Scenarios of Air Transport Development to 1990 by SMIC 74— A New Cross-Impact Method*

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ABSTRACT

The purpose of this paper is to describe the results of the application of the SMIC 74 method to a study of the air transport development in the Paris area to 1990. SMIC 74 is a new cross-impact method that provides three kinds of results: (a) Consistent information on the events that may occur and influence the evolution of air transport, (b) Cardinal ranking of the possible air transport development scenarios, (c) Sensitivity analysis. This method helps the decision-maker to choose between alternative strategies. For more detailed information the reader should refer to [1–3, 5].

1. Framework of the Investigation

Just as it is possible to summarize past history by listing a sequence of salient happenings, so can we visualize possible futures by envisaging a series of impending events, which, if they materialize, will have determinant effects during the time range considered. This set of possible events constitutes a frame of reference containing as many different versions of what the future is likely to be as there are different combinations of those events. In practice, when we consider a system of N events (e_1, $e_2, \ldots, e_N$), that system implies 2^N possible combinations or scenarios. For instance, if we say that at a given date events $e_1, e_2, e_4, \ldots, e_N$ will have occurred, but not e_3, this corresponds to one of the 2^N possible scenarios.

1.1. STRATEGIC ISSUES

Everything is uncertain about the future, but the fact that what is desired will rarely happen. Nevertheless, the decision-maker is compelled to deal with three basic problems:

(a) What will happen, if s/he does nothing?
(b) What should s/he do in order to obtain the desired results?
(c) What can s/he do, considering the available means and the external contraints?

1.2. THE RESULTS GIVEN BY SMIC 74

SMIC 74 helps the decision-maker to deal with the three basic problems listed above. More precisely, the results consist of:

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A consistent set of probabilities for the events that may occur and influence the evolution of the system studied;

a cardinal ranking of possible scenarios for this system of events, so that, the area of plausible scenarios can be circumscribed by retaining only those which have a probability rating higher than zero;

within this plausible area, we can identify scenarios which are more probable than others, i.e., trend-based scenarios as opposed to divergent alternatives;

a strategic sensitivity analysis which consists of evaluating the impacts of action on an event through the estimate of the variation $\Delta P(j)$ of the probability of j $P(j)$ consequently on a variation $\Delta P(i)$ of the probability of i $P(i)$.

In conclusion SMIC 74 helps the decision-maker to choose between alternative strategies and to increase the probability ratings of his desired scenarios.

1.3. SMIC 74

1.3.1. Available Data

The principle underlying the method is extremely simple and is based on the assumption that the experts consulted are able to give opinions concerning:

The list (H) of the N separate events which are considered relevant to the exercise at hand

$$H = (e_1, e_2 \ldots e_N)$$

The probabilities $P(i)$ of the separate events $e(i)$, i.e., the probability of materialization of $e(i)$ within the period considered.

The conditional probabilities of the separate events taken in pairs

$$P(i/j) = \text{Probability of } i \text{ if } j \text{ occurs},$$
$$P(i/\bar{j}) = \text{Probability of } i \text{ if } j \text{ does not occur}.$$

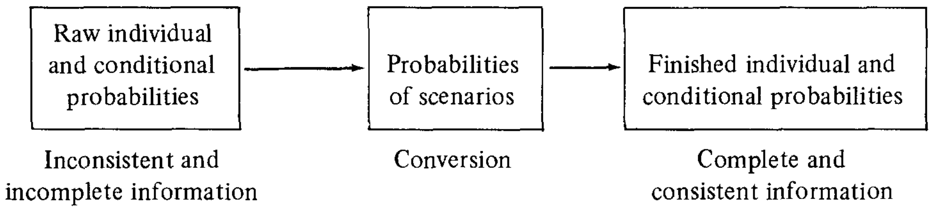
In practice, the opinions given in response to certain specific questions concerning non-independent events disclose some degree of inconsistency, thus, these "raw" opinions have to be corrected in such a way that the "finished" probabilities are in conformity with the following prescriptions.

$$\text{(a)}\ 0 \leqslant P(\ \ ) \leqslant 1,$$
$$\text{(b)}\ P(i \cdot j) = P(i/j)\,P(j) = P(j/i) \cdot P(i),$$
$$\text{(c)}\ P(i) = P(i/j)\,P(j) + P(i/\bar{j})\,(1 - P(j)).$$

1.3.2. Objectives and Principles of SMIC 74

The SMIC method is designed to enable checking of the expert's estimates for consistency with the above prescriptions. The raw estimates need to be corrected and converted into "finished" i.e., consistent estimates.

The principle which we adopted, starting with a body of inconsistent and incomplete information concerning the probability of separate events, was that of striving towards a consistent and complete "finished product" by considering the probabilities relating to the possible scenarios of the system composed by those separate events.



2. Application to a Forecast of the Air Transport Development in the Paris Area

We consider the events which could conceivably occur during the period 1975–1990. An event is defined as being either a germ of change or the threshold point of a trend. We select six such events, which in simplified form, are characteristic of the development over the study period of a number of trends specific to the system.

We have six separate events:

e_1 : *Total air tourists exceed 50 million.* This event sums up two trends : the growing number of passengers (business and tourism) and the increasing share of tourists.

e_2 : *Average number of air passengers per movement over 150.* This event integrates a minimum load factor and also an increase in average aircraft capacity by generalizing the use of large capacity planes.

e_3 : *Average delay for take-off over 20 minutes.* This event includes several phenomena, e.g., saturation of the air-space which can result from the prohibition of night-flights.

e_4 : *The decrease of the air fares in constant value of money over 3% per year.* I.e, a ticket which costs 100 francs in 1975 will only cost 63 francs in 1990. If this event does not occur it is unlikely that aircraft transport becomes a mass transport.

e_5 : *French GNP increases by more than 4% a year in volume during the period.* On one hand, economic growth involves additional air traffic either for business or for tourism motivations, and on the other hand, the growth of the number of aircraft movements over urban areas increases environmental problems.

e_6 : *Restrictive rules involve a fall of 20% in the potential volume of aircraft movements.* It may be a limit to the number of aircraft movements or a strict prohibition of night flights.

2.1. THE RAW OPINION INPUT

The panel which includes experts from Aeroport de Paris and SEMA replies to the following questions for each event $(i) = e_1, e_2, \ldots, e_6$

$P(ei)$	Probability that *ei* will occur during 1975–2000
$P(ei/ej)$	Probability that *ei* will occur given that *ei* has occurred in the period
$P(ei/\bar{e}j)$	Probability that *ei* will occur, given that *ej* has not occurred during the period (see Table 1 and Fig. 1)

This information supplied by the experts is inconsistent according to the classical prescriptions on probabilities (cf. 131). In order to obtain corrected results, we calculate

TABLE 1

Individual Probabilities ($P(i)$)

e_1	Total air tourists exceed 50 million	0.4
e_2	Average number of air passengers per movement over 150	0.7
e_3	Average delay for take off over 20 min.	0.6
e_4	The decrease in air fares in constant value of money over 3% per year	0.4
e_5	French GNP increases by more than 4% a year in volume during the period	0.6
e_6	Restrictive rules involve a fall of 20% in the potential volume of aircraft movements	0.7

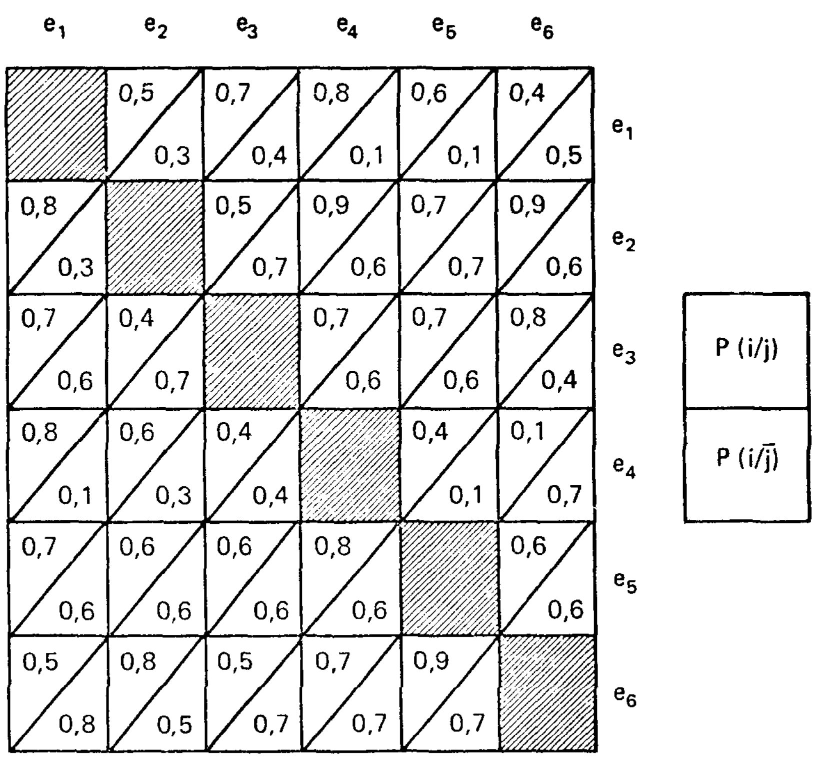


Fig. 1. Conditional probabilities.

the probabilities of the scenarios that were not expressed by the experts but are implicit in their overall replies to the questionnaire. These scenario probabilities are derived from the SMIC programme [5].

2.2. "FINISHED" INFORMATION

For convenience of explanation, we first of all describe the corrected results for the individual and conditional probabilities. The scenario probabilities which enabled us to adjust the original information are discussed subsequently (see Fig. 2).

In this example the individual probabilities are not perceptibly modified. Usually, changes are rather more important.

By contrast, a large number of the conditional probabilities are substantially amended; there is a simple explanation for this : it is often a great deal easier to give an individual probability than a conditional one. For instance : The probability that total air tourists exceed 50 million in 1990, given that at this time average delay for take-off is over 20 minutes, $P\ (e_1/e_3)$ falls from 0.7 to 0.5. (This probability was overestimated by the experts.)

On the contrary, $P\ (e_4/\bar{e}_5)$, the probability that the decrease in the air fares in constant value of money is over 3% per year, given that, at this time the growth of French GNP has been under 4% a year during the preceeding period, was underestimated because it rises from 0.1 to 0.28.

		e_1	e_2	e_3	e_4	e_5	e_6
0,41	e_1		0,55 / 0,14	0,50 / 0,29	0,83 / 0,13	0,50 / 0,25	0,35 / 0,57
0,67	e_2	0,89 / 0,51		0,57 / 0,83	0,85 / 0,55	0,66 / 0,69	0,77 / 0,42
0,60	e_3	0,72 / 0,52	0,51 / 0,79		0,63 / 0,58	0,60 / 0,60	0,63 / 0,54
0,40	e_4	0,81 / 0,11	0,51 / 0,18	0,42 / 0,38		0,47 / 0,28	0,31 / 0,62
0,64	e_5	0,78 / 0,54	0,63 / 0,67	0,64 / 0,64	0,75 / 0,57		0,66 / 0,61
0,70	e_6	0,59 / 0,78	0,81 / 0,48	0,73 / 0,66	0,54 / 0,81	0,72 / 0,68	

j

i . . . P (i/j) / P (i/$\bar{j}$)

Fig. 2.

2.3. SCENARIO PROBABILITY RATINGS

If we consider this set of six separate events, there are $2^6 = 6^4$ possible scenarios.

	e_1	e_2	e_3	e_4	e_5	e_6
E_1	1	1	1	1	1	1
E_2	0	1	1	1	1	1
E_3	1	0	1	1	1	1
.						
.						
.						
E_{12}	–	–	–	–	–	–
.						
.						
.						
E_{63}	1	0	0	0	0	0
E_{64}	0	0	0	0	0	0

Each scenario, E_k comprises an unknown probability Π_k with $\Sigma\ \Pi_k = 1$. As, they are exclusive each other and one is certain to occur.

2.3.1. Ranking of Scenarios

The possible scenarios can be ranked in terms of their probability of occurrence as follows :

E_{12} (001011) with $\Pi_{12} = 0.158$
E_{14} (010011) with $\Pi_{14} = 0.110$
E_{30} (010001) with $\Pi_{30} = 0.097$
E_1 (111111) with $\Pi_1 = 0.092$
E_{60} (001000) with $\Pi_{60} = 0.070$
E_{37} (110110) with $\Pi_{37} = 0.063$
E_{33} (111110) with $\Pi_{33} = 0.057$
E_{26} (011001) with $\Pi_{26} = 0.056$
E_{17} (111101) with $\Pi_{17} = 0.051$
E_9 (111011) with $\Pi_9 = 0.046$
E_5 (110111) with $\Pi_5 = 0.035$
E_{35} (101110) with $\Pi_{35} = 0.032$
E_{48} (000010) with $\Pi_{48} = 0.029$
E_{56} (000100) with $\Pi_{56} = 0.027$
E_{25} (111001) with $\Pi_{25} = 0.021$
E_6 (010111) with $\Pi_6 = 0.021$
E_{18} (011101) with $\Pi_{18} = 0.017$
E_{63} (100000) with $\Pi_{63} = 0.014$
E_{53} (110100) with $\Pi_{53} = 0.004$
E_{36} (001110) with $\Pi_{36} = 0.001$

Finally, 20 scenarios have a probability greater than zero; they constitute the plausible area. The probability of the remaining scenarios is equal to zero, i.e., they are not plausible. Nevertheless, it is of a great interest to comment upon these results.

Let us consider for instance :

E_{64} (000000) with $\Pi_{64} = 0$, The probability that none of the events studied takes place is equal to zero; this result shows that the set of events considered was adequate and relevant enough since one of them at least will occur during the period.

E_{40} (000110) with $\Pi_{40} = 0$. If the decrease in the air fares in constant value of money is over 3% per year and at the same time French GNP increases by more than 4% a year in volume during the period, at least one of the following events is certain to occur.

e_1 : Total air tourists exceed 50 million
e_2 : Average number of air passengers per movement over 150
e_3 : Average delay for take-off over 20 minutes
e_4 : The decrease of the air fares in constant value of money over 3% per year

E_8 (000111) with $\Pi_8 = 0$. It is not plausible that the three last events e_4, e_5, e_6 take place without at least one of the three first events e_1, e_2, e_3 occuring. If we consider e_4, e_5, e_6 as external variables and e_1, e_2, e_3 as specific variables of the air transport system, it means that this system is sensitive to external evolution.

2.3.2. The Trend-Based Scenarios

If we consider the first ten scenarios of the preceeding list there are more than 80 chances out of 100 that one of them will correspond to the situation in 1990. More precisely, E_{12} , E_{14} , E_{30} . E_1 constitutes the hard core of the trend-based scenarios. There being almost one chance out of two that one of them will take place in that range of time.

E_{12} (001011) with $\Pi_{12} = 0{,}158$. *Scenario of saturation without noticeable increasing of air traffic*. Total air tourists do not exceed 50 million and the average number of air passengers per movement is not over 150. Moreover the decrease in air fares is not perceptible. At the same time, the average delay for take off is over 20 minutes, the GNP increases rapidly and restrictive rules involve a fall of 20% in the potential volume of aircraft movement.

E_{14} (010011) with $\Pi_{14} = 0{,}110$. *Restrictive rules for movement limit the increase in total air traffic.* In this scenario e_2, e_5 and e_6 only occur. The GNP increases rapidly (e_5), and environmental problems in urban areas lead the government to put into force restrictive rules (e_6) which involves a decrease of 20% in potential aircraft movement. In order to enable a growth of the total number of passengers without increasing noticeably the number of aircraft movements, the air transport companies generalize the use of large capacity planes and the average number of passengers per movement is over 150. E_{30} (01001) with $\Pi_{30} = 0{,}097$. *Limited increase in GNP and in total air traffic* (this scenario is similar to the preceding one).

E_1 (111111) with $\Pi_1 = 0{,}092$. *It is the "conflict" scenario* in which every event takes place. In spite of restrictive rules total air traffic increases noticeably, but rapid economic growth intensifies environmental problems.

2.3.3. Divergent Scenarios

Divergent scenarios have a small probability of occurrence, for instance:

E_{33} (111110) with $\Pi_{33} = 0{,}057$. *Scenario of unlimited growth*. Restrictive rules are likely to be imposed on aircraft movements if the first five events take place, i.e., a rapid and unlimited increase in air traffic.

E_{48} (000010) with $\Pi_{48} = 0{,}029$. *Scenario of air transport independent of economic growth.* A rapid economic growth is unlikely to occur without having an impact on air transport.

2.4. STRATEGIC SENSITIVITY ANALYSIS

It is useful for the decision-maker to know all the possible scenarios of evolution of the system studied and his strategic decision-making process has to take into account the direct or indirect effects that each decision may have on the whole system.

It is noteworthy to isolate the decisions with "boomerang" effects. I.e., actions which have satisfactory primary effects, but, the secondary effects of which are opposite to the desired results. On the contrary, in order to obtain a given result, indirect actions upon the target variables are very often more efficient; such actions are called decisions with "rebound effects".

The sensitivity analysis consists of measuring the variation ΔP_j of P_j consequent on a variation ΔP_i of P_i. By constructing an elasticity matrix we are able to draw a distinction between events which are typically prime movers and events which are typically subordinated.

Elasticity coefficients measure the effects of action on each event, thus the decision-maker knows what he can do in order to increase the probability ratings of his desired scenarios. Elasticities

$$e_{ij} = \frac{\Delta P_j / P_j}{\Delta P_i / P_i}$$

are computed from the corrected results.

The following matrix summarizes the results :

	P (i) 1	2	3	4	5	6	$\sum_j \lvert e_{ij} \rvert$
1		– 0,12	– 0,24	– 0,47	– 0,23	– 0,54	1,60
2	0,40		– 0,10	0,24	– 0,71	– 0,21	2,66
3	– 0,28	– 0,96		– 0,64	– 0,74	– 0,64	3,26
4	0,37	– 0,20	– 0,39		– 0,30	– 0,61	1,87
5	– 0,13	– 0,71	– 0,74	– 0,26		– 0,69	2,53
6	– 1,32	– 0,09	– 0,73	– 1,60	– 0,76		4,50
$\sum \lvert e_{ij} \rvert$	2,50	2,08	3,20	3,21	2,74	2,69	

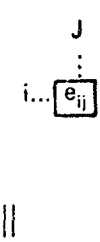


Fig. 3.

Notes on Matrix. The horizontal totals show that events e_3 (average delay for take-off over 20 minutes) and e_6 (restrictive rules) are more of a prime mover than the others with

$$\sum_j |e_{3j}| = 3{,}26 \text{ and } \sum_j |e_{6j}| = 4.50.$$

More over, we notice that

$$\sum_j |e_{4j}| = 1{,}87 \text{ and } \sum_j |e_{1j}| = 1.60.$$

The decrease in air fares and in the number of tourist passengers have not a strong impact on this system of events.

The vertical totals show that events e_3 and e_4 are the most conditioned of the six, with $\sum_i |e_{i3}| = 3.20$. This result is chiefly explained by the value of $e_{23} = -1.10$. It implies that if the probability of e_2 increases by 100% the probability of e_3 decreases by 110%. The use of large capacity planes decreases considerably the risk of saturation of air traffic control, with $\sum_i |e_{i4}| = 3.21$. This result is chiefly explained by the value of $e_{64} = 1.60$. It implies that if the probability of e_6 increases by 100%, the probability of e_4 decreases by 160%. The companies of air transport include in the air fares the taxes resulting from restrictive rules.

The event e_3 is both the prime mover and the most conditional. Consequently, saturation of air traffic control is the most sensitive event with respect to the future development of the air transport system.

Moreover, the following is noteworthy: $e_{61} = 1.32$, restrictive rules are unfavorable to the development of unscheduled flights; $e_{51} = -0.13$, air traffic for tourism motivations is not very sensitive to the rate of economic growth; $e_{24} = 0.24$, the use of large capacity planes does not involve a noticeable decrease in air fares.

3. Conclusion

The SMIC 74 method places the possible future scenarios in the "most probable" order and enables us to distinguish from among the plausible areas the trends based on the divergent scenarios for air transport development. This new cross-impact method constructs a coherent set of probabilities of the events which may occur and influence the air transport development.

Moreover, the sensitivity analysis shows that this method is also a way of evaluating the effects of action on each event and thus of helping to choose between alternative strategies. This consideration of external effects is in line with "technology assessement" thinking.

Finally, most of the results of SMIC 74 conform to the primary intuition, as for instance, the companies of air transport include in the air fares the taxes resulting from restrictive rules. Nevertheless, this method leads to counter-intuitive findings, such as the use of large capacity planes does not involve a noticeable decrease in air fares.

The main advantage of such a method is to question opinions which are widely accepted and to promote further reflection in order to improve the decision-making process.

The SMIC 74 method has already been applied by the Sema Metra International Group, by Paris Airport, by the French Atomic Energy Commission (C.E.A.), and by the French Electricity Board (E.D.F.).

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