This is not a tool for technological forecasting, since the technical, economic, and operative factors of the evaluated systems have to be known fairly well, but may aid the direction of technological innovation in the firm planning phase.)

212. Lien, Arthur **P.,** ***Continuous Technical Planning: Tools, Techniques and Tactics,*** paper presented at AMA Course on Fundamentals of Planning, New York, **16** Dec, **1965;** prepublication manuscript, Battelle Memorial Institute, Columbus, Ohio, **1965, 24** p.

(A short discussion of the relationship between technological planning and forecasting, with reference to Battelle's working scheme.)

213. McCrory, R.J., ***Derivation of Business Opportunities Through Technical Planning,*** paper presented at the Design Engineering Conference, Chicago, Ill., **9-12** May **1966,** ASME (American Society of Mechanical Engineers), New York.

(The use of technological forecasting in the technical planning process, as developed at the Battelle Memorial Institute.)

214. McCrory, R.J., ***The Design Method - A Scientific Approach to Valid Design,*** ASME paper **63-MD-4,** presented at the Design Engineering Conference of ASME in May **1963,** American Society **of** Mechanical Engineers, New York, reproduced in condensed form in lit. ref. **32.**

(The outline of a feedback model for technological planning developed at the Battelle Memorial Institute.)

215. Myers, M. Scott, ***Conditions for Manager Motivation,*** Harvard Business Review, Vol. 44, No. **1,** Jan/Feb. **1966,** pp. **58-71.**

(An account of a company-wide survey of motivation at Texas Instruments, and the role of motivation in planning, by Texas Instruments' Manager of Management Research.)

216. Quinn, James Brian, ***Long-Range Planning of Industrial Research,*** Harvard Business Review, July/August **1961.** Partly reproduced in lit. ref. **32.**

(An integrated research planning system is proposed, including the following functions: objective setting, determining technological threats and opportunities, research strategy, project selection.)

216*a*. Quinn, James Brian, ***Technological Forecasting,*** Harvard Business Review, Vol. **45,** No. **2,** March/April **1967,** pp. **89-106.**

(An authoritative summary of present management attitudes to technological forecasting, special techniques in use, and organisational forms encountered today in advanced-thinking American industry. A number of examples from industry illustrate the points made. The final section " Integrating with Decisions -- favours the integration of forecasting and planning in industrial decision-making.)

217. Quinn, James Brian, ***Top Management Guides for Research Planning,*** in ***Research, Development and Technological Innovation,*** lit. ref. **32,** pp. **677-700.**

(A brilliant synthesis of interviews with **120** top executives in **35 US** companies. Technological forecasting has been encountered and is described for a few actual activities. The general aspects of technological forecasting discussed include: concepts, forms of organisation, assessment of long-term technological threats and opportunities, procedures for project selection in the light of company goals and capacities, the fitting of research to company strategy.)

218. Schaidt, Leander, ***Program Management Techniques at Martin Orlando,*** IEEE Transactions on Engineering Management, Vol. EM-10, No. 3, Sept. **1963,** pp. **124-137.**

(Five-year plans are updated every six months. They include projections of potential business which then becomes a subject of heavy concentration.)

219. Schnyder von Wartensee, Robert, ***Prospektive Haltung,*** Industrielle Organisation, **1965, No. 8, pp. 1-6.**

(An attempt to distinguish between " prospective," as used by the French and introduced by Gaston Berger, and " long-range planning," understood as coming dose to dirigism—the latter notion is a common misunderstanding in Europe. A clear idea of future desires and goals, furthered by the attitude of " prospective," helps to overcome determinism.)

220. Scott, Brian W., ***Long-Range Planning in American Industry,*** American Management Association, New York **1965.**

(An analysis of corporate long-range planning on the basis of interviews conducted with senior executives of **12 US** companies. The three parts are headed: background, mission, organisation. Chapter 6 on " Assumption About the Future," pp. 104-122, Chapter 7 on " Anticipation of Technological Change," pp. 123-135, and Chapter 8 on " The Choice of a Strategy," pp. 136-154 are of interest for technological forecasting. Technological forecasting is recognised as a marked tendency since the late 1950's, but is not discussed in greater detail.)

220a. Sloan, Alfred Pritchard, ***My Years with General Motors,*** Doubleday, Garden City, N.Y., **1963.**

(The concept of consequent decentralised management which the author introduced in GM when he was their Chairman of the Board.)

221. Smelt, Ronald, ***Capitalising on Creative Capabilities,*** Manuscript, Lockheed Aircraft Corp., Burbank, Calif.

(The process of industrial innovation with examples from Lockheed, described by Lockheed's Vice-President and Chief Scientist.)

222. Steiner, George A., (ed.), ***Managerial Long-Range Planning,*** McGraw-Hill, New York, **1963, 334** p.

(Descriptions of the organisation of long-range planning in **17 US** companies and government agencies, by their directors of long-range planning).

223. Stockfish, J.A., (ed.), ***Planning and Forecasting in the Defense Industries,*** Wadsworth Publishing Co., Belmont, California, **1962.**

(Papers presented at a UCLA seminar on **4-5** May **1960.)**

224. Suits, Guy, ***Selectivity - a Modern Research Necessity,*** address given before the American Management Association, at Chicago, Ill., Sept. **15, 1964,** reprinted by General Electric Co., **8** p.

(A brief account of General Electric's basic philosophy in technological forecasting, by the then Vice President and Director of Research. A number of practical examples concerning the guidance recent R & D projects received from technological forecasting makes it particularly interesting.)

225. Swager, William L., ***Industrial Implications of Technological Forecasting,*** paper presented to the Fourth Symposium of the Engineering Economy Division of the American Society for Engineering Education in Chicago, Ill., **19** June **1965.** Battelle Memorial Institute, Columbus, Ohio.

(A general discussion of the organisation of technological forecasting in industry.)

226. Tolkowsky, Dan, ***R & D and Industry in Israel - Some prevalent Attitudes and Misconceptions,*** pre-publication manuscript, **1966, 5** p.

(The thorny problem of Israel's delayed industrialisation, and the implications for research and development. Technological factors should not be considered to be solely responsible: marketing and other factors are perhaps more important.)

227. Wilson, Joseph C., ***The Conscience of Business,*** John Findley Green Lecture at The Westminster College, Fulton, Missouri, **16** Nov. **1965, 18** p.

(An address by the President of Xerox Corporation.)

See also references: **13, 32.**

B.6. ORGANISATION OF TECHNOLOGICAL FORECASTING AND PLANNING IN NON-INDUSTRIAL ENVIRONMENTS

228. Burn, Duncan; Seale, J.R.; Ratcliff, A.R.N., ***Lessons from Central Forecasting,*** Eaton Paper **6,** The Institute of Economic Affairs, London, **1965, 62** p.

(A critique of forecasts, mostly for five- to ten-year periods, for the British economy done by British Government agencies. The accent is on the obvious shortcomings.)

229. Capron, William M., ***The Potential Role of Cost Effectiveness Analysis for Evaluation of Government Domestic Programs,*** paper given at the Symposium on Cost Effectiveness Analysis at the Institute for Defense Analyses, 15 June 1965, Washington **D.C.** Manuscript, 15 p.

(The introduction of the Planning-Programming-Budgeting System to civilian government.)

230. Enke, Stephen (ed.), ***Defense Management,*** Prentice-Hall, New York 1966.

(Hitch's book—lit. ref. 233—presented the basic concepts for the " new look " of the US Department of Defense management and this volume makes the first attempt, so far as unclassified discussion allows, to evaluate the experience gained.)

231. Enke, Stephen, ***Using Costs to Select Weapons,*** The Journal of the American Economic Association, Vol. LV, No. 2, May 1965, pp. 416 to 426.

(A brief description of the evolution, accomplishments, and limitations of the cost/effectiveness concept, given by one of the key people in its development.)

232. Freeman, Raoul J., ***The Science Corps,*** Memorandum P-3217, The RAND Corporation, Santa Monica, Calif., Aug. 1965, 6 p.

(Advances the idea of a central government agency to provide comprehensive national research strategy and organisation, conduct evaluations of specific proposals, perform technical scientific audits, etc.)

233. Hitch, Charles J., ***Decision-Making for Defense,*** University of California Press, Berkeley and Los Angeles, and Cambridge University Press, Cambridge (UK), both 1965.

(A broad discussion of the US Department of Defense management and the basic concepts introduced by Secretary McNamara and the author, who was Assistant Secretary during the period 1961-1965. These concepts include: the combined evaluation of strategic alternatives, weapons technology, and economic resources; systems analysis; planning-programming-budgeting; cost/effectiveness, etc.)

234. Massé, Pierre, ***Les Principes de la Planification Française***, manuscript, 1 Oct. 1963, 22 p. Has been published in various countries, for example in the Weltwirtschaftliches Archiv (Kiel, Germany), Dec. 1963.

(An account of the evolution of the principles guiding the French Plan. The " median way " of an interaction between all economic and social factors is emphasised. The author was head of the Planning Department until 1965.)

235. Mesthene, Emmanuel G., ***On Understanding Change: The Harvard University Programme on Technology and Society,*** Technology and Culture, Spring 1965, pp. 222-235.

(A brief account of the Programmes organisation and envisaged aims, by its Executive Director.)

235a. Novick, David (ed.), ***Programme Budgeting... Program Analysis,*** The RAND Corporation, Santa Monica, California, 1964 and 1965. For sale at the Superintendent of Documents, US Government Printing Office, Washington, D.C. 20402, 236 p.

(The Planning-Programming-Budgeting System of the United States government.)

236. OECD ***Examination of the United States, Report by the Examiners,*** Document MO/(63)5, Manpower and Social Affairs Committee, OECD, Paris, 20 February, 1963.

(A discussion of technology forecasting in the United States, with emphasis on occupational requirements.)

237. OECD, ***Government and Allocation of Resources to Science,*** report prepared for the Second Ministerial Meeting on Science, Paris, Jan. 1966, OECD, Paris.

(The report, prepared by H. Brooks, C. Freeman, L. Gunn, J. Saint-Geours, and J. Spaey, contains a short chapter on " Criteria for national policy-making," subdivided into scientific, social, and economic needs and opportunities.)

238. OECD, ***The Role of Government in Stimulating Technical Innovation,*** working paper CMS-CI/65/63-C, Interim Committee, Ministerial Meeting on Science, OECD, Paris, 15 Dec. 1965, 123 p.

(Information submitted by Member governments, including US contributions on " Cost Reduction and R and D Contracting "—discussing the shift from cost-plus to fixed-price or incentive contracts in Department of Defense practices—and on " Federal Support of Contractor Initiated Technical Effort," especially in the areas of the Department of Defense, NASA, and the Atomic Energy Commission.)

239. Rowen, Henry S., ***Improving Decision Making in Government,*** paper given at the Summer Seminar on Systems Analysis and Program Evaluation, US Bureau of the Budget, **1965.** Manuscript, **28** p.

(The introduction of the Planning-Programming-Budgeting System to civilian government.)

240. UK Advisory Council on Scientific Policy, ***Annual Report of the Advisory Council on Scientific Policy 1963-1964,*** presented to Parliament by the Secretaty of State for Education and Science; Her Majesty's Stationery Office, London, Dec. **1964, 48** p.

(The last report of the Council under the chairmanship of Lord Todd contains an outline for a future national science policy with much bearing on technological forecasting in fundamental research—ideas similar to the American COSPUP are developed—, innovation in industry, and government programsme in technology.)

241. *US* Department of Defense, ***Planning - Programming-Budgeting System,*** pamphlet, Department of Defense, Washington, D.C., **1965, 47** p.

(A popularised review of the PPBS, introduced into the Department of Defense in **1961,** and gradually—since Oct. 1965—into other US Government agencies. PPBS consists of three phases: military planning and requirements determination; formulation and review of programmes; preparation of annual budget estimates. Technological forecasting enters in the first phase, where systems analysis and cost/effectiveness studies are prepared. The principal objectives of PPBS are: **1.** plan programmes around missions rather than services; **2.** relate resources requirements to the programmes; **3.** provide capability for making cost/effectiveness studies of alternative force structures; **4.** appraise programmes on a continuous basis; **5.** co-ordinate long-range planning with budgeting.)

See also reference **184.**

B. 7. ACCURACY OF TECHNOLOGICAL FORECASTING

242. Ewell, L.N., ***Uncle Sam Gazes into his Crystal Ball,*** Armed Forces Chemical Journal, Vol. **VI,** Jan. **1953,** pp. **9-15.**

(Reviews the Paley Commission report on estimates for **1975,** and finds various disagreements between different experts.)

243. Gilfillan, S. Colum, ***The Prediction of Inventions,*** in: US National Resources Committee, ***Technological Trends and National Policy,*** Part One, Section **II,** pp. **15-23,** June **1937,** see lit. ref. 284.

(A " classic," supporting a very optimistic view on the possibility of forecasting inventions. The author evaluates past sets of forecasts, including Edison in **1911,** Steinmetz in **1915,** the " Scientific American " in **1920,** the author himself, and others, finding a score of more than **75** per cent correct predictions. The author ventures a forecast concerning the questions of fighting fog for flying, and recognising 25 different potential means of conquering fog and expresses confidence that success will be achieved by a number of these; in an article **15** years later—lit. ref. 40—he points out that 9 out of these **25** means are already in use, but that he had not foreseen the most important one, radar, because he had not known of the secret development already under way in **1937.** The author, who is a well-known economist, points out that he is not technically trained. A good bibliography on older technological forecasts is included.)

244. Klein, Burton H., ***The Decision Making Problem in Development,*** in: ***The Rate and Direction of Inventive Activity,*** lit. ref. **65,** pp. **477-497,** comments by F.M. Scherer and replies by Klein, pp. **497-508.**

(An " early learning hypothosis " could be proved, with a linear relationship, for development time estimates of eight missile programmes, with **35** individual estimates of availability at various stages of development. For development costs, such an " early learning hypothesis " could not be proven. Klein stresses the technical uncertainties in developments which tend to change others en route, a notion which Scherer rejects.)

245. Male, Donald Warren, ***Prophecies and Predictions in Aviation,*** unpublished Master's Thesis, Massachusetts Institute of Technology, Cambridge, Mass., **1958.**

(Lenz, lit. ref. **151,** comments on this work as follows: " D.W. Male has concluded from a study ***of*** over **200** forecasts in the field of aviation, that, ' Of the predictions containing both a valid trend element and a time element, less than one-third were judged valid concerning the time element.' It is apparent from Male's study that systematic methods, capable of consistently accurate predictions have not been used by aviation forecasters. ")

246. Marshall, A.W., and Meckling, W.H., ***Predictability of the Costs, Time, and Success of Development,*** in: ***The Rate and Direction of Inventive Activity,*** p. **461-475,** lit. ref. **65.**

(A case study **of 22** weapons systems, resulting in the conclusion that early estimates were over-optimistic. Increases in cumulative costs of production of the order of 200 to **300** per cent, and extensions of development time by **1/3** to **1/2** were the rule, whereas performance was nearly fulfilled, in general. The degree of error in estimates varied widely from one weapon to another.)

247. Patterson, William **A.,** ***The Long Flight,*** Mainliner, Vol. **10,** No. **4,** United Air Lines, Chicago, Ill., April 1966, **3** p.

(A look at the first 40 years of United Airlines, by its Chairman of the Board, culminating in the statement that the author had never visualised the speed and comfort of today's jet travel, the volume of air traffic, or the role of air transportation in American national life.)

248. Peck, Merton **J.**, and Scherer, Frederic **M.,** ***The Weapons Acquisition Process - An Economic Analysis,*** Division of Research, Harvard Business School, Boston, Mass. **1962.**

(Chapter **2,** on " The Unique Environment of Uncertainty in Weapons Acquisition," pp. **17-54,** is of particular interest to technological forecasting. It discusses external uncertainties—e.g., technological change—and internal uncertainties, such as cost and time estimates. A review of the authors' and other evaluations of case histories leads to the following average values of the ratio **of** real and estimated factors: development costs **2.4** to **3.2;** development time **1.6;** performance factors **0.8** to 2.0—this means that performance estimates were on the pessimistic side, cost and time estimates on the optimistic side. The development cycle in **US** advanced weapons development is calculated **as 8-11** years.)

249. Science, ***The Trouble with Technological Forecasting,*** Science, Vol. **144, 16** May **1964.**

(Not reviewed.)

250. Summers, Robert, ***Cost Estimates as Predictors of Actual Weapon Costs - A Study of Major Hardware Articles,*** Memorandum **RM-3061-**PR, abridged (unclassified version), The RAND Corporation, Santa Monica, California, March **1965.** Will also be published as a chapter in lit. ref. **53.**

(An investigation of predictions of production costs for **22** different US weapon systems, for which approximately **100** individual production cost estimates had been made at different stages of development; **67** of them were used for the evaluation. Actual costs turned out to be higher in the end for **80** per cent of the cases. During development, production cost estimates approach the actual value more or less linearly. The slope **of** the line varies with the project. In general, the ratio of actual to estimated production cost can be expressed in function of time, technological advance, and possibly other variables, a number of which will be further investigated by the author.)

See also references: 52, **228.**

250*a*. Architectural Design, 2000 +, special issue of Architectural Design, London, February **1967.**

(The principal contents are: R. Buckminster Fuller, " Profile of the industrial revolution " and " The year **2000** "; John McHale, " 2000 + "—with sections of the future of the future, outer space, inner space, Man +, new symbiosis, world game, the people future; Theodore J. Gordon, " The effects of technology "; Neil P. Hurley, " Communications revolution ".)

251. Auger, Pierre, ***Current Trends in Scientific Research,*** UNESCO, Paris, **1961.**

(A comprehensive and homogeneous account, on the basis of a large number of individual inquiries, of the state of the art of the scientific and technical disciplines in **1959/60,** pointing out qualitative trends into the more immediate future.)

252. Bellamy, Edward, ***Looking Backward,*** United States, **1887.**

(A look backward from the year **2000.** H.S. Commager comments: " Nothing he described in the new world was scientifically or mechanically impossible, but almost everything he assumed about reason and morality was improbable. ")

253. Birkenhead, Earl of, ***The World in 2030 A.D.,*** Hodder and Stoughton, London, **1930, 215** p.

(A broad and apodictic forecast by a non-scientist, active in the fields of law and politics, High Steward of Oxford University and Lord Rector of Aberdeen University. The forecasts are remarkably good on performance factors of new technologies, less good on specific technologies for achieving these performances, and fairly poor on social and economic impact. About two-thirds of the performances forecast for **2030** had been more or less realised by **1960,** such as nuclear energy, transatlantic air travel at **50,000** feet altitude and **600** miles an hour using jet propulsion—but the author assumed that nuclear engines would be necessary, first preparations to reach Mars —a journey to the Moon is rejected as " a cold and unattractive proposition, " synthetic cheap textiles, colour television, etc. In contrast, the disappearance of dirt and pollution, the complete silence of all machines and of road traffic, the latter forecast as only four times greater than in **1930,** and the disappearance of epidemic diseases express a naive optimism concerning social questions which is probably no longer valid today.)

254. Bliven, Bruce, ***Men Who Make The Future,*** Pilot Press, London **1943.**

(An imaginative account by **a** scientific journalist of scientific areas in which breakthroughs could be projected. The closing chapter calls for needed " social inventions. ")

255. Bliven, Bruce, ***Preview for Tomorrow: The Unifinished Business of Science,*** New York **1953.**

(Not reviewed.)

256. Brech, Ronald, ***Britain 1984: Unilever's Forecast - An Experiment in the Economic History of the Future,*** Darton, Longman **&** Todd, London **1963.**

(A **20-** to 25-year economic forecast augmented by technological forecasting on the basis of things that are known to be in preparation, and using the " synoptic model " described in lit. ref. **99.** The focus is on the consumer market and the forecasting of income distribution and buying patterns. Psychological and sociological factors are discussed seperately from the economic analysis—the " synoptic model " has **been** left incomplete for this exercise. Technological areas taken into account include: power, new materials, factory processes and machine design, transportation.)

257. Brown, Bernice; Gordon, T.J.; and Helmer, **Olaf,** ***Appendix to the Report on a Long-Range Forecasting Study,*** The RAND Corporation, Santa Monica, California, Sept. **1964.**

(Appendix to lit. ref. **269.**)

258. Brown, Harrison, The Challenge *of* Man's Future - An Inquiry Concerning the Conditions *of* Man During the Years that Lie Ahead, Viking Press, New York, 1954.
(Principally a resources approach to the three great themes: food, energy, materials. Chapter VII on " Patterns of the Future " contains some excellent socio-economic thinking, including a discussion of problems of developing countries and the possible impact of new technologies. The forecast for nuclear energy, with a commercial start in 1975, and electricity generating costs approaching 6 mills/kWh, was still overcautions. The author is planning a new version of this book.)

259. Brown Harrison; Bonner, James; Weir, John, The Next Hundred Years, Viking Press, New York, 1957, 193 p.
(The distillation of a series of symposia on long-range considerations of resources and population problems of interest to industry, which were started by Robert V. Bartz, Director of the Industrial Associates Program at the California Institute of Technology. The book is an important example of the derivation of long-range forecasts by resources thinking, particularly in the fields of raw materials, manpower, food, energy and education.)

260. Business International, Corporate Planning Today for Tomorrow's World Market, BI Research Report No. 84, Business International, 757 Third Avenue, New York, N.Y. 10017, July 1964, $40.
(A broad survey and outlook, including some technological, social, and political forecasting, from the point of view of corporate planning.)

261. Calder, Nigel (ed.), The World in *1984,* The Complete New Scientist Series, 2 Volumes, Pelican Book A 720 (Vol. 1) and A 721 (Vol. 2), Penguin Books, Harmondsworth, Middlesex, 1965, 215 p. (Vol. 1) and 205 p. (Vol. 2).
(The complete series of 99 short papers by outstanding people in the natural and social sciences and in public life, appearing in the " New Scientist" in 1964, plus an article by the editor summing up the main forecasts of changes and consequences. A brainstorming exercise which is unique in the quality and public reputation of its contributors. The resulting mosaic does not give a consistent picture of the world in 1984, although the themes have been carefully chosen so as to cover all important scientific and technical areas as well as the economic, political, social and artistic aspects of the future. It comes as a surprise that this array of famous names produced hardly any major ideas or views beyond those already under discussion—partly a consequence of the 20-year time-frame which leaves little space for the maturing of principles which are not yet applied in the laboratories, and partly a consequence of the procedure of this " brainstorming by letter " which invited comments on opportunities rather than trying to arrive first at a consensus on a pattern of missions (desires and necessities) and then " invent the future " accordingly. This does not detract from the many valuable aspects of this extraordinary undertaking.)

262. Clarke, Arthur C., *Profiles of* the Future - An Enquiry into the Limits *of* the Possible, Victor Gollancz Ltd., London, 1962. 223 p.
(The author, former President of the British Interplanetary Society, is one of the least prejudiced—and at the same time one of the most imaginative and " sensitive "— of the technological forecasters, see also lit. ref. 295. This book, including forecasts up to the year 2100, bears testimony to his imagination as well as to his solid scientific background. A summary " chart of the future " foresees, for example: 1990 fusion power, 2000 colonising planets, artificial intelligence, " wireless " energy, sub-nuclear structure, 2010 telesensory devices, 2015 weather control, 2025 control of heredity, 2030 space mining, 2035 contact with extra-terrestrials, bio-engineering, 2065 artificial life, 2075 climate control, near-light speed, 2080 machine intelligence exceeds man's, 2085 interstellar flight, 2090 matter transmitter, materials replicator, 2095 world brain, immortality, 2100 meetings with extra-terrestrials, astronomical engineering. Some of the estimates up to 2000 even appear conservative for our present state of knowledge, the estimates beyond, more fantastic. The chart is probably better balanced than our uncritical intuition.)

263. Dewhurst, J. Frederick; Coppock, John O.; Yates, P. Lamartine; et al., Europe's *Needs of Resources,* Twentieth Century Fund, New York, 1961, and Macmillan, London.
(A comprehensive study, with resources projected for 1970, and a future consumption pattern.)

264. Engineers' Joint Council, ***The Nation's Engineering Research Needs 1965-1985***, Subcommittee Reports of the Engineering Research Committee, Engineers' Joint Council, New York, 1962. 212 p.

(An ambitious undertaking of technological forecasting to define the needs in 12 fields for which existing institutions and programmes have appeared inadequate. The implications for social technology emerge in engineering areas which are sometimes surprising.)

265. Esso Rivista, ***Tra 25 Anni,*** Esso Rivista, Anno XVII, No. 5, Sept.-Oct. 1965. 28 p.

(A broad 25-year forecast, compiled by the Italian Esso Company, and comprising 8 contributions by distinguished Italian authors in the fallowing areas: cultural development, scientific research, North and South, labour, cities, economy, agriculture, education.)

266. Furnas, C.C., ***The Next Hundred Years - the Unfinished Business of Science,*** Williams & Wilkins, Baltimore, Md., 1936.

(A review of opportunities and missions in many fields, by a well-known and very productive metallurgist and engineer. Although the author recognises many technological potentials, he is over-cautions in forecasting their realisation and impact. For example, on nuclear energy: " The last word has not been said yet but do not buy any stock in an Atomic Energy Development Company. You will certainly lose." Or on television—Zworykin had already invented his " iconoscope": " I am waiting for my television but I cannot wait forever. When I think that the first radio impulse transmission was accomplished by Joseph Henry in 1840 and the first radio broadcast was not until 1920 I feel a little discouraged about the arrival of this television business while my eyes still function. No one has dared even to think of television in natural colours as yet." When these words were published, the first regular television broadcasts were about to start in the UK, and the invention of colour television was less than a decade away.—Although the author recognised in a remarkable way some of the missions and requirements, he lacked the understanding of the powerful driving force they can exert to push developments—as was proved later in World War II. Believing in a self-acting development process, the author distrusts the potential revealed by his excellent technical insight.)

267. Galton, Lawrence, ***Science Stands at Awsome Thresholds,*** New York Times Magazine, 2 Dec., 1962.

(A broad forecast in fundamental science and technology.)

268. Good, Irving John (ed.), ***The Scientist Speculates - an Anthology of Partly-Baked Ideas,*** Heinemann, London 1962.

(A rather unsystematic collection of more than 100 ideas, partly derived from requirements, partly pointing out opportunities. A discussion of social implications is sometimes included. The contributing scientists are often not very widely known. Some reflections under the heading " Ideas About Ideas, " especially a treatise on " The Place of Speculation in Modern Technology and Science" by J.D. Bernel are somewhat superficial.)

269. Gordon, T.J., and Helmer, Qlaf, ***Report on a Long-Range Forecasting Study,*** report P-2982, The RAND Corporation, Santa Monica, California, Sept. 1964. French translation ***Prospective à long terme*** in " Futuribles, " No. 88, Paris, 10 March 1965. Partly reprinted in lit. ref. 134 A.

(A large-scale application of the " Delphi " technique, with panels in six different broad areas: scientific breakthroughs, population growth, automation, space progress, probability and prevention of war, future weapon systems. A 50-year time-depth was generally aimed at. Cross sections are derived for the world in the years 1984 and 2000, and conceivable futures are outlined for 2100.)

270. Hutchings, Jr., Edward (ed.), ***Frontiers in Science, A Survey,*** Basic Books Inc. (USA), *1958.*

(A rather superficial collection of articles, written partly by eminent scientists, on the state of the art and on some future implications in the physical and life sciences. Included is an interesting controversy between Sir Charles Darwin, with his article

" Forecasting the Future, " pp. **100-116,** containing a discussion of population forecasts and some gloomy technological forecasting, and Fred Hoyle replying with " Forecasting the Future?," pp. **117-121,** in which he points out feedback possibilities that may influence population growth.)

271. Jungk, Robert, ***Die Zukunft hat schon begonnen;*** English translation ***Tomorrow is Already Here - Scenes from a Man-Made World,*** Hart-Davis, London **1954.**

(Feuilleton-type appraisals of current scientific and technological progress, with few explicit forecasts.)

272. Kahn, Herman, ***On Alternative World Futures : Issues and Themes,*** Report HI-525-D for the Martin Company, Hudson Institute, Harmon-on-Hudson, N.Y., 20 May **1965;** revised version of first chapter, ***Some Basic Techniques, Issues, Themes, and Variables,*** presented at the Harris Conference on New Approaches to International Relations, University of Chicago, Ill. **1-4** June **1966,** Report HI-525-D (Ch. **1** only, Rev. **3**), 1 March **1966** (Restricted).

(An attempt to look at alternative patterns for the future, using the Hudson Institute's and the author's specific techniques of historical analogy, " scenario writing," " pre-search"-research, exposition and research in exposition—and using a broad simultaneous approach to cultural, political, economic and technological aspects. One of the aims is to develop a consistent methodology. Chapter IX on New Technological Themes discusses the envelope technique of extrapolation and reviews on **35** pages important issues from published technological forecasting.)

273. Landsberg, Hans H.; Fishman, Leonard L.; and Fisher, Joseph L., ***Resources in America's Future - Patterns of Requirements and Availabilities 1960-2000,*** Published for Resources for the Future, Inc., by The John Hopkins Press, Baltimore, Md., **1963, 1017** p.

(A comprehensive and impressive survey which does not attempt to grasp the full implication of technological change in the reference period. Apart from a short discussion of alternatives in future technology, resources are generally investigated to see whether they would suit any pattern developing among these alternatives—for example, whether both fossil and nuclear fuels are sufficiently abundant to support any energy pattern with no attempt being made to forecast the split between them. The volume is divided into three main parts: requirements for future living, demand for key materials, adequacy of the resource base. Probabilistic forecasts are given on three levels: high, medium, low. The general outlook gives reason for optimum.)

274. McGraw-Hill, ***The American Economy - Prospects for Growth Through 1980,*** McGraw-Hill Department of Economics, McGraw-Hill Publications, Inc., New York, Sept. **1965. 17** p.

(A summary of economic forecasts, including many aggregated effects of technological change. For example, **35** per cent of investment will be in automation in **1980** as against **11** in **1955,** the rate of innovation in industry will show that **60** per cent of all products had not been produced **15** years earlier as against **40** per cent in **1965,** R & **D** effort will rise from $ 22 billion in **1965** to **$ 46** billion in **1980,** productivity will increase by 50 per cent, etc.)

275. New York Times Magazine, ***The Future,*** New York Times, **19** April **1964,** Section **6,** Part 2, pp. **86-118.**

(A broad popularised forecast, mainly in general terms, composed of the following six contributions: A. Toynbee, " At Least The Beginning of One World "—world unity is forecast by 2,000 A.D.; H.S. Commager, " A Visit in the Year 2000 "—the US will not be Utopia, many new problems having replaced the old ones; C. Randall, " Industry: Incredible New Markets "—many of the basic industrial concepts will change radically; J.B.S. Haldane, " A Scientific Revolution? Yes "—science, by eliminating happiness, may mean misery, the science of 5 centuries hence will be psychophysics; M. Mead, " Human Nature Will Flower, If, "—stone-age men in the 20th century have the potential of greatness; H.L. Dryden " No Tourists on the Moon " —by **2,000** A.D. moon-voyaging will be commonplace for astronauts, not for the average man.)

276. Plessner, Max, ***Ein Blick auf die grossen Erfindungen des 20. Jahrhunderts,*** Berlin **1892.**
(Considered the most extraordinary work of broad technological forecasting in the 19th century, with a much better understanding of technical feasibility—the author was an engineer—than in the more " poetical " approaches that were abundant at that time. One example is the fairly accurate description of television.)

277. Prehoda, Robert W., ***Designing the Future - The Role of Technological Forecasting,*** expected to be published by Chilton Books (US) in June **1967.**
(The author was manager of corporate market research and diversification planning at Electro-Optical Systems Inc., in Pasadena, California. The book is divided into three parts : Economic Considerations ; Promising Material Development ; and Biological Applications. A bibliography is included.)

278. ***Réflexions pour 1985,*** La Documentation Française, Paris, **1965.**
(A somewhat popularised presentation of the findings of the " Groupe **1985** " which contributed long-range forecasts to the 5th French National Plan. Twenty-year projections in approximately 30 different fields, sometimes including manpower forecasts and indications for a research strategy, are given.)

279. Sarnoff, David, ***By the End of the Twentieth Century,*** Fortune Magazine, May **1964,** p. **116-119.**
(A list of apodictic forecasts, without analytical arguments, by R.C.A.'s Chairman of the Board. About 50 specific forecasts are made for the year **2000** AD in the following fields: Food, Raw Materials, Energy, Health, Genetics, Communications, Travel, Defense, Air and Space. Most of the predictions relate to developing technological applications of scientific discoveries already made. This list updates a similar list by General Sarnoff, which Fortune Magazine had published in **1955.)**

279*a*. Science Journal, ***Forecasting the Future,*** planned for the Oct. **1967,** issue.
(Forecasts in the following fields: science, medicine, space, natural resources, food, energy, materials, automation, communication, transport, cities, population and world futures. The aim is to present serious forecasts which are forming the basis for actual planning, not just speculation.)

280. Scientific American, ***The Future as Suggested by the Development of the Past 75 Years,*** Scientific American, Oct. **1920.**
(A broad 75-year forecast with 65 definite predictions of invention.)

280*a*. Stine, **G.** Harry, ***Forecast*** 2000 AD, to be published in US in **1967.**
(Forecasts based mainly on trend extrapolation.)

281. Syracuse University Research Corporation, ***Science and Technology in the I985 Era,*** Syracuse, N.Y. **15** March **1964.** Clearinghouse for Scientific and Technical Information number AD **613,525. 44** p.
(Supplement to a full report, " The United States and the World in the **1985** Era, " prepared for the US Marine Corps. A number of very sketchy forecasts in five selected **technologies — transportation,** communications, computers and automation, electric power, space technology—as well as for natural resources, and in the field of public health and medicine. No analysis given.)

282. Teller, Edward, ***The Next Hundred Years,*** in : ***Technological Planning at the Corporate Level,*** lit. ref. **195, 1962,** p. **148-166.**
(A number of forecasts by the noted physicist.)

283. Thomson, Sir George, ***The Foreseeable Future,*** University Press, Cambridge (UK), **1955,** rev. ed. **1960. 145** p.
(Forecasts by the British Nobel Prize winner for Physics, **1937,** in the broad fields indicated by the following titles of chapters: Energy and Power; Materials; Transport and Communications; Meteorology; Food; Some Applications of Biology; Some Social Consequences; Thought, Artificial and Natural. The method used is **to** " consider what further technical advances are likely and then to **see** what reaction they are likely to have on people's lives, " **as** opposed to that of starting from a view

of how society is likely to change and then proceeding to " invent the future, " in D. Gabor's words. Thomson's specific forecasts, not very numerous, but derived through thoughtful analysis, thus represent conventional forecasting with limited value for a world which is, in fact, setting out to " invent " its future. His analysis, however, is also of considerable interest because he recognises the importance of assessing natural limitations and of thinking in terms of " principles of impotence.")

284. US National Resources Committee, ***Technological Trends and National Policy - Including the Social Implications of New Inventions,*** a report of the Subcommittee on Technology, US National Resources Committee, US Government Printing Office, Washington, D.C., June 1937.

(Perhaps the first serious attempt of technological forecasting at national level, still unsurpassed in many respects, Three parts: I. Social Aspects of Technology; II. Science and Technology; III. Technology in Various Fields.—Part I contains two contributions by S.C. Gilfillan, listed separately as lit. refs. 243 and 365 in this bibliography. Part III contains an account of the state of the art in various fields, a discussion of trends and of hopeful but unproved developments, an evaluation 03 the effects of technological change and of economic and social factors, e.g. ' Will the public accept television and pay for it?,' an assessment of possible new markets, and an outline of future research areas.)

285. Vassiliev, M., and Gouschev, S., (editors), ***Life in The Twenty-First Century,*** translated from Russian, first published in Russia 1959, Penguin Special, Penguin Books, Harmondsworth, Middlesex, 1961. 222 p.

(A very bad account, full of half-understanding and misunderstanding, of the interviews on future developments which the two journalists had had with 29 noted Russian scientists and engineers. Their inability to ask detailed technical questions and to understand the state of the art and current trends leads them frequently to marvel at the obvious and at short-range implications and to overlook the interesting aspects. Moreover, they feel an obligation to write up part of the interviews in a novelistic form, as " scenes from the future, " and to stress wherever possible the supremacy of Russian technics and dialectic materialism as a pre-requisite for these achievements. For the knowledgeable reader, an attempt to try to trace the original elements of the 50-year forecasts, for 2007 A.D., by Russian scientists, might still be worthwhile.)

See also references **41,** *289a.*

B.9. ACTUAL TECHNOLOGICAL FORECASTS: SPECIFIC BROAD FIELDS

286. Aerospace Industries Association, ***Aerospace Technical Forecast 1962-1972,*** Aerospace Industries Association (AIA), Washington, D.C., 1962.

(A broad forecast with the principal aim of defining requirements in the fields of materials, components, subsystems, testing, etc.)

287. Andrade, **E.N.** da C. ***The Atom,*** Benn's Sixpenny Library **No.** 103, Ernest Benn Ltd. London, 1927. 78 p.

(Grasps the potential of fusion and fission due to the mass defect.)

288. Ayres, Robert U., ***Technology and the Prospects for World Food Production,*** report HI-640-DP (Rev. 2), Hudson Institute, Harmon-on-Hudson, New York, 19 April, 1966. 71 p.

(A highly original treatise on this old and much-discussed subject. The general approach is indicated by the titles of the central chapters:Losses and Inefficiencies, and Capital/Energy Conversion. Under the latter heading, possible future technologies, such as artificial environments, synthesis from fossil fuels, mariculture and weather control are discussed in a highly critical spirit. The general outlook for meeting food production requirements is not bad.)

289. Brennan, Donald G., et al., ***Future Technology and Arms Control,*** report HI-504-RR, Hudson Institute, Harmon-on-Hudson, New York, 1 June 1964. (Classified)

(Not reviewed.)

289*a*. Calder, Nigcl, ***The Environment Game,*** Secker & Warburg, London **1967.**

(A fascinating and generally well-founded systems analysis study of man's relation to his environment, seen in the light of future technologies. The book concentrates on food production technology and concludes that, towards the year 2,000, agriculture will be replaced by synthetic food production; before that, science will contribute significantly to the raising of agricultural productivity. Man, born as a hunter, will—after one more generation of slavery—be able to liberate himself from the " unnatural " burden of agricultural food production, and devote himself to renewed ends that will challenge his intellect. The critical point is that the world food problem will have to be solved in the last third of the 20th century, during which time the population of the world is expected to double.)

290. CECA, La ***Consommation d'Energie dans Certaines Branches Industrielles,*** Document 2765/65 f, Communauté Européenne du Charbon et de l'Acier, Haute Autorité, Luxembourg, **5** May **1965. 45** p.

(A survey of information sources, methods of analysis, and principal results of CECA's forecast of fuel consumption, taking into account technological change.)

291. CECA, ***Der Energieverbrauch in bestimmten Industriezweigen - Entwurf eines zusammenfassenden Berichts,*** Band **II,** Kapitel 1, Der Energieverbrauch der Zementindustrie, Dokument 4485/65 d, Communauté Européenne du Charbon et de l'Acier, Haute Autorité, Luxembourg, June **1965.** (Internal document.)

(A part of the synthesis of technological forecasts of fuel consumption in different industrial sectors up to **1975.)**

292. CECA, CEE, and CEAA, ***Etude sur les perspectives énergétiques à long terme de la Communauté européenne,*** Haute Autorite de la Communauté Europeenne du Charbon et de l'Acier, Commission de la Communauté Économique EuropQnne, Commission de la CommunautC Européenne de l'Energie Atomique; Luxembourg **1964. 639** p.

(A comprehensive forecast in the energy field for the period **1965-1975,** taking into account technological change.)

293. CECA, ***Objectifs Généraux " Acier, "*** Memorandum sur les objectifs de **1965,** Méthodes d'élaboration et résultats détaillés; Communauté Européenne du Charbon et de l'Acier, Haute Autorité, Luxembourg **1962. 540** p.

(A five-year forecast of demand and of technological change in the steel industry of the member countries of the Community. A normative forecast which sets goals.)

294. CECA, ***Objectifs Généraux " Acier, "*** Rapport sur l'état d'exécution des objectifs généraux " acier " pour l'année **1965;** Communauté Européenne du Charbon et de l'Acier, Haute Autorité, Luxembourg, **1964. 109** p.

(A check-up on the fulfilment of the five-year normative forecast for the **1960-65** period, for the years **1960-63.)**

295. Clarke, Arthur C., ***Extraterrestrial Relays,*** in Wireless World, Oct. **1945.**

(The first proposal, on a scientific basis, to use artificial satellites in stationary orbits for communication, and a discussion of the characteristics of such a system. An example for technological forecasting that was not taken seriously at the time, but became a reality almost precisely as proposed.)

296. Clarke, J.S., ***The Outlook of an Engineer on Social Problems,*** Paper AD L **1/65,** Automobile Division, The Institution of Mechanical Engineers, London, **1964, 44** p.

(A comprehensive survey of future technological potentials in the automobile sector, in a framework of social factors, by Joseph Lucas's Chief Engineer.)

297. Colborn, Robert (ed.), ***Modern Science and Technology,*** Van Nostrand, Princeton, New Jersey, **1965.**

(A revised compilation of articles from " International Science and Technology, " mainly imaginative state-of-the-art reports with indications of future trends.)

297*a*. Cole, Dandridge M., ***Beyond Tomorrow - The Next 50 Years in Space,*** Amherst Press, Amherst, Wisconsin, **1965. 168** p.

(50,000 ton space ships for 10,000 passengers each; freight rockets started by means of linear electromagnetic acceleration; up to one million people could live in the interior of a hollow asteroid, 30 km long and 15 km wide, with sunlight reflected into it.)

298. Deutsche Bundesbahn, ***Vorstellungen des Vorstandes zur Verbesserung der wirtschaftlichen Lage,*** DB-Schriftenreihe, Folge **13,** Deutsche Bundesbahn, Frankfurt/Main (Federal Republic of Germany), **1** Sept. **1964. 64** p.
(Technological and economic forecasting by the Board of the German Federal Railways, including preliminary recommendations for an action programme.)

299. Diebold, John, ***Management and Railroad Cybernetics,*** presented before the International Union of Railways, on **4** Nov. **1963** in Paris; Diebold Group Professional Paper, The Diebold Group, Inc., New York, **1963. 13** p.
(A broad forecast of the future impact of information technology on railroad systems.)

300. Diebold, John, ***What's Ahead in Information Technology,*** Harvard Business Review, Sept./Oct. **1965.**
(We are on the threshold of an " information revolution " that will considerably affect the practice of management.)

301. Dubos, René, ***Mirage of Health : Utopias, Progress, and Biological Change,*** Harper and Bros., New York, **1959.**
(Not reviewed.)

302. Eddington, Sir Arthur, ***New Pathways in Science,*** Messenger Lectures **1934,** Cambridge University Press, London **1947 ;** Ann **Arbor** Paperbacks, University of Michigan **1959.**
(Contains a chapter on " Subatomic Energy, " written in **1932** and based on a speech the author gave at the World Power Conference in Berlin **1930,** which discusses the possibility of annihilation energy between protons and electrons—a mistaken conception, before the dicovery of anti-particles—and the possibility of nuclear fusion. The latter is correctly assessed to be feasible between hydrogen nuclei, with the energy yield assessed correctly, and the required temperatures almost correctly—20 million degrees instead of **100** million degrees Kelvin.)

303. ENEL, ***Relazione del Direttore Generale al Consiglio di Amministrazione sull'Attività dell'Ente nel 1964.*** Ente Nazionale per l'Energia Elettrica, Roma, April **1965. 464** p.
(The annual report of the director-general of the Italian nationalised utility companies, Prof. Angelini, including a substantial chapter " Previsioni e programmi " which contains considerable technological forecasting.)

304. EURATOM, ***Dokumentation - Lage und Perspektiven der Kernenergie in der europdischen Gemeinschaft,*** EURATOM, (Europaische Atomgemeinschaft), Brussels, June **1965, 274** p.
(A comprehensive background report on Euratom's nuclear energy forecast up to the year **2000,** with a detailed discussion of input information, methods, and conclusions. Some findings are not represented in the conclusions explicitly, but can be found in the discussion material. Lit. ref. **305** gives the conclusions in a political context.)

305. EURATOM, ***Erstes hinweisendes Programm für die europdische Atomgemeinschaft,*** Euratom Commission, Brussels, June **1965. 39** p.
(The summary of a broad technological forecast for nuclear energy up to the year **2000** which is documented in more detailed form in lit. ref. **304.)**

306. Gardner, John W., ***Electricity without Dynamos - The Coming Revolution in Power Generation,*** Pelican **Book** A **625,** Penguin Books, Harmondsworth, Middlesex, **1963. 158** p.
(A description of the state of the art and the prospects, on the basis of a " consensus of informed opinion, " for direct conversion from heat to electricity, especially fuel cells, magnetohydrodynamic, thermionic and thermoelectric generators. Written

when the wave of uncritical optimism in this field was at its peak, this book also neglects any thorough look at present and future economic environments. By 1966 the picture would have been seen differently.)

307. Gee, Cyril C., ***The Structure and Future Prospects of the Electronic-Based Industries in the United Kingdom,*** Heywood & Co., London 1960. 36 p.
(Stimulated by Mullard's conference on "The Changing Pattern of Industrial Electronics in the Sixties," London 1960. The main parts, bearing on technological forecasting, are "Areas of Future Growth," pp. 27-29 and "Problems Facing the Industry," pp. 29-33. The roles of micro-miniaturisation and of industrial electronics in 1965 have been fairly correctly predicted. As for computers, the forecast cryogenic elements in 1965 have not yet become reality. The need of a dynamic approach to selling is recognised, but nothing is said on demands upon future R & D.)

308. Guéron, J., ***et. at.*** (editors); ***The Economics of Nuclear Power,*** Vol. 1, in the series "Progress in Nuclear Energy," Pergamon Press, London 1956.
(In part, reprints of papers prepared for the Geneva Conference in 1955. Not very much direct technological forecasting, but the discussions of resources and needs are already on fairly solid grounds.)

309. Haase, R.H., ***Analysis of Some Land Transportation Vehicles - Today and Tomorrow,*** report P-2625, The RAND Corporation, Santa Monica, California, August 1962.
(A forerunner of a systems analysis approach reported more comprehensively in lit. ref. 131.)

310. ICAO, ***Air Freight - Trends and Developments in the World Air Freight Industry, A Preliminary Study and Forecast,*** Document 8235-C/937, International Civil Aviation Organisation, Montreal, Canada, 1962, 111 p.
(The forecast part concerns 1975. The impact of new technologies is one of the basic elements of the report.)

311. ICAO, ***The Economic Implications of the Introduction into Service of Long-Range Jet Aircraft,*** Document 7894-C/907, International Civil Aviation Organisation, Montreal, Canada, June 1958, 66 p.
(A thorough economic and technological forecast before the start of the large-scale introduction of commercial jet aircraft, with detailed quantitative forecasts up to 1961. These played a decisive role in the rapid introduction of jet aircraft.)

312. ICAO, ***North Atlantic Traffic Forecasts (March 1966),*** Circular 76-AT/11, International Civil Aviation Organisation, Montreal, Canada, March 1966, 33 p.
(Passenger, cargo, and air mail traffic forecasts for 1975, for the North-Atlantic region. Economy of operation, load factors, price trends are included. The impact of new technologies, including the introduction of supersonic jets in 1972 and 1974, is taken into account throughout the forecast.)

313. ICAO, ***Questions Relating to Outer Space,*** Working Paper C-WP/4316, 16 Nov. 1965, International Civil Aviation Organisation, Montreal, Canada, 11 p.
(A proposal for participation of ICAO in programmes for the exploration and use of outer space, including technological forecasting functions.)

314. ICAO, ***The Technical, Economic and Social Consequences of the Introduction into Commercial Service of Supersonic Aircraft - A Preliminary Study,*** Document 8087-C/925, International Civil Aviation Organisation, Montreal, Canada, Aug. 1960, 118 p. Addendum No. 2: A Summary of the Comments of Contracting States on the Preliminary Report, Supplemented by Material from other Sources, Document 8087-C/925, Add. No. 2, June 1962, 41 p.
(A technological forecast in the form of a complete systems analysis—including the support system, and various forms of impact. Due to proprietary considerations, the technical basis for this report was not complete.)

315. Industrial Research, ***Exploring the Sea, etc.,*** Series of articles in Industrial Research, March 1966, p. 7-114.

(Seven articles, whose authors include J.Y. Cousteau and W.A. Nierenberg, giving a broad outlook on the future development of oceanics, taking into account economic exploitation of underwater resources and military aspects.)

316. Institute of Radio Engineers, ***Communications and Electronics - 2012 A.D.,*** Proceedings of the IRE, Vol. ***50,*** No. ***5,*** May 1962, p. 562-656, The Institute of Radio Engineers, Inc. (since then incorporated in the IEEE—The Institute of Electrical and Electronics Engineers), New York.
(A series of 60 short articles, many of them by the foremost US scientists, engineers, and research managers in the field. A losely structured brain-storming effort that produced a lot of general philosophy, some logical extrapolation in concrete terms, and a few fascinating and remote—but probably attainable—ideas.)

317. Jantsch, Erich, ***Research and Development Trends in the Materials Sciences,*** Working paper DAS/SPR/66.3, OECD, Paris, 14 June 1966. 106 p.
(The reproduction of a paper, entirely written in 1963, mainly trying to point out research tasks, opportunities emerging from existing knowledge, and the future impact of inter-disciplinary developments. In particular, the importance of a " unified materials science " and the potential impact of biological research on materials developments, are pointed out. Economic implications are forecast only for a fraction of the wide materials field.)

318. Jantsch, Erich, ***Some Aspects of Potential Economic Implications of Current Research and Development Trends in the Energy Field,*** Working paper DAS/SPR/66.2, OECD, Paris, 31 May 1966. 126 p.
(A rehash written in 1963 of current ideas, and forecasts available in 1962-63. A " synoptic " and comprehensive view of the broad field, structured by a long-range evaluation of the resources aspect, provides the basis for the recognition of avenues to future developments and a discussion of broad economic implications up to the year 2000 and beyond).

319. Kármán, Theodor von, ***Towards New Horizons,*** report submitted on behalf of the US Air Force Scientific Advisory Group, 7 Nov. 1944.
(A " classic " in military technological forecasting and a forerunner of the later periodic US Air Force efforts. By attempting to recognise the alternative ways of developing gas turbine technology and to point out action points for various technical options, it became a guideline for research and development in the field of aircraft propulsion. Supersonic aircraft are forecast and the feasibility of ICBM's is recognised.)

320. Leach, Gerald, ***New Sources of Energy,*** Progress of Science Series, Phoenix House, London, 1965.
(A review of technological potentials in energy conversion).

321. Levy, Lillian (ed.), ***Space: Its impact on Man and Society,*** W.W. Norton & Co., New York, 1965.
(With contributions by President L.B. Johnson, James E. Webb, Glenn Seaborg, and others. A rather popularised account of forecast social implications, with some technological forecasting in satellite communication, weather control, nuclear space propulsion, medicine, food technology, etc.).

322. Litton Systems, Inc., ***US Defence Posture - Overview 1964-1974,*** publication No. 3373, Guidance and Control Systems Division, Litton Systems, Inc., June 1964.
(The political and military context of the US defense market over the next ten years.)

323. Lundberg, Bo K.O., ***Pros and Cons of Supersonic Aviation in Relation to Gains or Losses in the Combined Time/Comfort Consideration,*** Journal of The Royal Aeronautical Society, Vol. 68, No. ***645,*** Sept. 1964, p. 611-630.
(A " total systems analysis " approach by the Director-General of the Aeronautical Research Institute of Sweden. The conclusions are unfavourable to supersonic aviation for safety, noise and other reasons, examined in the context of economic and technical forecasts.)

324. Lundberg, Bo K.O., ***Speed and Safety in Civil Aviation,*** presented at the Third International Congress of the Aeronautical Sciences (ICAS 111), 27-31 August 1962, Stock-

holm. *Part I: Speed,* FFA Report 94 (1963), *Part II: Safety,* FFA Report 95 (1963), *Part III: Speed versus Safety; Concluding Remarks: Discussion,* FFA Report 96 (1964), Flygtekniska Forsoksanstalten—The Aeronautical Research Institute of Sweden, Stockholm.

(A comprehensive investigation of the technical and economic characteristics of supersonic aviation and its impact on economy and society in general. The author, Director-General of FFA, is highly concerned about safety, noise, and other factors and warns against the premature introduction of supersonic aviation. He plots the conditions for its successful introduction, and proposes a compromise for a transitional period. Transonic aviation—Mach 1.1 to 1.5—and hypersonic aviation—above Mach 5—are also considered briefly. A prominent example of technological forecasting on a broad basis, approaching "total systems analysis," and trying, in particular, to forecast the consequences for society.)

325. Mentzer, William C., *The Next 40 Years,* Mainliner, Vol. 10, No. 4, United Air Lines, Chicago, Ill., April 1966. 2 p.

(A 40-year forecast for the development of civilian aircraft technology and air traffic, by United Air Lines' Senior Vice-President, Engineering and Maintenance.)

326. Muller, H.J., *Out of the Night - A Biologist's View of the Future,* Victor Gollancz, London, 1936.

(Written in 1925, the main biological views expressed in this book date back to 1910 when the future Nobel Prize winning geneticist was still a student. Muller points far into a future which we are entering only now through molecular biology. This book made a profound impact by discussing the possibilities of eugenics and influencing genetic characteristics, and giving a bold view of the most penetrating "social invention" that one can think of even today. "The making of such inventions will be favoured when we have a system in which their value will be duly appreciated"—an early case for the formulation of social goals.)

321. Ogburn, William Fielding; with Adams, J.L., and Gilfillan, S. Colum, *The Social Effects of Aviation,* Houghton Mifflin Co., Boston, and Riverside Press, Cambridge, Mass., 1946.

(Contains two interesting general chapters, both apparently written by Gilfillan, "On Predicting the Future," pp. 32-57, and "On Predicting the Social Effects of Invention," pp. 58-82. The first distinguishes between prediction by measurement and prediction not based on measurement. The book contains generally very good technological forecasting, although it is intentionally vague on such subjects as the introduction of jet-aircraft for commercial traffic. However, prices are predicted to go down to 3 cents per passenger mile on transatlantic air traffic—which comes very close to actual conditions 20 years after the forecast was made. Many aspects of social impact are broadly discussed.)

328. OECD, *Energy Policy Problems and Objectives,* OECD, Paris, Aug. 1966.

(Includes an energy forecast, on an OECD regional and a global basis up to 1980, for nuclear energy up to 1985. The basis for the forecast was *(a)* an assessment of the general economic trend, and (*b*) a study of aggregated sectors, e.g. industry, transport, household, etc., with more detailed studies for some rapidly changing industrial sectors.)

329. Picard, Fernand, *The Future of Automobile Technique,* paper 980 A, presented at the International Automotive Engineering Congress, Detroit, Michigan, 11-15 Jan. 1965, Society of Automotive Engineers, New York. 14 p.

(A review of current and possible future developments.)

329*a*. Polak, Fred L., *The New World of Automation,* in Dutch, second printing, Sept. 1966. (Not reviewed).

330. PTT Switzerland, *Grundlagen für die Planung von Fernmeldeanlagen,* PTT, Berne (Switzerland) Nov. 1965, 33 p.

(A forecast up to the year 2000 for Swiss telecommunications and a brief discussion of the assumptions and methods used.)

331. Putnam, Palmer Cosslett, ***Energy in the Future,*** Van Nostrand, Princeton, **1953.** 107 p.
(An illustrative example of misleading technological forecasting by an AEC consultant and based on a study commissioned by AEC in **1949** to estimate plausible world demands for energy over the next **50** to 100 years. The basis of the estimates is the assumption that nuclear energy may cost twice as much as energy from fossil fuels and may then be used in certain areas and for certain purposes to an amount which will never exceed 10 to 20 per cent of total energy consumption. There is no attempt to study nuclear energy as a competitive alternative.)

332, Ramo, Simon (ed.), ***Peacetime Uses of Outer Space,*** McGraw-Hill, New **York, 1961.**
(Contributors include **L.V.** Berkner, E. Teller, W. Libby and other noted scientists. Broad technological forecasting comprising technical, social, political, and business views, and discussing implications in the following fields: communications, world navigation, earth travel, study of the universe, weather prediction, competitive private enterprise in space, nuclear energy, etc.

333. Samson Science Corporation, ***Microelectronics - Revolutionary Impact of New Technology,*** Samson Report No. 2, available from Samson Science Corporation, 270 Park Avenue, New York, N.Y., **1965.** 34 p.
(A very explicit discussion of the most important aspects of the advent of integrated circuits: structural changes in industry, vertical integration of production, competition between monolithic and hybrid technology, the position of IBM's Solid Logic Technology in the changing pattern, chances of leadership in the microelectronics industry, and future trends and impacts of the " obvious " and the " subtle " form.)

334. Samson Science Corporation, ***Satellite Communications - Comsat and the Industry,*** Samson Report No. 1, available from Samson Science Corporation, **270** Park Avenue, New York, N.Y., Dec. **1964. 84** p.
(A discussion of market trends is followed by a general market forecast up to **1975.** Ocean cables and communication satellites are compared on a thorough technical performance and cost analysis basis, with satellites showing marked advantages. The beginnings of commercial satellite systems and of military satellite systems are critically discussed and international agreements reviewed. The impact on industry in general in terms of new challenges and new opportunities, revenues and rates of satellite operation, and the financial outlook for Comsat are discussed, while a final chapter looks ahead into the more distant future. A comprehensive evaluation representing a " total systems analysis, " equally competent on technical and economic aspects.)

335. Sanders, Ralph, ***Project Plowshare - The Development of the Peaceful Uses of Nuclear Explosions,*** Public Affairs Press, Washington, **1962.**
(Includes a detailed discussion of economic potentials and economic, social, and political consequences.)

336. Schurr, Sam; and Marschak, Jacob, ***Economic Aspects of Atomic Power,*** published for the Cowles Commission for Research in Economics by Princeton University Press, Princeton, N.J., **1950.**
(A highly interesting example **of** technological forecasting on the basis of insufficient technical knowledge because of the secrecy at that time. The attempt to assess electricity generating costs on the basis of a careful 'evaluation of all non-classified statements available went completely astray because incomplete technical understanding led to two major errors: **(1)** breeder reactors were assumed which could burn up fissile and fertile material completely without any removal of the fuel except for the breeding gain—an AEC statement stressing the necessity of chemical reprocessing, fuel refabrication, etc., was ignored, The fuel cycle costs were thus calcuiated to **0.002** mills/kWh on the basis of $ 20/lb.U.; (2) it was assumed that " there is no information to support the view that the unit cost of these facilities will greatly decline with increases in plant capacity above **75 MW, "** although the available AEC estimates, in fact, did seem to support the now well-established strong effect of scaling. A range of **140** to **315** $/kW was assumed, and, on the basis of only **50** per cent load factor, **4** to **10.2** mills/kWh fixed costs were calculated. The discussion of the impact, however, is excellent and can be regarded as a " classic." Nine industrial sectors are carefully analysed with a view to three possible impacts: cost reductions, process changes,

changes in location. Further chapters deal with the impact on national and regional economies, and with the effect on the industrialisation of backward areas. **A** very good comparison between conventional and nuclear energy, and a discussion of the significance of different cost structures in conventional and nuclear power, are added. In general, the effects of nuclear power on the economy are not over-estimated—a one per cent increase in productivity, no substantial increase in power demand, etc.)

337. Scortecci, Antonio, ***Riflessioni sull'avenire della produzione siderurgica di massa e di qualità,*** presented at the University of Tokyo, **7** April **1965, on** the occasion of the 50th anniversary of the Iron and Steel Institute of Japan; La Metallurgica Italiana, Anno LVII, mensile n. **8,** agosto **1965,** p. **281-289.**
(A forecast on steel technology.)

338. Smith, Nicholas **M.,** ***Operations Research in the Next 20 Years: A Technological Forecast,*** Research Analysis Corporation, before **1965.**
(Not reviewed.)

339. Sporn, Philip, ***Electrical Power Demand and Supply in the United States, and the Role of Research in the Quarter-Century Ahead,*** Proceedings of the Institution of Electrical Engineers, Vol. **101,** Part 11, No. **82,** p. **390 ff.,** London, **1954.**
(An interesting discussion of a number of already well-known potential innovations and the conditions under which they could find broad economic incentives, for example heat pumps, solar energy, etc.—and conclusions for a future research strategy.)

340. Sporn, Philip, ***Research in Electric Power,*** Pergamon Press, Oxford, Macmillan, New York, **1966.**
(Not reviewed.)

341. Steel (Periodical), ***What Industry Hopes to Learn From Nature,*** Steel, **25** Nov. **1963.**
(Biotechnology may be the next great electronics growth market. ***An*** imaginative approach along lines that have not yet received the attention they merit—learning from Nature, instead of outdoing it as in the past.)

342. TEMPO, ***Future Navy Systems, Vol. I: Introduction to Political-Military Environment of Warfare,*** report **RM-61-TMP-95**, TEMPO—Technical Military Planning Operation, General Electric, Santa Barbara, California. **31** Dec. **1961, 83** p. Defense Documentation Center number **AD-401, 346.**
(The background to a complete systems study of naval warfare, determining missions and requirements from broad political, military, and geographic environments.)

343. Thirring, Hans, ***Energy for Man—Windmills to Nuclear Power,*** Indiana University Press, Bloomington, Ind., **1958.**
(A frequently quoted book, which contains only rather vague technological forecasting, but good thinking on energy resources and utilisation patterns. For some technologies, for example thermal machines, trend evaluations of important parameters are included.)

344. UK National Research Development Corporation, ***The Implications for Economic Growth of Research on New Materials,*** London, unclassified version planned to be published in **1967,** but becoming unlikely.
(Originally planned as fully-fledged technological forecasting in the materials sciences, this report seems to represent mainly a comprehensive national survey of new materials under development in the UK.)

345. United Nations, ***New Sources of Energy and Energy Development,*** Report on the United Nations Conference on New Sources of Energy (Solar Energy, Wind Power, Geothermal Energy), Rome (Italy), **21-31** August **1961;** United Nations, New York **1962.**
(The proceeding of a conference which included various technological forecasts in this field, mainly aligned to the needs and desires of developing countries.)

346. United Nations, ***Water Desalination in Developing Countries,*** 1 volume; French Version ***Le Dessalement de l'Eau dans les Pays en Voie de Développement,*** **3** volumes, both United Nations, New York, Sept. **1964.**

(An assessment of water needs and incentives for water desalination as well as of feasible technical solutions.)

347. US Atomic Energy Commission, ***Civilian Nuclear Power ... A report to the President-1962,*** AEC, Washington, D.C., 20 Nov. 1963.
(The optimistic long-range forecast going beyond 2000 A.D. on nuclear power, prepared by AEC, with the help of US industry. This report made a deep impact and may be considered the turning point between a period of gloomy outlook and the courageous start of large-scale nuclear power installation.)

348. US National Academy of Sciences—National Research Council, ***Economic Benefits from Oceanographic Research,*** Publication 1228, Committee on Oceanography, National Academy of Sciences—National Research Council, Washington D.C., 1954, 50 p. (Out of print).
(It is a pity that this first attempt of a cost/benefit analysis for a field of fundamental research which is now developing into an applied field goes astray due to an erroneous mathematical basis for the assessment. The economic analysis, using a discounted cash flow, approach to calculate the present net value of investment in oceanographic research, is outlined in an appendix; it is wrong in several respects, and assumes ***a priori*** that benefits from research increase continuously at a rate of 100 per cent per year, The results for benefits ranging from fisheries to long-range weather forecasting and near-shore recreation—indicating discounted benefit/cost ratios between 1.0 and 8.1, with a total average of 4.4—must be seen in the light of these ***apriori*** assumptions and are—alas—completely worthless.)

349. Wagle, B., ***Forecast of Future Transport Requirements in the United Kingdom,*** Esso Petroleum Co. Ltd., London 1965, paper submitted for publication to the Oxford Bulletin of Statistics. 46 p.
(A summary of the forecasts then available in this field, and a forecast for 1975, refining the Hall Committee report, which is believed to be overpessimistic. For example, 18.3 million passenger cars are forecast against 14 to 15.5 million forecast by the Hall Committee.)

350. Wolstenholme, Gordon (ed.), ***Man and his Future,*** a Ciba Foundation Volume, J. & A. Churchill Ltd., London, 1963. 410 p.
(The papers and discussions of a Ciba Foundation symposium which united 27 distinguished contributors from biology and medicine. The main subjects were: Evolution of Man (J. Huxley); World Food Resources (C. Clark, J.F. Brock); World Population (G Pincus, A.S. Parkes); Sociological Aspects (C.S. Coon, A. Glikson, D.M. MacKay); Health and Disease (A. Szent-Györgyi, H. Koprowski, A. Comfort); Eugenics and Genetics (H.J. Muller, J. Lederberg—both Nobel Laureates stress the negative feedback from cultural progress to genetic progress and call for social devices for democratic control and the ultimate application of eugenics on the basis of future progress in biology); Future of Mind (H. Hoagland, B. Chisholm); Ethical Considerations (J.B.S. Haldane),—A bibliography with 109 entries is added to the Report on this important symposium.)

351. Zebroski, E.L., The ***Timing of Large-scale Utilisation of Plutonium,*** paper presented at the Conference on Commercial Plutonium Fuels, 1-2 March, 1966, Washington D.C., General Electric Co., San José, Calif. 12 p.
(An outline of General Electric's forecast of the future development of nuclear power and the pace of the introduction of fast reactors. A "total system" approach shows the dependence of fast reactor economy on the development of water reactor economy in a transitory dual thermal and fast reactor economy, as well as the synergistic effect, i.e. a mutually beneficial improvement in the operating economics of water reactors.)

Sec also references: 119, 131, 190, 243.

B.10. ACTUAL TECHNOLOGICAL FORECASTS: SOCIAL AND NATIONAL GOALS AND IMPACTS

352. American Academy of Arts and Sciences, ***Working Papers of the Commission on the Year 2000***, Vol. I: Preliminary Statement; Transcripts of Commission Meetings 22-24 Oct. 1965 and 10-12 Febr. 1966; Vol. II: The Next Thirty-Four Years, a Context

for Speculation; Vol. III: Questions and Caveats about Forecasting; The Political Structure; Vol. IV: Values and Rights; Vol. V: Intellectual Institutions; The Life-Cycle; The International System. Commission of the Year 2000, American Academy of Arts and Sciences, Boston, Massachusetts, **1966** (private circulation only). A condensed version of the working papers will appear in the summer **1967** issue of Daedalus.

(Detailed working papers and discussions of which a synthesis will be published Volume III contains an article by D.A. Schon on "The Problem: Forecasting and Technological Forecasting," giving a negative view on the potential of technological forecasting and denying that it is widely practised.—The general aim of the Year 2000 Committee is to let the spirit roam freely in the area of broad issues of social technology—as its chairman, Daniel Bell, puts it: to gain the experience of a *Luftmensch.*)

353. American Scholar, ***The Electronic Revolution,*** series including articles by J. Bronowski, M. McLuhan etc., The American Scholar, Spring **1966.**

(Not reviewed.)

354. Baade, Fritz, ***Der Wettlauf zum Jahre 2000,*** 5th ed. **1962,** English translation: ***The Race to the Year 2000,*** Doubleday, Garden City, N.Y., **1962,** and The Cresset Press, London, **1962.**

(A global view which comprises relatively little direct technological forecasting, but provides good background for it in the following fields: demography, food-production, East-West race, manpower, energy, steel, education race. Not very imaginative.)

355. Barach, A.B., ***1975 and the Changes to Come,*** Harper & Brothers, New York, **1962.**

(Not reviewed.)

356. Bryson, Lyman, (ed.), ***Facing the Future's Risks—Studies Toward Predicting the Unforeseen.*** Report on a Conference Marking the 200th Anniversary of the Establishment of Mutual Insurance in America, New York **1952;** Harper & Brothers, New York **1953.**

(Mainly broad social and political issues are treated. The article by L.N. Ridenour on "Physical Science and the Future," see lit. ref. **14,** is of interest to technological forecasting.)

357. Bloomfield, Lincoln P. (ed.), ***Outer Space: Prospects for Man and Society,*** Prentice-Hall, Englewood Cliffs, N.J., **1962.**

(Not reviewed.)

358. Darwin, **Sir** Charles Galton, ***The Next Million Years,*** Doubleday, Garden City, N.Y. **1953.**

(A discussion of the population explosion in a Malthusian spirit. Darwin believes that no stabilisation over a long period is possible and that sooner or later the starving margin will appear in all areas, so that population will be again controlled by high death rates.)

359. Diebold Group, Inc., ***Automation: Impact and Implications,*** Communications Workers of America, AFL-CIO, Washington, April **1965. 182** p.

(Not reviewed.)

360. Diebold, John, Beyond ***Automation - Managerial Problems of an Exploding Technology,*** McGraw-Hill, New York, **1964.**

(The impact of future information technology.)

361. Diebold, John, ***Time Will Have No Stop,*** expected to be published in the **US** in **1967.**

(Social implications of information technology. The title is a response to Aldous Huxley's stipulation "Time Must Have a Stop.")

362. Dunlop, John *T. (ed.),* ***Automarion and Technological Change,*** The American Assembly (Columbia University), Spectrum Book **S-AA-7,** Prentice-Hall, Englewood Cliffs, N.J., **1962,** second printing Feb. **1965. 186** p.

(The papers and the final resolution of the Twenty-First American Assembly, 3-6 May, 1962, Columbia University. A rather general, not very well structured discussion of technological change and its impact on society. The resolution formulates recommendations for private and public policies " to improve significantly the results of the complex process of technological change.")

363. Friedrichs, Günter (ed.), ***Automation - Risiko und Chance,*** 2 volumes, Europäische Verlagsanstalt, Frankfurt/Main (Germany) 1966, 1172 p.

(The proceedings of a conference, sponsored by I.G. Metall—the German labour union for the manufacturing section—in Oberhausen in March 1965. Contributions are included from the American union leader, W.P. Reuther, N.W. Chamberlain, W. Claussen, M.S. Harris and O. Brenner. The general German union attitude to automation is that of suspicion and dramatisation of assumed future unemployment effects.)

363*a*. Fuller, R. Buckminster; and McHale, John, ***World Design Science Decade, 1965-1975,*** Document One: Inventory of World Resources, Human Trends and Needs (R.B. Fuller and J. McHale); Document Two: The Design Initiative (R.B. Fuller); Document Three: Comprehensive Thinking (R.B. Fuller); Document Four: The Ten Year Program (J. McHale). Published by the World Resources Inventory, Southern Illinois University, Carbondale, Illinois, 1963 to 1965.

(The first results from a continuous ten-year research programme, proposed by R.B. Fuller to the International Union of Architects in 1961, and sponsored by the Southern Illinois University. Its primary aims are outlined in Annex A.5.13.)

364. Gabor, Dennis, ***Inventing the Future,*** Secker & Warburg, London 1963, Pelican, Book A 663, Penguin Books, Harmondsworth, Middlesex, 1964. 199 p.

(The title of this book became the label of a world-wide movement of scientists and " futurists " who maintained that the future ought to be chosen from many possible futures. Starting from the three great dangers which our civilisation faces—nuclear war, overpopulation, and the Age of Leisure—a counter-strategy is developed to mobilise man's ability not only to survive but to enjoy life. The role of technology in this struggle is characterised by Gabor with the following words: " Till now man has been up against Nature; from now on he will be up against his own nature. " The author is Professor for Applied Electron Physics at the Imperial College of Science and Technology in London, and Fellow of the Royal Society—his ability to speak as an authority on scientific and technological subjects (and on the numerous well-chosen examples) adds to the value of this book which is already considered to be a " classic " exerting wide influence.)

365. Gilfillan, S. Colum, ***Social Effects of Inventions,*** in: ***US*** National Resources Committee, ***Technological Trends and National Policy,*** Part One, Section III, see lit. ref. 284.

(Deriving incentives for innovations from the point of view of social desires and needs, the author—who is remarkably successful in forecasting when he starts from the technical side, see lit. ref. 243—cannot always avoid the pitfalls of " wishful thinking, " against which he warns in lit. ref. 40.)

366. Gordon, Theodore, J., ***The Future,*** St. Martin's Press, New York, 1965.

(Not reviewed.)

367. Greenberger, Martin (ed.), ***Computers and the World of the Future,*** MIT Press, Cambridge, Massachusetts, 1962.

(Outstanding conference addresses by V. Bush, C.P. Snow, N. Wiener, and others.)

368. Hearle, Edward F.R., ***Electronic Data Processing for Cities - The Broad Look,*** Memorandum P-2714, The RAND Corporation, Santa Monica, California, February 1963, 11 p.

(A brief outline of the possibilities of technological advances contributing to a broad social goal.)

369. Keynes, John Maynard, ***Essays*** in ***Persuasion,*** Rupert Hart-Davis, London 1931, new ed. 1951.

(Part V, The Future, consists of two articles: " Clissold," pp. **349-357,** written in **1927-** comments on H.G. Wells' pessimistic " The World of William Clissold "—and " Economic Possibilities for Our Grandchildren, " pp. **358-373,** written in **1930.** The latter article, " taking wings into the future, " advances the famous economist's optimistic view that rapid economic progress was not slowing down because of the world economic crisis at that time. He stresses the importance of technical innovation, which will cause history to take a different course from that of earlier times. The economic problem is not the permanent problem of the human race and may be solved completely in **100** years.)

370. Lapp, Ralph E., ***Man and Space - The Next Decade,*** Secker & Warburg, London **1961.**
(An attempt to see the space problem in a social environment. For example, the large costs **of** flying beyond the moon will lead to co-operation between countries, etc. The problem of proper goals and objectives for the space programme is discussed—the change from an originally well-defined scientific and military goal to a more amorphous set of goals, including aspect of foreign policy, has led to an inner " stress " in the American space programme.)

371. Little, Arthur **D.,** Inc., ***Projective Economic Studies of New England,*** prepared as part of Comprehensive Planning Programme for Development and Conservation of Water Resources, for the **US** Army Engineer Division, New England Corps of Engineers, Waltham, Mass.; Arthur D. Little, Inc., Cambridge, Massachusetts, **1964/65, 528** p.
(A regional development forecast up to the year **2000,** taking into account the development of manufacturing industries, employment patterns, etc. Technological forecasting plays a peripheral role.)

372. Lundberg, Ferdinand, ***The Coming World Transformation,*** Doubleday, Garden City, N.Y., **1963.**
(Not reviewed.)

373. Mazlish, Bruce (ed.), ***The Railroad and the Space Program - An Exploration in Historical Analogy,*** in the Series Technology, Space, and Society, prepared by the American Academy of Arts and Sciences, The MIT Press, Cambridge, Massachusetts, **1965. 223** p.
(The first attempt at a systematic major application of historical analogy to a major " social innovation " of our time. A preface outlines the method, and the first chapter, by the editor, draws the conclusions. The other seven chapters are more or less railroad history, with little or no analogy to the space programme attempted.)

374. McLuhan, Marshall, ***Understanding Media : The Extensions of Man,*** McGraw-Hill Paperbacks, McGraw-Hill, New York **1965,** third printing Jan. **1966. 364** p.
(A visionary **book** by the Canadian sociologist and cultural critic developing the idea of the extension of man's central nervous system through electricity, following the extension of power through mechanisation and seeing the centuries of explosion and increasing specialisation now followed by the implosion of the electronic age. About a quarter of the chapters, in outlining the consequences of this change, contain some of the farthest-reaching technological forecasting to be found anywhere.)

375. Neumann, John von, ***Can We Survive Technology,*** Fortune, June **1955.**
(Not reviewed.)

376. Österreichische Volkspartei, ***Aktion 20,*** unpublished paper, Österreichische Volkspartei, Vienna, (Austria), Jan. **1966.**
(An initial framework for a 20-year normative forecast in the following areas: Education, Public Health, Legislation and Society, International Position, National Economy.—Subjects amenable to technological forecasting appear mainly under the last heading.)

377. Paine, Thomas **O.,** ***The City as an Information Network,*** address delivered at IEEE International Convention and Exhibition, on **22** March **1966,** in New York; paper 66-TMP-32, TEMPO Center for Advanced Studies, General Electric Company, Santa Barbara, California, **1966.** 8 p.
(A broad vision of technological progress in a framework of social goals.)

378. Philipson, Morris (ed.), ***Automation - Implications for the Future,*** Vintage Books **V-46,** Alfred A. Knopf and Random House, New York, **1962.** **456** p.

(Mainly an anthology of previously published articles, this book anticipates changes that automation will bring to economic, social, and political organisation. It occasionally forecasts specific technological progress and examines the implications for industry, labour, theory, government, the social sciences, education, and leisure. The **18** authors include J. Diebold, D. Gabor, A. Goldberg, S. Ramo, W.P. Reuther, N. Wiener. Part Two on " Implications for Theory, " including a discussion on the possibility of future " intelligent " machines, is perhaps of central interest for technological forecasting. In particular, an article by Dennis Gabor, " Inventing the Future " (not to be confused with his book with the same title and which does not include this article) will be of interest for problems of technological forecasting, investigating the guiding vision and the motive power of a few technological innovations, and outlining the idea of an electronic " predictor box " for trend evaluation.)

379. Réalités, ***Le Colloque*** de ***l'Avenir,*** Réalités, No. **245,** June **1966,** p. **49-64.**

(The first part, " Quarante spécialistes de dix pays différents explorent les chemins du futur " summarises, in a deplorably sketchy and journalistic way, the findings of a conference on the methodology of long-range forecasting which the periodical had convened in Paris, **29-30** March **1966.** Participants included M. Abrams, L. Armand, D. Bell, **O.** Helmer, B. de Jouvenel, P. Massé, P. Uri, but the **9** pages cite their publications rather than giving an account of the conference.—The second part, " Cinquante sages dont 25 prix Nobel et le Dalai Lama répondent aux questions qui passionnent l'Humanité " is supposed to represent a certain consensus on important questions in the social, political, economic and technical future; these are mixed with a number of questions of permanent and universal importance. Not even a list of the 50 " wise men " is given.)

380. Scientific American, ***Technology and Economic Development;*** contributors include Asa Briggs, Kingsley Davis, J.W. Feiss, F. Harbison, W. Leontief, E.S. Mason, R. Revelle, S.H. Schurr, N.S. Scrimshaw. Originally published as a symposium in the " Scientific American, " Sept. **1963** issue; in book form by Alfred A. Knopf, New York, **1963,** and Pelican Book A **761,** by Penguin Books, Harmondsworth, Middlesex (England) **1965, 237** p.

(Population, natural resources, education and problems of industrialisation seen in relation to the needs of developing countries. A bibliography of **65** items is included.)

381. Theil, Pierre, Pour ***que*** les ***Hommes vivent mieux,*** Hachette, Paris, **1958.**

(Forecasts in the social technology area, particularly in food technology.)

382. US National Aeronautics and Space Administration, ***Conference*** on ***Space, Science, and Urban Life,*** held in Oakland, California, **28-30** March **1963;** NASA report **SP-37,** Washington, D.C., **1964.**

(A high-level conference with government, science, and industry participation, exploring future potential applications of space exploration to daily life. Discussions centered around the " Space-Age City " and the broad application of new technologies to urban living. The city of Oakland expressed its ambition to become the first " Space-Age City. ")

383. US National Commission on Technology, Automation, and Economic Progress, ***Technology and American Economy,*** Vol. 1, Febr. **1966.** Available through Superintendent of Documents, US Government Printing Office, Washington, D.C., **20402.** **115** p.

(This Report to the President deals mainly with employment and income structure problems in the light of rapidly advancing automation and general technology. Particular interest may be found in comparing the carefully recorded dissenting views of industrialists and union leaders on certain problems. However, the extent of agreement attained is considered a very encouraging basis for more precise future formulations of the problem. Vol. **1** contains only the full text of the Commission's report. Further volumes, to be published, will contain the individual studies commissioned for this report, among them lit. ref. **183.)**

384. US President's Commission on National Goals, The ***Goals for Americans - Programs for Action in the Sixties,*** comprising the Report of the President's Commission on National Goals, and Chapters Submitted for the Consideration of the Commission, A Spectrum Book, Prentice-Hall, New York, **1960,** eighth printing Jan. **1964.** **372** p.

(This effort of the Eisenhower administration resulted in a broad and fairly comprehensive statement, with particular emphasis on **US** foreign policy, but remained rather vague concerning proposed action. A chapter on "Technological Change," by Thomas J. Watson, Jr., then President of IBM, advocated the formulation of social goals for technological development.)

See also references: **20, 284, 296, 300, 301, 309, 314, 321, 323, 324, 325, 326, 327, 332, 343, 345, 346, 350.**

B.11. Utopia and Science Fiction

385. Conklin, Groff (ed.), ***Great Science Fiction by Scientists,*** Collier Books, New York, **1962.** **313 p.**

(Short science fiction stories by **16** scientists, including A.C. Clarke, J.B.S. Haldane, J. Huxley, J.R. Pierce, L.N. Ridenour, L. Szilard, and N. Wiener. From a writer's point of view, few of them are "great." However, a few stories are interesting because they attempt to warn against the abuses of science, sometimes by ridiculing the methods of science today.)

386. Daedalus, ***Utopia,*** Daedalus (Journal of The American Academy of Arts and Sciences), Boston, Mass., spring **1965.**

(A broad discussion of the phenomenon of utopia, mainly from a social point of view. Includes an article by John R. Pierce on "Communication Technology and the Future.")

387. Huxley, Aldous, ***Brave New World,*** Albatross Modern Continental Library Vol. **47,** Hamburg **1934.**

(The famous science fiction work which gave birth to a pessimistic attitude towards the future and concern for long-range implication in the area of social technology.)

388. Mann-Borgese, Elisabeth, ***Ascent of Woman,*** German translation: ***Aufstieg der Frau - Abstieg des Mannes*?** List Verlag, Munich, **1966.**

(Optimistic utopia, by Thomas Mann's youngest daughter, based on confidence **in** biological and cultural evolution. Conditions resembling Huxley's "Brave New World", such as the artificial procreation and raising of children are viewed in a positive light and fit into the pattern of a future global super-organism which **will** evolve from a society in which collective consciousness dominates. Eventually, the two sexes will merge into one evolutionary pattern from female youth to male maturity which every human being will undergo.)

389. Szilard, Leo, ***The Voice of the Dolphins,*** and other stories, Simon and Schuster, New York, **1961, 123** p.

(Short science fiction stories by the famous physicist. The story "The Voice of the Dolphins" is a retrospective from the **1980's** with a serious undertone, demonstrating the need for long-range planning in political and social areas. "Report on Grand Central Terminal," also of value in a serious context, is a satire on scientific prejudice.)

B.Z2. International Co-operation and Problems of Developing Economies

390. Hollomon, J. Herbert, ***International Co-operation in Technological Progress,*** presented at the Symposium on International Co-operation in Advanced Technology, **2** May **1966,** Hanover, (Germany). **14** p.

(A speech by the **US** Assistant Secretary of Commerce for Science and Technology, listing the following broad issues for possible international co-operation : meteorology and atmospheric sciences, water resources, biomedicine, high speed transport, rapid industrial growth and urban concentration.)

391. Karaosmanoglu, A., ***Science Planning and Economic Planning,*** in : ***Scientific Research and Economic and Social Development,*** Proceedings of the Fourth Meeting of the National Directors of the Pilot Teams Project on Science and Economic Development, Paris, **16-17** Dec. **1965.** Working paper **DAS/SPR/66.1,** OECD, Paris, **17/28** June **1966.**

(The role of technological forecasting in developing economies is discussed and demonstrated through the example of OECD's Pilot Teams' Project. Particular emphasis is given to social requirements for technological change.)

392. United Nations Advisory Committee on the Application of Science and Technology to Development, ***Second Report,*** United Nations, New York, May **1965.**

(The following research areas contributing to the needs of the developing countries are selected: protein, population problems, water, desalination, breeding of salt-resistent plants.)

393. United Nations Advisory Committee on the Application of Science and Technology to Development, ***Third Report,*** Economic and Social Council, Official Record : Forty-First Session, Supplement No. **12,** United Nations, New York, May **1966, 124** p.

(Part **IV** deals with the application and adaptation of existing knowledge and the acquisition of new knowledge. Under the latter category, the following fields are discussed: food supply including questions of water resources and desalination, health, population problems, natural resources, industrialisation, housing and urban planning, transportation and communications, education, including new educational techniques.)

394. United Nations, ***Conference on the Application of Science and Technology for the Benefit of the Less Developed Areas,*** held in Geneva, Feb. **1963,** United Nations, New York **1964.**

(Not reviewed.)

395. **US** Senate, ***United States Foreign Policy—Possible Non-Military Scientific Developments and Their Potential Impact on Foreign Policy Problems of the United States,*** Washington D.C., **1959.**

(Contains, apart from a discussion of nuclear energy and other developments, an investigation into the economic implications of the synthesisation of natural materials, especially for raw material producing countries.)

See also reference **380.**

B.13. Periodical Publications

395*a*. ***Atomes,*** monthly (France).

(Occasional serious forecasts.)

395*b*. ***The Futurist,*** bimonthly, published by the World Future Society, P.O. Box **19285,** Twentieth Street Station, Washington, **D.C. 20036.**

(A " Newsletter for Tomorrow's World " which started in July **1966,** comprising feature articles, news, and bibliographical references. The February **1967** issue had grown to **16** pages.)

396. ***Znternational Science and Technology,*** monthly (US).

(State-of-the-art reports, with future trends.)

397. ***McGraw-Hill Yearbook of Science and Techolnogy***, McGraw-Hill, New York (US).

(Yearly previews, since **1961,** to be added to the McGraw-Hill Encyclopedia of Science and Technology, McGraw-Hill, New York, **1960.** They will be included in the new edition of the Encyclopedia.)

398. Neue Ziircher Zeitung, ***Technische Beilage***, weekly supplement (Switzerland).

(State-of-the-art reports, with future trends.)

399. ***New Scientist,*** weekly **(UK).**
(Specialises in collecting specific forecasts, and in proposing early interpretations of the potential value of scientific discoveries to technological developments.)

400. New York Times, ***Science Review,*** weekly supplement **(US).**
(Mainly fundamental science and technology.)

400*a*. ***Prognosen - Plane - Perspektiven,*** weekly, published by Institut fur Ziikunftsfragen, Vienna, Austria, started **4** Feb. **1967** later temporarily suspended.
(Short feature articles, news, and literature reviews in areas of interest to future planning.)

400*b*. ***Science Journal,*** monthly (UK).
(The October, **1967** issue will be devoted to a series of articles " Forecasting the Future," based on serious technological forecasting—see lit. ref. 279*a*.)

401. ***Scientific American,*** monthly **(US).**
(State-of-the-art reports, with future trends.)

For classified military publication series, and special subscription series put out by forecasting institutes and consulting firms, see also the following sections of Annex A:
A.1. **5, 7.** 8, **9. 12. 13, 14:**
A.2. **2; 4;** 5; .
A.3. **6.**

B.14. BIBLIOGRAPHIES AND LISTS OF INFORMATION SOURCES

402. Caldwell, Lynton **K.,** ***Science, Technology and Public Policy: A Selective and Annotated Bibliography 1945-1965.*** Preliminary Draft. Institute for Public Administration, Indiana University, Bloomington, Ind., 1 Nov. **1965.**
(A well annotated bibliography of more than 1,000 books in twelve broad subject categories of science policy, including " Nature and Impact of Technology," " Science, Politics, and Government " and others of importance for technological forecasting. **A** revised version, **1966,** includes articles from twenty periodicals.)

403. Comité de Liaisons des Centres Nationaux de Productivité des Pays Membres de la CEE, ***Sources d'Information Economique a la Disposition des Chefs d'Entreprise des Pays de la Communauté Europkenne Économique Dksireux de pratiquer une Gestion Prkvisionnelle,*** Comité de Liaison des Centres Nationaux de Productivité des Pays Membres de la CEE, Brussels **1964, 91** p.
(A list and brief description of centres, organisations, associations, banks, etc. able **to** furnish input material of a generally economic nature for purposes of forecasting.)

404. Institut fur Zukunftsfragen, ***Horizonte,*** Institut für Zukunftsfragen, Vienna, Austria.
(A quarterly bibliographical review, with indicative abstracts of publications of the future, mainly in social, political, and economic areas. Planned to start in **1967.)**

405. Johnston, R., ***The Factors Affecting Technical Innovation : Some Empirical Evidence,*** OECD, Directorate for Scientific Affairs, Paris, **5** March **1965** (Restricted) **34** p.
(A bibliography comprising 98 items preceded by a critical synthesis.)

406. Kamrany, Nake M., ***Economic Development Planning and Informations Systems: A Discussion and Bibliography,*** Report **SP-2167,** System Development Corporation, Santa Monica, Calif., **10** Jan. **1966, 90** p.
(A bibliography of close to **1000** items, preceded by a very short discussion of the application of computer-based information systems in economics of development planning. A large part of the bibliography, " Development Planning Methodologies, ·· includes publications having a bearing on technological forecasting.)

407. SÉDÉIS, ***Les Futuribles à travers livres et revues,*** in the following issues of Futuribles: No. **61 (1** July 1963**),** No. 67 **(10** Nov. 1963**),** No. **77 (10** May 1964**),** No. **83** (1 Nov. 1964**),** No. **104 (10** Nov. 1965**),** No. **107 (20** Dec. 1965**), SÉDÉIS -** Société d'Études et de Documentation Economiques, Industrielles et Sociales, Paris (France).

(200 very thorough informative abstracts of publications on the future, mainly in the social, political, and economic areas, with some bearing on technological forecasting.)

408. Smith, Bruce L.R., ***The Concept of Scientific Choice: A Brief Review of Literature,*** report P-3156, RAND Corporation, June 1965, 54 p. Clearinghouse for Federal Scientific and Technical Literature number AD 616,977.

(A selected bibliography of 53 items, preceded by a critical synthesis with footnotes referring to these and other publications.)

409. Stromer, Peter R., ***Long-Range Planning and Technological Forecasting: An Annotated Bibliography,*** Special Research Bibliography SRB-63-12, Lockheed Missiles and Space Company, Sunnyvale, California, Nov. 1963, 39 p. Clearinghouse for Federal Scientific and Technical Literature number AD-441,618; NASA Scientific and Technical Information Facility number N 64-22200. ***Supplement 1,*** special Research Bibliography 65-1, 1965, 33 p. Clearinghouse number AD-457,949, NASA number N 65-19831.

(96 entries in the main bibliography, and 77 in the supplement, all well annotated. Emphasis is on planning within the aerospace and defense industries.)

410. Thornton, S.F., ***Planning:*** A ***Bibliography,*** report TM-1391-00-01, System Development Corporation, Santa Monica, California, 14 February 1964, 36 p. Clearinghouse for Federal Scientific and Technical Literature number AD-341,331.

(The bibliography includes publications on forecasting.)

411. United Nations, A ***Select Bibliography on Industrial Research, from 1944 to June 1964,*** Reference Paper 1, prepared for the Inter-regional Seminar on Industrial Research and Development Institutes in Developing Countries, 30 Nov.-12 Dec. 1964, Beirut (Lebanon); Centre for Industrial Development, Department of Economic and Social Affairs, United Nations, New York, 1964, 37 p.

(References to 288 items, subdivided into seven broad subject matter groups.)

412. US National Science Foundation, ***Current Projects*** on ***Economic and Social Implications of Science and Technology 1964,*** Publication NSF 65-16, National Science Foundation, June 1965, 180 p. Available through Superintendent of Documents, US Government Printing Office, Washington, D.C. 20402.

(An excellent, annotated compilation of 405 research projects in the US, also indicating their form of publication. Many of these projects include elements of technological forecasting, especially those grouped in the sections " Impacts on Selected Industries," " Automation and Impacts on Labour," " Innovation, Including Impacts of Specific Inventions and New Processes," and " Decision-Making.")

413. Wasserman, Paul; and Silander, Fred S., ***Decision-Making: An Annotated Bibliography,*** with a ***Supplement, 1958-1963,*** Cornell University, Graduate School of Business and Public Administration, supplement published in 1964.

(Not reviewed. Possibly comprehensive, since decision theory started only about 1945.)

See also the following references: 83, 89, 91, 101, 104*a*, 116, 142, 183, 184, 243, 277, 350, 380.

B.15. AUTHOR INDEX TO BIBLIOGRAPHY[1]

1. The figures refer to the literature references in the bibliography.

*Annex **C***

LIST OF CONTACTS ESTABLISHED FOR THE PURPOSES OF THIS REPORT

This Annex contains a complete list of the contacts made for the purpose of the present investigation. The list is arranged by countries, in alphabetical order. In almost all cases visits were made to the actual addresses given in the list; sometimes, for practical reasons, discussions with the people responsible took place elsewhere. In a few cases, telephone conversations had to replace the planned visits, but were considered sufficient for inclusion in this list.

Institutions which kindly offered their help in establishing contacts in the respective countries are marked with an asterisk.

C.1. AUSTRIA
(8 Oct. 1965; 11 Feb. 1966)

Institut fur Zukunftsfragen, Goethegasse 1, Vienna 1. (Prof. Dr. Ernst F. Winter, Co-Director).

Metallwerk Plansee A.G., Reutte, Tirol. (Dr. W.M. Schwarzkopf, Exec. Vice-Pres.; Dr. Sedlatschek, Director, Res. Dept.).

C.2. BELGIUM
(9 and 16 Nov. 1965)

CEE - Communauté Economique Européenne (Common Market), Direction Générale des Affaires Économiques et Financières, 80, rue d'Arbon, Bruxelles **4.** (Georges Brondel, Head of the Energy Division; M. Molitor, Secretary of the Medium-Range Planning Committee.)

CNPS - Conseil National de la Politique Scientifique, 8, rue de la Science, Bruxelles **4.** (Jacques Wautrequin.)

Euratom - Communauté Européenne de l'Énergie Atomique, Direction Générale Économie et Industrie, **45,** rue Béliard, Bruxelles **4.** (J.C. Leclercq, Head, and M. van Meerwink, Division Programme nucléaire - politique énergétique).

European Research Associates (Union Carbide), **95,** rue Gatti Gamond, Bruxelles **18** (Uccle). (Roger M. Gillette, Managing Director).

Gevaert - Agfa N.V., Septestraat 27, Mortsel (Antwerpen). (Ir. J. Fierens, Research Director.)

C.3. CANADA
(12-13 May 1966)

Centre for Culture and Technology, University of Toronto, **96,** St. Joseph Street, Toronto **5,** Ont. (Prof. Marshall McLuhan, Head.)

ICAO - International Civil Aviation Organization, **1080** University Street, Montreal 3, P.Q. (T.S. Banes, Director, Air Navigation Bureau; J.A. Newton, Chief, Flight Branch; Dr. J.H. Heierman, Chief, Ground Branch; T.Y. Yang, Chief, Economics Section; A.D. Hayward, Economist; E.M. Lewis, Chief, External Relations.)

On **13** May **1966** a discussion meeting was arranged in Ottawa under the chairmanship of Mr. J.E. Orr, Industrial Research Adviser, Department of Industry, with the following participants:

Atomic Energy of Canada Ltd., Kent Building, 150 Kent Street, Ottawa, Ont. (L.R. Haywood, Vice-President, Engineering.)

Canada Packers Ltd., Executive Offices, St. Clair Avenue West, Toronto, Ont. (Dr. G.F. Clark, Vice-President.)

Canadian Industries Ltd., P.O. Box 10, Montreal, P.Q. (Dr. J.A. Bilton, Research Manager.)

The Consolidated Mining and Smelting Co. of Canada Ltd., 630 Dorchester Blvd. W., Montreal 2, P.Q. (R.B. Heath, Research and Corporate Development.)

Defence Research Board, Canadian Forces Headquarters, Ottawa 4, Ont. (Dr. G.S. Field, Vice Chairman—also Chairman, NATO Long-Term Scientific Studies Committee.)

Department of Citizenship and Immigration, Economics and Research Division, Laurier Building, 340 Laurier Ave. W., Ottawa, Ont. (G. Alexandrin.)

Department of Defence Production, General Services Branch, No. 4 Temp. Building, Ottawa, Ont. (M. Eliesen, Data Processing Division.)

*Department of Industry, Program Advisory Group, Office of the Industrial Research Advisor, MacDonald Building, 123 Slater Street, Ottawa 4, Ont. (J.L. Orr, Industrial Research Advisor; H.C. Douglas, Deputy Industrial Research Adviser; D.H.E. Cross; F.H. Lehberg.)

Department of Mines and Technical Surveys, Mines Branch, 555 Booth Street, Ottawa, Ont. (V.A. Haw, Special Projects Administration.)

Dominion Bureau of Statistics, Business Finance Division, Tunney's Pasture, Holland Avenue, Ottawa, Ont. (H. Stead, Scientific Expenditure Surveys.)

Dominion Tar and Chemical Co. Ltd., Sun Life Building, Montreal, P.Q. (Dr. C. Marchant, Director of Development.)

Dunlop Research Centre, Sheridan Park, Ont. (Dr. G.W. Tarbet.)

Economic Council of Canada, Royal Trust Building, 116 Albert Street, Ottawa, Ont. (A.H. Wilson.)

Ethyl Corporation of Canada Ltd., 48 St. Clair Avenue East, Toronto, Ont. (R.H. Shannon, Manager, Chemical Products Department.)

The Griffith Laboratories Ltd., 757 Pharmacy Avenue, Scarborough, Ont. (J.S. Wenzel, Vice-President, Operations.)

Imperial Oil Enterprises Ltd., P.O. Box 3022, Sarnia, Ont. (G.A. Purdy; R.G. Reid.)

The International Nickel Co. of Canada Ltd., 55 Yonge Street, Toronto 1, Ont. (L.S. Renzoni, Assistant Vice-President and Manager of Process Research.)

Litton Systems, 25 Cityview Drive, Rexdale, Ont. (Dr. J.J. Green, Director of Research.)

Maple Leaf Mills Ltd., 43 Junction Road, Toronto, Ont. (J.H. Hulse, Director of Research.)

National Energy Board, Colonel By Towers, 969 Bronson Avenue, Ottawa, Ont. (T.L. de Fayer, Director, Economics Branch; O.W. Hamilton, Chief, Markets & Forecasts Division; M. Schwarz, Markets & Forecasts Division.)

National Research Council, 100 Sussex Drive, Ottawa, Ont. (Dr. J.D. Babbitt and G.T. McColm, International Relations and Economic Studies; R.E. McBurney, Industrial Research Assistance; R. Scott, Technical Information Services.)

New Brunswick Research and Productivity Council, P.O. Box 1236, Fredericton, N.B. (M. Cowley.)

Northern Electric Co. Ltd., P.O. Box 3511, Station C, Ottawa, Ont. (J.A. Grant.)

Ontario Research Foundation, 43 Queen's Park Crescent East, Toronto 5, Ont. (J.D. Jones.)

Polymer Corporation Ltd., Sarnia, Ont. (E.L. Litchfield, Corporate Planning.)

Privy Council Office, Science Secretariat, East Block, Ottawa, Ont. (Dr. J.R. Whitehead, Deputy Director.)

Province of Ontario, Department of Economics and Planning, Toronto, Ont. (W.G.R. Cameron.)

Pulp and Paper Research Institute of Canada, 570 St. John's Road, Pointe Claire, P.Q. (Dr. L.R. Thiesmeyer, President; F. Stevens.)

Research Council of Alberta, 87th Ave. & 114th Street, Edmonton, Alberta. (Dr. E.J. Wiggins, Director of Research.)

Research Council of Manitoba, Norquay Building, Winnipeg 1, Manitoba. (D.W. Craik, Director.)

Saskatchewan Research Council, University of Saskatchewan, Saskatoon, Sask. (Dr. T.E. Warren, Director.)

United Aircraft of Canada Ltd., P.O. **Box** 10, Longueil, P.Q. (G. Valdmanis.)

C.4. FEDERAL REPUBLIC OF GERMANY
(13-15 Dec. 1965)

BBC - Brown, Boveri & Cie. Aktiengesellschaft, Kallstadter Strasse, Mannheim-Kafertal. (Dr. Depenbrock, Head, Department " New Products -- ; Mr. Weyss.)

Bundeswirtschaftsministerium (Federal Ministry of Economic Affairs), Bonn. (Min. Rat. Dr. Lotz.)

Deutsche Bundesbahn (German Federal Railways), Hauptverwaltung, Friedrich-Ebert-Anlage **43-45,** Frankfurt/Main. (Min. Rat Dipl. Ing. Hans Pottgiesser ; Bundesbahnoberrat Dipl. Ing. Kurt Bauermeister.)

Farbwerke Hœchst, Frankfurt-Hochst. (Dr. Dorrer and Dr. Karl Damaschke, Technische Direktionsabteilung.)

SEL - Standard Elektrik Lorenz A.G., Hellmuth-Hirth-Strasse **42,** Stuttgart-Zuffenhausen. (Erich Runge, Co-ordinator for Product Planning.)

Studiengruppe fur Systemforschung, Werderstrasse **35,** Heidelberg. (Dr. Helmut Krauch, Head; Reinhard Coenen; Mr. Czemper.)

C.5. FRANCE
(Jan./Feb. 1966)

BIPE - Bureau d'Informations et de Prévisions Economiques, **122,** avenue de Neuilly, Neuilly (Seine). **(H.** Aujac, Director.)

Centre d'Études Prospectives, **17,** rue d'Astorg, Paris. (Louis Villecourt.)

CGE - Compagnie Générale d'Électricité, **54,** rue La Boetie, Paris **8e.** (Gerard Lehmann, Scientific Director.)

Commissariat Général du Plan, **18,** rue de Martignac, Paris **7e.** (M. Lemerle.)

CSF - Compagnie Générale de Télégraphie sans Fil, Direction de la Prospective, Domaine de Corbeville, **91,** Orsay. (B. Blachier, Assistant Director.)

*Délégation Générale à la Recherche Scientifique et Technique, Service du Plan de Developpement, **103,** rue de l'Université, Paris **7e.** **(M.** Cognard, Head; Louis Villecourt.)

Ministbre des Armées, Centre de Prospective et d'Évaluations, **231,** Bld. St. Germain, Paris **7e.** (M. de l'Estoile, Head.)

Prof. Jacques Monod, Institut Pasteur, **25,** rue du Docteur-Roux, Paris **15e.**

NATO - North Atlantic Treaty Organisation, Place du Maréchal de Lattre de Tassigny, Paris **16e.** (Dr. John **L.** McLucas, Assistant Secretary-General for Research; Dr. Wattendorf; Dr. Schall.)

NATO - North Atlantic Treaty Organisation, AGARD—Advisory Group on Aerospace Research and Development, **64,** rue de Varenne, Paris **7e.** (Dr. Jones, Director.)

Régie Nationale des Usines Renault, Centre Technique, Direction des Etudes et Recherches, **112,** rue des Bons Raisins, Rueil (Seine-et-Oise). (Fernand Picard, Director).

*J. Saint-Geours, Director for Planning, Ministry of Finance, and Chairman of the temporary " Groupe Saint-Geours."

Saint-Gobain, Division Glaces, **62,** Bld. Victor-Hugo, Neuilly (Seine). (Gérard Pédraglio.)

Saint-Gobain, Techniques Nouvelles, **23,** bld. Georges-Clemenceau, Courbevoie (Seine). (Claude Oger, Head of Development Service.)

SÉDÉIS - Société d'Études et de Documentation Économiques Industrielles et Sociales, **205,** bld. Saint-Germain, Paris **7e.** (Bertrand de Jouvenel, Director General).

UNESCO - United Nations Educational, Scientific and Cultural Organization, place Fontenoy, Paris **7e.** ***(Y.*** de Hemptinne, Director.)

C.6. ISRAEL
(14-27 February 1966)

Agricultural Research Institute, Beit-Dagon. (Prof. Arnon, Director.)

Atomic Energy Commission, Tel-Aviv. (Prof. Ernst David Bergmann, Chiarman—since then retired.)

Bank of Israel, Jerusalem. (Dr. Dov Zussman.)

General Choref, Ministry of Defence, Jerusalem, and Chairman, National Commission on Automation.

Dead Sea Works, Sdom. (Mr. Shamil, Works Manager; Dr. Kenat, Head, Res. & Dev. Dept.).

Discount Bank, Investment Company, Tel-Aviv. (Dan Tolkovsky, Director.)

Prof. Dostrovski, Weizmann Institute, Rehovot; National Co-ordinator of Water Research.

Economic Planning Authority, Prime Minister's Office, Jerusalem. (Mr. Danieli.)

Elron Electronics Co., 88 Hagiborim Street, Haifa. (Mr. Galil, Director.)

Mr. S. Freier, Physics Department, Weizmann Institute, Rehovot.

Hebrew University, Jerusalem. (Prof. Amiran, Vice-President.)

Hebrew University, Kaplan School of Economic and Social Sciences, Jerusalem. (Dr. Yehezkel Dror.)

Hebrew University, Research and Development Authority and " Yissum " Research and Developinent Corporation, Jerusalem. (Prof. Gross, Chairman of the Authority.)

Israel Institute of Productivity, Tel-Aviv. (Mr. Meidan, Director.)

Israel Mining Industries, Laboratory, P.O. Box 313, Haifa. (Dr. Baniel, Director; Ir. Y. Araten, Director, New Fertilizers Division.)

Ministry of Foreign Affairs, Jerusalem. (Ya'acov Yannai, Deputy Director of Economic Affairs; Zvee Dover, Cultural Affairs.)

National Committee for Technological Manpower Forecasting, Jerusalem. (S. Ishai; Prof. Hanani.)

*National Council for Research and Development, Prime Minister's Office, Hakiria 3, Jerusalem, and 84, Hachashmonaim Street, Tel-Aviv. (Prof. Alexander Keynan, Chairman; S. Ishai; Dr. Lapidot; Dr. Braunstein; Ben Zvi; Mr. Eschel; Naomi Amzalak.)

National Physics Laboratory, Hebrew University, Jerusalem. (Prof. Harry Tabor, Director.)

National Water Planning Corporation, Tel-Aviv. (Mr. Gurevitch.)

Negev Institute for Arid Zone Research, P.O. Box 79, Be'er Sheva. (Mr. Schechter, Director; Mr. Matz, Head, Res. & Dev. Dept.)

Technion (Israel Institute of Technology), Haifa. (Mr. Goldberg, Director; Prof. Jules Cahen; Prof. Pinkas Naov; Prof. Ben Uri, Dept. of Electrical Engineering; Dr. Mordechai M. Levy, Dept. of Industrial and Management Engineering.)

Technion Research and Development Foundation, 59 Hagalil Street, Haifa. (Prof. Karni, Director; R. Zernik, Industrial Services.)

Timna Copper Mines, Eilat. (Mr. Weiss, Technical Manager; Theodore Balberyszski, Head of Research and Development.)

Weizmann Institute for Science, Rehovot. (Prof. Lifson, Academic Director; Prof. Gillis, Dean, Graduate School.)

Weizmann Institute for Science, " Yeda " Development Corporation, Rehovot. (Dr. Salomon, Managing Director; Prof. Taub.)

C.7. ITALY
(13-28 Oct. and 17-19 Dec. 1965)

ANIE - Associazione Nazionale Industrie Elettrotecniche ed Elettroniche, via Donizetti 30, Milano. (Prof. Ing. Giuseppe Bauchiero, Member of the Council.)

Prof. Adriano Buzzati-Traverso, Direttore, Laboratorio Internazionale di Genetica e Biofisica, CNR, via Claudio 1, Napoli.

*Centro di Specializzazione e Ricerche Economico-Agrarie per il Mezzogiorno, Università di Napoli e Cassa per il Mezzogiorno, Corso Garibaldi 100, Portici (Napoli). (Prof. Manlio Rossi Doria, Director.)

CNR - Consiglio Nazionale delle Ricerche, Ufficio Attivith di Ricerca di Interesse Industriale, piazzale Rodolfo Morandi **2,** Milano.

Confindustria - Confederazione Generale dell'Industria, piazza Venezia, Roma. (Dr. Mattei, Deputy Secretary-General; Dr. Orfeo Bosone.)

CSM - Centro Sperimentale Metallurgico, via Barberini **36,** Roma. (Prof. Oscar Masi, Director.)

ENEL - Ente Nazionale Energia Elettrica, Direzione Generale, via del Tritone **181,** Roma. (Prof. Ing. Arnaldo Angelini, Director General.)

ENEL - Ente Nazionale Energia Elettrica, Direzione per la Programmazione, via del Tritone **61,** Roma. (Ing. Carlo Giordani, Director.)

Fertilmacchine, Associazione Nazionale Commercianti di Prodotti per l'Agricoltura, piazza G.G. Belli **2,** Roma. (Prof. Bassanelli.)

FIAT S.p.A., Divisione Bilancio, Corso Marconi **10,** Torino. (Dott. Giuseppe Carbonaro, Director.)

FIAT S.p.A., LRCAA (Laboratories), Corso G. Agnelli **200,** Torino. (Ing. Carlo F. Bona, Director of FIAT Laboratories.)

*IRI - Istituto per la Ricostruzione Industriale, via Veneto 89, Roma. (Dott. Gaetano Cortesi, Director General; Ing. Guido Frigessi di Rattalma.)

Prof. Alfonso Liquori, Direttore, Istituto Chimico, Università di Napoli, via Mezzocannone **4,** Napoli.

*Ing. G. Mancinelli, Direttore, Istituto Ricerche Spaziale del CNR, via Serchio 9, Roma.

Ing. Gino Martinoli, piazza Sant' Erasmo **5,** Milano.

Ministero per la Ricerca Scientifica e Tecnologica, piazza della Minerva 38, Roma. (Dott. Rossi, Chief of Cabinet.)

Montecatini, Societh Generale per l'Industria Mineraria e Chimica (since then fusioned with the Societa Edison to form the new " Montecatini Edison S.p.A. "), via Filippo Turati **18,** Milano. (Prof. Luigi Morandi, Vice-Predident; Prof. Mazzanti, Head, Research Division; Dott. Paolo Oldano, Head, Planning Service; Dott. Umberto Colombo, Research Division.)

Ing. C. Olivetti S.p.A., Ivrea. (Ing. Sergio Descovich, Director of the Central Research Laboratory; E. Piol, Head, Central Office for Product Planning.)

Pirelli S.p.A., piazza Duca d'Aosta **3,** Milano (central offices), Albicocca factories. (Ing. Valentino Zerbini, Director of Rubber Research Laboratories.)

*Prof. Antonio Scortecci, Cattedra di Siderurgia, Facolta di Ingegneria, Università di Genova; private address: via Assarotti **56,** Genova.

SNAM - Societh Nazionale Metanodotti (ENI Group), Laboratori Riuniti Studi e Ricerche, San Donato Milanese—Metanopoli, c.p. **3757,** Milano. (Prof. Dino Dinelli, Director; Ing. Adriano Caprara, Head of Planning, ENI.)

Societa Italiana Telecomunicazioni Siemens S.p.A., piazzale Zavattari **12,** Milano. (Ing. Giorgio Dal Monte, Director General.)

*STET - Societh Torinese degli Esercizi Telefonici (now holding company of all national telecommunication companies), via Paesiello **27,** Roma. (Ing. Graziani; Ing. Sartorio.)

C.8. LUXEMBOURG

(8 November ***1965)***

CECA - Communauté Européenne de Charbon et de l'Acier, Haute Autorité, Direction Générale Economie et Energie, Direction " Etudes et Structure, " **29,** rue Aldringer, Luxembourg. (Pierre Maillet, Director; J.P. Abraham, Head of Energy Division.)

C.9. NETHERLANDS

(10-15 November ***1965)***

AKU - Algemene Kunstzijde Unie N.V., **76,** Velperweg, Arnhem. (Drs. Mulder, Head, Investment Planning Dept.; Mr. Minkema.)

BPM - Bataafse Internationale Petroleum Maatschappij N.V. (Royal Dutch/Shell Group-International Research Division, **21**, President Kennedylaan, Den Haag. (Ph. M. Huis) man, Head, Group Research Coordinator Office.)

ISYS - Informatie Systemen N.V. (Philips Group), **144,** Noordeinde, Den Haag. (Prof. Ir. J. M. **Unk,** President.)

Kamerlingh Onnes Laboratory, University of Leiden, **18,** Nieuwsteg, Leiden. (Prof. Dr. J. van den Handel, Assistant-Director.)

Organon N.V., ***6,*** Kloosterstraat, ***Oss.*** (Prof. Dr. M. Tausk, Director.)

PTT Bedrijf - Netherlands Postal and Telecommunication Services, **12,** Kortenaerkade, Den Haag. (H. Reinouds, Director-in-Chief of Financial and Economic Affairs; Mr. van Duren, Director, Research Laboratories.)

State Mines, Geleen. (Dr. C. van Heerden and Ir. P.H. de Bruijn, both Central Research Laboratories.)

Technical University Delft, Department of General Science, Subdivision Mathematics, **134,** Julianalaan, Delft. (Prof. Dr. Ir. L. Kosten.)

Technisch-Physische Dienst TH and TNO, 1, Stieltjesweg, Delft. (Ir. G.J. van Os, Adjoint Director.)

TNO - Central Organization for Applied Scientific Research in the Netherlands, **148,** Juliana van Stolberglaan, Den Haag. (Prof. Dr. W.H. Julius, President.)

TNO - Central Laboratory, **2,** Schoemakerstraat, Delft. (Prof. Dr. A.J. Staverman.)

*TNO - Economic Technical Department, **21,** Koningin Marialaan, Den Haag. (Drs. J.C. Gerritsen, Head; Drs. I. Pels.)

TNO - Department of Clinical Research of Medicaments, **148,** Juliana van Stolberglaan, Den Haag. (Dr. W.G. Zelvelder.)

C.10. SWEDEN
(22 ***Nov.-3 Dec. 1965)***

ASEA - Almanna Svenska Elektriska A.B., Vasteras. (Ing. Ralf Thorburn, Assistant, Technical Directorate; Ing. Knut Bonke, Manager, Admin. Dept., Central Laboratories ; Jan Ollner ; Kurt Oster.)

A.B. Bofors, Bofors-Karlskoga. (Ing. Sten Henstrom, Chief Engineer, Head, Design Dept. for Guns and Vehicles; Ing. Tord Krey, Chief Engineer, Head, Metallurgical Dept.; Dr. Erik Bengtsson, Director, Chemical Division; Ing. Stig Djure and Ing. Per-Erik Jarnholt, Research and Development, Electronics and Ammunition Division.)

L.M. Ericsson, Telefon A.B., L.M. Ericssonsvagen **4-8,** Midsommarkransen (Stockholm **32).** (Dr. C. Jacobaeus, Technical Director.)

FOA - Forsvarets Forskningsanstalt (Swedish Defense Research Establishment), Linnegatan **89,** Stockholm 80. (Dr. Martin Fehrm, Director General; K.G. Mattson.)

Forsvarsstaben (Swedish Defense Staff), Östermalmsgatan 87, Stockholm **90.** (Captain P. Rudberg.)

FTL - Forsvarets Teletekniska Laboratorium (Swedish Military Electronics Laboratory), Linnégatan **89,** Stockholm **80.** (Torsten Gussing, Director.)

A.B. Gotaverken, Stjarngatan **9,** Goteborg. (Jan Stefenson, Chief Engineer, Head, Engine Dept. ; Mr. Bjorkenstam, Head, Planning Dept.)

Husqvarna Vapenfabriken, Huskvarna. (Gosta Rehnqvist, Managing Director; Gunnar Brynge, Technical Director; Ivar Ljungberg ; Mr. Wickenberg ; Mr. Borg.)

Incentive A.B., Arsenalsgatan **4,** Stockholm. (Hans Wagner, Scientific-Technical Director.)

*IVA - **Ingeniorsvetenskapsakademien** (Royal Swedish Academy of Engineering Sciences), Grev Turegatan **14,** Stockholm **5.** (Prof. Sven Brohult, Director; A. Carlsson; Hans G. Forsberg.)

Axel Johnson institutet for industriforskning (Central Research Laboratory of the Johnson Group), Nynashamn. (Ing. Olof Hormander, Director.)

Bo Lundberg, Director General, Flygtekniska Forsoksanstalten (The Aeronautical Research Institute of Sweden), Ranhammarsvagen **12-14,** Bromma (Stockholm.)

Nordiska Armaturfabrikerna A.B., Gelbgjutaregatan **2,** Linkoping. (Ing. Thure Wilhelmsson, Technical Director.)

Ing. Gosta Rydbeck, President, Swedish National Committee IEC (International Electrotechnical Commission), Kontors-Center, Hagagatan **29,** Stockholm.

SAAB - Svenska Aeroplan Aktiebolaget, Linkoping. (Doz. Tore Gullstrand, Technical Director.)

SAS - Scandinavian Airlines System, Ulvsundavagen 193, Bromma flygplats, Bromma 10 (Stockholm). (Johan H. Paus, Director, Traffic; Mr. Isaakson, Commercial Research Manager.)

Statsradsberedningen, Forskningsberedningen (Science Advisory Council), Lilla Nygatan 1 (postal address: Mynttorget 2), Stockholm **2.** (Prof. Bror Rexed.)

Telestyrelsen, Kungliga (Royal Telecommunication Board), Brunkebergtorg **2,** Stockholm. (Dr. Hakan Sterky, Director General—since then retired.)

C.11. SWITZERLAND

(4-12 October and 15 December 1965)

Prof. Dr. Jakob Ackeret, ETH (Technical University), Chair for Aerodynamics, Zurich.

Battelle Memorial Institute, **7** route de Drize, **1227** Carouge-Genève. (Dr. Fontela, Head, Social Economic Research; Dr. Csillaghy; André Gabus; Dr. Clement Velay.)

BIGA - Bundesamt fur Industrie, Gewerbe und Arbeit, Bundesgasse **8,** Bern. (Dr. K. Wegmann, Deputy Director.)

A.G. Brown, Boveri & Cie., 5401 Baden. (Dr. Rudolf Sontheim, Delegate of the Board of Trustees; Dr. Ernst Jenny, Head, Thermal Development Laboratory.)

CIBA Aktiengesellschaft, Klybeckstrasse 141, 4000 Basel **7.** (Dr. Hans Joerg, Deputy Director in Charge of Corporate Planning.)

Commission Économique pour l'Europe (affiliated to UN), Palais des Nations, Genève. (J. Rudzinski, Research and Planning Division; Mr. Dilloway, Energy Division.)

Prof. Andreas Dreiding, University Zurich, Chemical Institute, Ramistrasse **76,** Zurich.

*Dr. Eduard Fueter, Neugut, **8820** Wadenswil.

Dr. Fritz Hummler, Delegate of the Board of Trustees, Ateliers de Construction Mécaniques de Vevey, Vevey; formerly also Eidgenossischer Delegierter fur Arbeitsbeschaffung und Kriegsvorsorge.

*Prof. R. Mercier, EPUL - École Polytechnique de l'Université de Lausanne, **33** avenue de Cour, Lausanne,

Meynadier & Cie., A.G., Vulkanstrasse 110, Zurich-Altstetten. (Dr. Eduard Buhl, Research Director.)

Nestlé Alimentana Afico, Research Laboratory, Entre deux Villes, Vevey. (Dr. Kobert Egli, Director.)

PTT - Swiss Postal and Telecommunication Services, Speichergasse *6*, Bern. (R. Trachsel, Head, Planning Section.)

Gebr. Sulzer, Winterthur. (Dr. de Haller, Research Director; Mr. Zublin, Director for Corporate Planning.)

Stanford Research Institute, European Office, Pelikanstrasse **37,** Zurich 1. (Dr. J. Olin, Director.)

C.*12.* UNITED KINGDOM

(10-22 January 1966)

Albright and Wilson Ltd., 1 Knightsbridge Green, London S.W.1. (W.E.K. Piercy, Director in Charge of Development.)

Prof. P.M.S. Blackett, President, The Royal Society, London; also Deputy Chairman, Advisory Council on Technology.

BP - The British Petroleum Company Ltd., Britannic House, Finsbury Circus, London E.C.2. (J.L. Gillam, Central Planning Dept.; J.N. Haresnape, Research Coordination Dept.; Mr. Duckworth.)

Ronald Brech Ltd., 18 Wimbledon High Street, London S.W. 20. (Ronald Brech.)

*Cabinet Office, Whitehall, London S.W.1. (Fergus **H.** Allen, Chief Scientific Officer; Dr. T. Swaine.)

CEGB - Central Electricity Generating Board, Sudbury House, **15** Newgate Street, London E.C.1. (Dr. **L.** Rotherham, Member for Research.)

CIBA Foundation, 41 Portland Place, London W.1. (A.V.S. de Reuck, Deputy Director.)

*Sir John Cockroft, The Master, Churchill College, Storey's Way, Cambridge.

Cryosystems Ltd., 40 Broadway, London S.W.l. (Lord Ironside, Manager,)

Department of Education and Science, Curzon Street, London W.1. (G.J. Spence, Secretary, Council for Scientific Policy.)

DOAE - Defence Operational Analysis Establishment, Byfleet, Surrey. (Mr. Brittain.)

Elliott Automation Ltd., 34 Portland Place, London W.1. (B. Asher, Group Economist.)

Esso Petroleum Company Ltd., Esso House, Victoria Street, London S.W.I. (D.M.A. Masterman, Corporate Planning Dept. A.J. Caines.)

Christopher Freeman, Director, Unit for the Study of Science Policy, University of Sussex, Falmer, Brighton, Sussex.

Prof. Dr. Ing. Dennis Gabor, Imperial College of Science and Technology, Dept. of Electrical Engineering, City and Guilds College, Exhibition Road, London S.W.7.

GEC - General Electric Co. Ltd., Hirst Research Centre, East Lane, Wembley, Middlesex. (Peter Alexander Demetriou.)

ICI - Imperial Chemical Industries Ltd., Imperial Chemical House, Millbank, London S.W.l. (Lord Beeching, Deputy-Chairman; A.G. Cooke, Central Res. & Dev. Dept.).

IRD - International Research and Development Co. Ltd. (Parsons Group), Fossway, Newcastle-upon-Tyne 6. (H. Rose, Research Manager.)

Joseph Lucas Ltd., Great King Street, Birmingham 19. (Dr. J.S. Clarke, Group Chief Engineer.)

Sir Harrie Massey, University College, London, Dept. of Physics, Gower Street, London W.C.1.; also Chairman, Council for Scientific Policy.

Ministry of Aviation, (now incorporated in Ministry of Technology), Horseguards Avenue, London S.W.I. (Sir Walter Cawood, Chief Scientist.)

Ministry of Defence, Whitehall, London S.W.1. (Dr. A.H. Cottrell, Deputy Chief Scientific Adviser, Studies; W.B.M. Lord, Assistant Chief Scientific Adviser, Research.)

Ministry of Technology, Millbank Tower, Millbank, London S.W.1. (Dr. J.B. Adams, Controller—now Member for Research, Atomic Energy Authority; Dr. Alcon C. Copisarow; D.H. Tompsett; Mr. Goat.)

Mullard Ltd. (Philips Group), Mullard House, Torrington Place, London W.C.I. (Clive Barwell, General Manager, Central Marketing Services; Dr. K. Hoselitz, Deputy Director, Mullard Research Laboratories; P.E. Senker, Manager, Economic and Market Research Dept.)

The New Scientist, Cromwell House, Fulwood Place, London W.C.I. (Nigel Calder, Editor.)

NRDC - National Research Development Corporation, Kingsgate House, 66-74 Victoria Street, London S.W.I. (Dr. Basil J.A. Bard, Member; M. Zvegintzov; Dr. Fendley.)

Dr. Max Perutz, Deputy Director, Medical Research Council Laboratory for Molecular Biology, Hills Road, Cambridge.

The Plessey Company Ltd., Vicarage Lane, Ilford, Essex. (D.H.C. Scholes, Technical Director.)

*Science Journal, Associated Iliffe Press Ltd., Dorset House, Stamford Street, London S.E.I. (Robin Clarke, Editor.)

Shell International Petroleum Co. Ltd., Group Oil Planning Co-ordination, Shell Centre, London S.E.I. (L.C. Kuiken, Planning Techniques, Supply and Planning; Mr. Jenkins, Environment, Supply and Planning.)

Smiths Industries Ltd., Aviation Division, Kelvin House, Wembley Park Drive, Wembley, Middlesex. (C.J.E. Hosegood, Financial Manager.)

Prof. Lord Todd, University Chemical Laboratory, Lensfield Road, Cambridge; formerly Chairman, Advisory Council on Scientific Policy.

Unilever Ltd., Research Division, Unilever House (New Bridge Street and Victoria Embankment), London. (Dr. D.H. Laney; A.C. Smith; Mr. Armstrong.)

Urwick Diebold Ltd., 40 Broadway, London S.W.I.

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Dean O. Bowman, Vice-President, Management Systems and Planning, Autonetics Division of North American Aviation;

Dean Harvey Brooks, Harvard University;

Dr. Robert Charpie, Director of Technology, Union Carbide Corp.;

Aaron Gellmann, Vice-President, Planning, North American Car Co.;

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Personal contacts which contributed information to this report, were established with the above-mentioned conference speakers as well as with:

Prof. James R. Bright, Harvard Univ., Grad. School of Business Adm.;
Prof. Norman Kaplan, Program of Policy Studies, George Washington Univ.
W.T. McInarnay, Senate Small Business Committee, Subcommittee on Science and Technology;
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SUBJECT INDEX

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