SYSTEMS RESEARCH INSTITUTE
POLISH ACADEMY OF SCIENCES

INTERNATIONAL INSTITUTE FOR APPLIED SYSTEMS ANALYSIS

CONTRACTED STUDY AGREEMENT REG / POL / 1

"CONCEPTS AND TOOLS FOR STRATEGIC REGIONAL SOCIO-ECONOMIC CHANGE POLICY"

STUDY REPORT

PART 1

BACKGROUND METHODOLOGIES

COORDINATOR, IIASA: A. KOCHETKOV
COORDINATOR, SRI PAS: A.STRASZAK

ZTS/ZPZC/ZTSW 1-36/85

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Consisting of 3 Parts

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II. METHODOLOGY OF APPLICATION OF A CROSS-IMPACT TECHNIQUE TO PREPARATION OF THE REGIONAL DEVELOPMENT SCENARIO

by Andrzej Jakubowski

II.1. Introduction

One of the more promising new tools for long-range forecasting via scenario generation is cross-impact analysis. It can be defined as a method for revising subjectively estimated probabilities of future events in terms of estimated interactions among those events. The general notion of the method was first suggested by Gordon and Hayward (1968). Cross-impact analysis has now been expanded and applied to a number of forecasting areas.

The motivation for application of cross-impact method arises from a basic aspect of long-range forecasting. There are usually strong interactions among a set of potential technological or other events and/or among a set of potential economical and social developments. In assessing the likelihood that any given event or development will occur, the interactions with other events are clearly relevant. In other words, the need to consider interrelations among members of the event set, i.e. to consider changes in the likelihood of occurrence of a particular event produced by the occurrence or nonoccurrence of any or all of other events, is obvious. However, the mechanism of such an undertaking is conceptually a very difficult exercise because of the dimensionality of the problem: only the number of pairwise (i.e. first-order) interactions increases as the square of the number of events. Even if a matrix describing interactions is available - e.g. from estimates furnished by a panel of experts - the task of taking into account the implications of these interactions gets rapidly out of hand. Moreover, in more advanced studies, the higher-order interactions among the events should be also taken into consideration. Thus, in order to apply the cross-impact formalism in the real-life conditions, some computational aid is required to account for the large number of interdependencies.

It follows immediately from the above that from the point of view of the Polish Case Study analysed in this report, the computer-aided cross-impact method may be chosen as the most suitable one for the analysis and generation of the regional development scenarios and strategies. The considered Bełchatów-Szczerców region, in which the large strip mining and power generation developments are introduced, may be viewed as some large-scale system of strong positively or negatively interconnected events and developments. This results from the fact that developments of region in question is characterized by various technological, agricultural, broader economical and societal aspects which should be taken into account when optimal or rational development policies are to be investigated (see Chapter I, Part 2)

The problem is additionally complicated because of the necessity of taking into account the long time horizon, i.e. some 40 years, connected with the realization of the full cycle of large-scale lignite strip mining introduced in the considered region. Thus, the long-range forecasts of the system development are to be in our case investigated. Moreover, the introduction of the mentioned lignite trip mining and accompying consequences of changes in the socio-economic and natural resource environment makes some significant "perturbation" in the predominantly agricultural Bełchatów-Szczerców region. This makes it impossible to apply the traditional forecasting techniques based on trend extrapolation.

In the subsequent Sections of this Chapter we introduce and describe the methodology of some version of a computer-aided Cross-Impact method accompanied by a Delphi inquiry from the point of view of its application to the regional development scenario and strategy generation. The results of this application are presented in Chapter V, Part 2 .

In Section II.2 some comments on the existing cross-impact techniques and their modifications as well as the bibliography on this theme are given. The Section II.3 contains the theoretical foundations of the Turoff´s version of cross-impact model which has been chosen by the authors as the most appropriate method for the problem in question. In Section II.4 the subseqent stages of the procedure of development scenario generation, i.e. the information stage, the passive simulation and the active simulation, are described. Some final remarks are given in Section II.5.

II.2. Existing Techniques and their Modifications

As it has been pointed out, the cross-impact analysis is the most widely referenced procedure for scenario generation by investigating the effect of interaction of events in the future oriented studies. Since the initial paper on cross-impact has been published by Gordon and Hayward (1968), numerous variations on the basic theme have been investigated. Other papers specifically on cross-impact have been issued mainly in the USA in two journals: "Futures" and "Technological Forecasting and Social Change". There are those by Enzer (1970, 1971, 1972), Dalby (1971), Dalkey (1972), Turoff (1972), Kane (1972), Duval, Fontela, Gabus (1975), Duperrin, Godet (1975), Godet (1976), Mitchell, Tydeman (1976, 1978), Mitchell, Tydeman, Curnow (1977), Eymard (1977), Helmer (1972,1977,1981), Jensen (1981) and others. In some of these papers the analysis of practical applicability of the method has also been carried out. Very closely related to cross-impact is the cross-support formalism analysed in Ralph´s work (1971).

Despite many differences characterising a number of alternative approaches suggested in the literature, the general idea of the method may be summarized by the following steps:

(i) Preliminary estimation of the probabilities of individual events;

(ii) Estimation of the interdependences in terms of a cross-impact matrix;

(iii) A Monte Carlo sampling of chains of events in which the probability of an event in the chain is modified by the cross-impact of the previonsly "occurring" event in the chain; and

(iv) Reestimation of the original probability of each event in terms of the relative frequency of the "occurrence" of that event in the sample of chains.

The differences among the mentioned approaches lie in the realization of the steps (ii) and (iii); i.e. in the mode of evaluation of the cross-impact matrix and the mode of modification of the probabilities.

The so called cross-impact factors being the elements of the cross-impact matrix can be estimated directly - as in the Gordon´s approach (1968), or indirectly - as in the Turoff´s approach (1972)

In the first approach (the original method), modification of the probabilities is effected by a heuristic algorithm. Cross-impacts are rated on a scale of - 10 to + 10. Adjustment of the successive probabilities is computed via a family of arbitrarily introduced quadratic forms of relations between updated and original probabilities.

In the second approach experts are required to provide the conditional probabilities of occurrence of particular events given that other events have occurred before. Then, taking into account these indirect estimates of between-event interactions, the cross-impact factors are computed using the formula derived via some theoretical investigations related to the information theory and the statistical mechanics. Also the probabilities of events are modified using the so calledcross-impact relationship obtained in the course of these investigations (for details see Section II.3). The second approach is conceptually clearer than the first, and it removes some of the arbitrariness associated with the first one.

The significant effort related to resolving the pairwise consistency of the estimates provided by experts has been also undertaken. Duperrin and Godet (1975) achieved this pairwise consistency by adjusting both original probability estimates and conditional probability estimates in their SMIC-74 fitting algorithm. It has been developed on the basis of the quadratic programming technique. In this approach the analyst minimizes the square of the difference between the joint probabilities which result from experts' opinions on the original and the conditional probabilities, and the theoretical probability factors which may be expressed in terms of the scenario probabilities. Some modifications of this method have been made by Mitchell and Tydeman (1976,1978) and Mitchell, Tydeman and Curnow (1977).

The further comparison of a number of alternative approaches related to the cross-impact analysis, as well as the review of bibliography one can find in the literature; see e.g. Duval, Fontela, Gaubus (1974), Kelly (1976), McLean (1976) and Alter (1979).

II.3. Theoretical Foundations of the Turoff´s Version of Cross-Impact Method

In this section we present the Turoff´s version (1972) of the cross-impact method. It has been chosen by the authors from the widely referenced in the literature cross-impact procedures as the most adequate method for the considered regional development scenario generation. The justification of it is that the Turoff´s approach was developed specifically for restructuring the cross-impact formalism in a manner suitable for use on an interactive computer terminal. The method makes it possible for the user to be able to modify or iterate on his estimates until he feels that the conclusions inferred from these estimates are consistent with his views. Some modifications of the Turoff´s version of the cross-impact method have been also made. They are connected with the necessity of taking into account some specific aspects of the considered regional development problem; the details are given in the subsequent section, where the development scenario preparation procedure is analysed.

The theoretical foundations of the method considered are the following:

Let us consider the set of N events $\{e_1,...,e_i,...,e_N\}$ which are to be taken into account when the given scenario of the system development in the time horizon T is prepared. We assume that this set of events defines the future (a priori unknown) state of the analysed system. We also assume that events to be utilized in the Turoff´s version of the cross-impact analysis (1972) are characterized by the following two properties:

(i) each event e_i (i=1,...,N) is expected to happen only once in the interval of time T under consideration (i.e. nonrecurrent events are considered).

(ii) any event e_i (i=1,...,N) may not occur at all in the time interval T.

If one holds to a classical "frequency" definition of probability then it is, of course, pointless to talk about the probability of nonrecurrent event. We, therefore, assume an acceptance of the concept of a subjective probability estimate having meaning for nonrecurrent events.

If we are considering N nonrecurrent events in the cross-impact method then there are 2^N distinct outcomes spanning the range from the state where none of the events have occurred to the state where all of them have occurred. Thus, for the set of N events there are 2^N possible scenarios of the system development if one ignores the ordering of event outcomes and permits only binary outcomes, i.e. occurrence or nonoccurrence.

It is assumed throughout this discussion that the set $\{e_1,\ldots,e_i,\ldots,e_N\}$ contains all the events which are crucial to the problem of forecasting of the future state of the analysed system. This state may of course be influenced by other events which are not taken into account within the given set. For simplicity we assume that these events can be considered as the,constant in time, impact of the environment.

Each of the events e_i (i=1,...N) can occur with the unknown probality.

$$P_i = P_i\ (e_i)\ ,\quad i=1,\ldots,N. \tag{II.1}$$

We do also not know the conditional probabilities

$$R_{ij} = P\ (e_i|e_j)\ ;\ i,j=1,\ldots N\ ;\ i\neq j \tag{II.2}$$

of occurrence of the event e_i, given certainty of occurrence of the j-th event; as well as higher-order conditional probabilities

$$\begin{aligned} &P\ (e_i|e_j,\ e_k)\ ;\ i,j,k=1,\ldots,N\ ;\ i\neq j\neq k\ , \\ &\vdots \\ &P\ (e_i|e_1,\ldots,\ e_{i-1},\ e_{i+1},\ldots,e_N)\ ,\ i=1,\ldots N. \end{aligned} \tag{II.3}$$

Thus in order to obtain the probability of occurrence of each scenario, at least 2^N distinct pieces of information connected with the above data are required. However, it has been found that experts experience great difficulties in estimating all the prior and conditional probabilities mentioned. So, some simplifications are to be made. In cross-impact analysis we usually ignore the higher-order conditionals assuming that their impact on the accuracy of the results is of no great importance.

Once the event set $\{e_i, i=1,\ldots,N\}$ is specified by experts, the Turoff's procedure requires answering of two questions

(i) The first question which is asked for all N events is: "What is the probability that an event e_i occurs in the interval of time from now to some specified point T in the future ?"

(ii) The second cross-impact question is asked for the remaining (N-1) events relative to a j-th event: "What is your answer to question (i) if you assume that it is certain to all concerned that event e_j will occur before the time point t_i $(t_i < T)$ in which you have considered the chance of occurrence of the event e_i?"

As the result of the answers to the questions posed we obtain:

- The set of the prior probabilities

$$P_i^o = P^o(e_i) \; ; \; i = 1, \ldots, N \qquad \text{(II.4)}$$

of occurrence of particular events e_i in the time period T, and

- The set of the conditional probabilities

$$R_{ij} = P(e_i | e_j) \; ; \; i,j = 1, \ldots, N \; ; \; i \neq j \qquad \text{(II.5)}$$

taking into account the 1-st order interactions among the considered events.

These probabilities form the matrix $\underline{R}$ which is shown in Table II.1.

$$\underline{R} = \left[R_{ij}\right] = \begin{bmatrix} P^o(e_1) & \ldots & P(e_1 | e_N) \\ P(e_2 | e_1) & & P(e_2 | e_N) \\ \cdot & & \cdot \\ \cdot & & \cdot \\ \cdot & & \cdot \\ P(e_N | e_1) & \ldots & P^o(e_N) \end{bmatrix}$$

TABLE II.1. The form of the matrix $\underline{R}$ of the prior and conditional probabilities.

It should be pointed out that the so-called "conditional probabilities" derived from the second cross-impact question are not the conditional probabilities in terms of formal probability theory; the appropriate axioms are usually not satisfied. Rather the answer to the second cross-impact question might better be termed as a "causal probability" which provides a relative measure of the degree of casual impact one event has upon another; see Turoff (1972) and Mitchell, Tydeman (1978). However, the term "conditional probability" has become so common in a lay sense that it is often easier to communicate and obtain estimates by referring to the answers to the question posed as "conditional probabilities".

The main goal of the cross-impact method considered is to revise estimated probabilities of future events on the basis of obtained set of prior and conditional probabilities; i.e. P_i^o and R_{ij} ; i,j=1,...N ; i≠ j. If we get modified probabilities P_i (i=1,...N) of considered events, taking into account all possible pairwise interactions among them, we will be able to determine a likely scenario of development of the analysed system. Note that due to the simplified assumptions adopted - we consider only the 1-st order interactions among the events - there is no guarantee that the most likely scenario will be generated.

Since we are trying to analyse a problem requiring 2^N items of information for a complete solution with just N^2 items of information, it would, therefore, seem that any approach to the analysis of the problem is an aproximation. Also, there does not appear to be any explicit test which will judge one approach to be better than another. One significant measure of utility is the ease with which estimators can supply estimates and whether they feel that the consequences, inferred by the approach from their estimates, adequately represent their view of the future.

For justification of further results, the following reasoning originally carried out by M. Turoff (1972), may serve.

Assume that the event set $\{e_i;\ i=1,...,N\}$ represents a state vector of the system under observation. We may, in fact, explicitly define the state of this system as a binary "message" composed of a binary bit for each event. A zero bit in the i-th position will indicate that the event e_i has not occurred and a one bit will indicate that it has occurred. At the present time the message constains all zeros since these events have not yet occurred.

We may further assume that there exists a set of probabilities $\{P_i\ ,\ i=1,...,N\}$ which indicate the likelihood of finding a one in an event position when we "read the message" at some future time T. These probabilities are therefore implicit functions of the time interval $[0,T]$, which begins with evaluation of values of the probabilities and ends with planned observation of the contents of the message. We also assume that the values of P_i (i=1,...N) take into account the interactions, i.e. causal relationships, if any, whereby some events may influence the occurrence or nonoccurrence of the other ones.

From the information theory one gets an expression for the information given at the beginning of the time interval with respect to the contents of our message at the end of the time interval:

$$I = \sum_{i=1}^{N} \left[P_i \ln P_i + (1-P_i) \ln (1-P_i) \right] \qquad (II.6)$$

The form of the above expression is based upon the fact that nonoccurrence as well as occurrence of an event, provide information. This expression has a minimum for all P´s equal 0.5, corresponding to a complete lack of knowledge about the likelihood of occurrence. The maximum occurs when all the P′s are either one or zero which implies complete certainty as to the occurrence or nonoccurrence of the events.

The causal relationship (i.e. cross-impact) whereby one event influences the occurrence of the other ones can be assessed in the following way: if the events are independent the probability of receiving any particular message (vector of events) is

$$\mathbb{P}(k) = \prod_{l \in S} P_l \prod_{m \notin S} (1-P_m) \quad ; \quad k=1,\dots,2^N , \qquad (II.7)$$

where the index l ranges over those events which occur (subset S) in the k-th message and m ranges over those events which do not occur (not in S) ; $\mathbb{P}(k)$ denotes the probability of the k-th scenario. The sum of the probabilities $\mathbb{P}(k)$ over all the 2^N scenarios is equal to one. In this case the probabilities P_i are directly equal to the prior probabilities P_i^o obtained as the answer to the first of the cross-impact questions; i.e. the question (i).

Since the events e_i are not necessarily independent and certain messages may be more or less likely than the quantity determined by (II.7), we introduce a set of weights W′s and define the probability of obtaining the k-th outcome of the 2^N as:

$$\mathbb{P}(k) = W_k \prod_{l \in S} P_l \prod_{m \notin S} (1-P_m) \quad ; \quad k=1,\dots,2^N . \qquad (II.8)$$

Formally the weights W_k may be viewed as made up of a complex expression of conditional probabilities of the form (II.2), (II.3).

It is still true, however, that

$$\sum_{k=1}^{2^N} \mathbb{P}(k) = 1 \qquad (II.9)$$

We now rewrite equation (II.9) utilizing (II.8) and a new set of 2^N constants G's as:

$$G_o + \sum_{i=1}^{N} G_i P_i + \sum_{i}\sum_{j>i} G_{ij} P_i P_j + \sum_{i}\sum_{j>i}\sum_{k>j} G_{ijk} P_i P_j P_k +$$

$$+ \dots + G_{12\dots N} \cdot P_1 P_2 \dots P_N = 1 \qquad \text{(II.10)}$$

Each of the G's in the above expression is uniquely defined as a linear combination of the W's in equation (II.8).

We now consider the problem of maximization (with respect to P_i) of the expression (II.6) for the total information under the constraint (II.10). The solution to this problem results in the set of updated probabilities $\{P_i;\ i=1,\dots,N\}$.

Using the Lagrange approach and taking the differentials with respect to P_i we have, for any particular event e_i:

$$\ln\left(\frac{P_i}{1-P_i}\right) = \lambda \Big[G_i + \sum_{j \neq i} (G_{ij} + G_{ji}) P_j +$$

$$+ \sum_{j \neq i} \sum_{k \neq i,j} (G_{ijk} + G_{jik} + G_{kij}) P_j P_k + \qquad \text{(II.11)}$$

$$+ G_{12\dots N} P_1 \dots P_{i-1} P_{i+1} \dots P_N \Big] \;;\; i=1,\dots N\,,$$

where λ - the Lagrange multiplier.
Note that the right hand side of the above equation does not contain P_i.

It now becomes clear what sort of approximations are being made in the considered cross-impact method:

(i) For any reasonable event set, it is infeasible to expect an expert to answer 2^N questions in order to evaluate all the conditional probabilities (II.2), (II.3) and, at the same time, all the coefficients G's or W's . Therefore, terms of P^2 or greater are ignored assuming that the three-, four- and higher-order interactions are sufficiently small.

(ii) The derivation is valid for the set of all potential events. Usually only a specific subset containing 5 to 20 events is utilized. Therefore all events not specified in the application of the cross-impact analysis are in effect lumped into the constants, since their probabilities of occurrence are assumed constant within the scope of the estimation process. In other words, we assume that these probabilities are independent of the considered time horizon T.

Under these approximations, using the notation

$$\Phi(P_i) = \ln\left(\frac{P_i}{1-P_i}\right) \quad ; \quad \gamma_i = G_i \ ; \quad C_{ij} = G_{ij} + G_{ji},$$

we may rewrite the equation (II.11) as

$$\Phi(P_i) = \ln\left(\frac{P_i}{1-P_i}\right) = \gamma_i + \sum_{j\neq i} C_{ij}P_j \ ; \quad i=1,\ldots,N, \qquad \text{(II.12)}$$

where the Lagrange multiplier λ has been incorporated in the constants and where both γ_i and C_{ij} are a function of the events not specified.

The function $\Phi(P_i) = \ln\left[P_i/(1-P_i)\right]$ defines the so called occurrence ratio being some measure of the likelihood of occurrence of the event e_i (see Turoff 1972). Values of this function range from $-\infty$ to $+\infty$, when the P_i values range from 0 to 1. Also, it can be easily observed that $\Phi(P_i)$ is the strictly increasing function of P_i for $P_i \in [0,1]$. The value $O_i = P_i/(1-P_i)$ has also some interpretation. Namely, O_i defines the odds of occurrence of the event e_i. The value of O_i ranges from 0 to $+\infty$ and $O_i(P_i)$ is a strictly increasing function of P_i for $P_i \in [0,1]$.

Equation (II.12) has an essential meaning for the method; it will be called the cross-impact relationship.

In essence, the γ_i - coefficient may be viewed as a measure of influence of the environment (unspecified events) on the event e_i; if γ_i is positive the unspecified events contributed to the occurrence of the i-th event and vice versa. Also if C_{ij} is positive, then the j-th event enhances the occurrence of the i-th event; if C_{ij} is negative, the j-th event inhibits the occurrence of the i-th event; if $C_{ij}=0$ there is no interaction between events e_i and e_j. The value C_{ij} provides a relative measure of the degree of causal impact one event has upon another. The ratio $C^*_{ij} = C_{ij}/\gamma_i$ gives a good measure or indication of how sensitive the i-th event is to the j-th event as compared with the rest of the environment. We assume that the coefficients C_{ij} and γ_i are constant in the considered time period $[0,T]$.

The coefficients C_{ij} will be called <u>the cross-impact factors</u> and the matrix of these coefficients $\underline{C} = [C_{ij}]_{NxN}$ will be called <u>the cross-impact matrix.</u>

We may rewrite the cross-impact relationship (II.12) as

$$P_i = \frac{1}{1 + \exp\left(-\gamma_i - \sum_{j \neq i} C_{ij} P_j\right)} \; ; \; i=1,\ldots,N. \qquad \text{(II.13)}$$

Equation (II.13) provides an explicit functional relationship between the probability P_i of the occurrence of the i-th event and the probabilities P_j ($j=1,\ldots,N$; $j \neq i$) of the occurrence of the other events. It has been proved that if these probability form a consistent set of values in the sense of equation (II.13), the total information known at the beginning of the considered time interval is maximal (with accuracy defined by the assumptions adopted). The amount of this information is determined by (II.6).

Thus, if coefficients γ_i and C_{ij} are known*) and if we have some additional information concerning occurrence or nonoccurrence of the events e_j ($j \neq i$), the primary advantage of equation (II.13) is that it provides the updated value P_i of the prior probability P_i° of the i-th event. The information mentioned regarding occurrence or nonoccurrence of the events e_j ($j \neq i$) may be obtained in the course of the computer Monte Carlo simulation runs; the details will be given in the subsequent section.

<u>Useful Relations</u>

It is useful, at this point, to introduce some relationships which are needed to actually apply results obtained. Namely, equation (II.12) yields the following relations:

Set $P_i = P_i^{o}$, $i=1,\ldots,N$.

If we assume that the occurrence of the j-th event becomes certain, then we have

$$P_j = 1 \quad \text{and} \quad R_{ij} = P_i^{\circ} \; ; \; i=1,\ldots,N, \qquad \text{(II.14)}$$

and from (II.12), (II.14)

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*) the method of evaluating these coefficients on the basis of the subjective experts opinions will be discussed later on.

$$\Phi(R_{ij}) = \ln\left(\frac{R_{ij}}{1 - R_{ij}}\right) = \gamma_i + \sum_{l \neq i,j} C_{il}P_l^{\circ} + C_{ij}. \qquad (II.15)$$

From (II.12) and (II.15), afer some transformation, we obtain

$$C_{ij} = \frac{1}{1-P_j^{\circ}}\left[\Phi(R_{ij}) - \Phi(P_i^{\circ})\right]; \ i,j=1,\dots,N \ ; \ i \neq j. \qquad (II.16)$$

Therefore, knowing P_i°, P_j° and R_{ij} we may calculate the cross-impact factors C_{ij}. We take $C_{ij}=0$, if $P_i^{\circ} = R_{ij}$.
Let us introduce the following notation:

$S_{ij} = P(e_i | \bar{e}_j)$ - the conditional probability of occurrence of the event e_i, given certainty that the j-th event shall not occur (which is denoted as $\bar{e}_j$).

If we assume that it is certain that the j-th event shall not occur, we have

$$P_j = 0 \text{ and } S_{ij} = P_i^{\circ} \ ; \ i=1,\dots,N \qquad (II.17)$$

and from (II.12), (II.17)

$$\Phi(S_{ij}) = \ln\left(\frac{S_{ij}}{1-S_{ij}}\right) = \gamma_i + \sum_{l \neq i,j} C_{il}P_l^{\circ} \qquad (II.18)$$

From (II.12) and (II.18) we obtain

$$C_{ij} = \frac{1}{P_j^{\circ}}\left[\Phi(P_i^{\circ}) - \Phi(S_{ij})\right] \ ; \ i,j=1,\dots,N \ ; \ i \neq j. \qquad (II.19)$$

Therefore, if we know P_i°, P_j° and S_{ij} we may also calculate the cross-impact factors C_{ij}. Similarly, we take $C_{ij}=0$, if $P_i^{\circ}=S_{ij}$. Justification for introduction of equation (II.19) is that in the real-life conditions it is often easier to evaluate the conditional probabilities S_{ij} than the probabilities R_{ij}.

From (II.16) and (II.19) we have

$$C_{ij} = \Phi(R_{ij}) - \Phi(S_{ij}) \ ; \ i,j=1,\dots,N \ ; \ i \neq j, \qquad (II.20)$$

which may be used to calculate R_{ij} given the values of S_{ij} and C_{ij}. On the other hand, from the equation (II.20) we may also calculate S_{ij} given the values of R_{ij} and C_{ij}.

From the expressions (II.12), (II.16), (II.19) and (II.20) we obtain the following approach:

If the experts who evaluate, on the basis of their subjective views on the problem considered, $(N^2 - N)$ conditional probabilities of the occurrence of the events e_i, provide some of their estimates as R_{ij} and the other ones as S_{ij}, we compute the values of C_{ij} from the equations (II.16) and (II.19), respectively (depending on the situation). Then, the lacking elements of the matrices $\underline{R}$ and $\underline{S}$ of the conditional probabilities are computed from (II.20).

Having obtained the values C_{ij} of the cross-impact factors we can calculate the coefficients γ_i; from (II.12) we have

$$\gamma_i = \Phi(P_i^\circ) - \sum_{j \neq i} C_{ij} P_j^\circ \quad , \quad i=1,\ldots,N. \tag{II.21}$$

Thus, on the basis of experts subjective estimates of the prior probabilities P_i^o (i=1,...N) and the conditional probabilities R_{ij} or S_{ij} (i,j=1,...,N; i≠j), after some calculations, we obtain:

- <u>The matrices $\underline{R}$ and $\underline{S}$ of the conditional probabilities,</u> which we jointly represent as (with the diagonal elements being the prior probabilities P_i^o):

$$\left[\frac{\underline{R}}{\underline{S}}\right] = \left[\begin{array}{c|c|c|c} P_1^o & \begin{matrix} R_{12} \\ S_{12} \end{matrix} & \cdots & \begin{matrix} R_{1N} \\ S_{1N} \end{matrix} \\ \hline \begin{matrix} R_{21} \\ S_{21} \end{matrix} & P_2^o & & \begin{matrix} R_{2N} \\ S_{2N} \end{matrix} \\ \hline \begin{matrix} \cdot \\ \cdot \\ \cdot \end{matrix} & & & \\ \hline \begin{matrix} R_{N1} \\ S_{N1} \end{matrix} & \begin{matrix} R_{N2} \\ S_{N2} \end{matrix} & \cdots & P_N^o \end{array}\right] \quad \text{and} \tag{II.22}$$

- <u>The cross-impact matrix $\underline{C}$</u> (with the γ- coefficients set as its diagonal elements):

$$\underline{C} = \left[\begin{array}{c|c|c|c} \gamma_1 & C_{12} & \cdots & C_{1N} \\ \hline C_{21} & \gamma_2 & & C_{2N} \\ \hline \begin{matrix} \cdot \\ \cdot \\ \cdot \end{matrix} & & & \\ \hline C_{N1} & C_{N2} & \cdots & \gamma_N \end{array}\right] \tag{II.23}$$

On the basis of the values obtained we may also define the following parameters:

- The effectiveness Ψ_i of influence of the i-th event on the all other events

$$\Psi_i = \sum_{j \neq i} \left| C_{ji} P_i^{\circ} \right| ; \qquad i=1,\ldots,N \qquad \text{(II.24)}$$

The parameters Ψ_i allow a selection of independent events from the event set $\{e_i, i=1,\ldots,N\}$; i.e. selection of events whose occurrence is largely unaffected by the other events in the set but may influence some subset of the other events.

- The sensitivity η_i of the i-th event with regard to the influence of the all other events.

$$\eta_i = \max_{j \in J} \left| \frac{C_{ij}}{\Psi_i} \right| ; \qquad i=1,\ldots,N \qquad J= 1,\ldots,(i-1),(i+1),\ldots,N . \qquad \text{(II.25)}$$

The parameters η_i make it possible to select from the event set $\{ e_i, i=1,\ldots,N\}$ the events which are (in terms of the dependence of their occurrence) a function of other events in the set.

If needed, we can also define:

- The sensitivity η_{ij} of the i-th event with regard to the influence of the j-th event; i.e.

$$\eta_{ij} = C_{ij}P_j^{\circ} - \overline{C_{ij}P_j} ; \text{ where } \overline{C_{ij}P_j} = \frac{1}{N-1}\sum_{j \neq i} C_{ij}P_j^{\circ} ; \qquad \text{(II.26)}$$

$$i,j=1,\ldots,N ; \quad i \neq j.$$

The cross-impact relationship (II.13) together with the parameters $\{P_i^{\circ} ; i=1,\ldots,N\}$, R , S , C , $\{\Psi_i ; i=1,\ldots,N\}$ and $\{\eta_i; i=1,\ldots,N\}$ directly evaluated and/or calculated on the basis of the experts' subjective estimates, form some mathematical model of causal relationships (interactions) among the analysed events. The investigated model allows one to generate, via given steps of the computer simulation runs, a likely scenario of development of the considered system. This procedure will be presented in details in the following section.

II.4. Development Scenario Preparation Procedure

The considerations contained in Section II.3 describe and justify the Turoff´s version of the cross-impact method. This method makes it possible to infer causal relationships from the interrelations among the different system development views which are established by perturbing the expert´s initial view, given certain knowledge as to the outcome of individual events. However the cross-impact analysis is only the beginning. It is the next stage, scenario generation and the subsequent evaluation of a likely "future" connected with the forecasted system development, which provides the greatest payoff to the decision maker. The procedure for preparation of such scenario consists of the following three stages:

- The information stage; determination of the input data for the cross-impact model;
- The passive simulation; investigation of the scenario which identifies the future state of the system;
- The active simulation; investigation of the scenario meant for achieving the system goals.

The passive and active simulation are directly associated with determination of the so called exploratory and normative forecasts of the system development (see Centron, Ralph 1971; Bright 1973).

II.4.1. The information stage

The information stage is connected with evaluation, on the basis of the experts´ subjective estimates, of the input data for the considered cross-impact model; i.e. the contents of the event set, the prior and conditional probabilities of the events, the cross-impact factors and the γ-, ψ- and η- parameters (see Section II.3). In order to obtain a consensus of the experts´ opinions, the realization of the information process requires application of the Delphi or other group decision making techniques.

The event set:

The first step in the construction of a cross-impact exercise is specification of the event set. At present, the workable and popular approach to this problem is to allow the individuals, who will participate in the application of the cross-impact technique, to specify the set of events which they feel are crucial to the problem under consideration. This process may be conducted in a face-to-face conference, committe approach, brain-storming technique or, when needed, in a Delphi exercise (see Turoff 1972, Enzer 1971, Helmer 1977). The success of the exercises, in terms of specifying a good event set, depends upon the knowledge the group has about the problem, as is the value of the quantitative estimates that will be obtained.

It should be stressed that when the event set is specified, only the nonrecurrent events should be taken into account. When dealing with recurrent events within the cross-impact framework, one should restate them as nonrecurrent events by either determining an exact number of occurrences within the time horizon T or utilizing special definitions for such events; by, for instance, application of phrases like "... will happen at least once".Some threshold values may also be established for the above purposes; e.g. "Power generation level related to lignite strip mining in the region will increase by at least X% in the time horizon T". Any recurrent event may thus be restated as a set of nonrecurrent events. Of course, dimensionality of the problem will thereby significiently increase. So, the limitation of our analysis to the set of nonrecurrent events only, becomes very often the main shortcoming of the method proposed.

When the Delphi technique is used for obtaining the compatible set of experts´opinions as to the event set, the indices of experts´ competence, connected with their level of knowledge in the analysed problems, should be taken into account.

In the Polish Case Study reported, we assume that each expert evaluates his own competence using the format given in Table II.2. In our case, the Delphi technique was applied for evaluating the mentioned threshold values associated with the events considered. These values were established in the course of several (usually 2 or 3) interactive computer-aided runs, as the weighted sum of particular experts´estimates; the weights were equal to the normalized (with respect to the sum) values of the mentioned competence indices. The list of 12 events selected in this manner is presented in Table V.2, Chapter V, Part 2. The distributions of the experts´opinions connected with the evaluation of the events in the successive iterations of Delphi procedure are illustrated in Figs V.2.1÷30, Part 2.An example of such a distribution resulting from

Rating	Statement
1.00	The expert is outstanding specialist in the problem. His theoretical investigations and/or applied work on the analysed area are of great importance.
0.80	Problematique considered is fairly similar to the area of theoretical and/or applied works of the expert.
0.60	The expert, from time to time, takes part in solving of practical aspects of such problems but the particular problem statement does not overlap the specific area of his scientific and/or professional activities.
0.40	Problematique considered rather differs from the scientific and/or professional interest of expert. He has not any practical experience in the area mentioned.
0.20	Problematique considered differs from the scientific and/or professional interests of expert. He has only very general view on the analysed problem.
0.00	The expert´s scientific and/or professional interests significantly differ from the considered area. He is unable to provide any opinion on analysed problem.

TABLE II.2. Experts´competence index descriptions and ratings.

the first (two-modal case) and the second (unimodal case) iteration of this procedure is also given in Table II.3.

From the practical experiences connected with application of the considered cross-impact technique it follows that the number N of events e_i analysed should not exceed 12 ÷ 15. Also, the nuber K of experts engaged in the estimation process should not exceed 15. It has been experienced that when the number of experts increases significantly over K=15, the efficiency of the considered procedure decreases rapidly.

All data provided by experts in the course of Delphi exercise, i.e. the quantitative values of threshold levels defined for some of the considered events, the prior probabilities of events discussed further on in this section, as well as the competence indices, have been communicated anonymously. For the sake of anonymity which is the essential property of the Delphi technique used, each expert

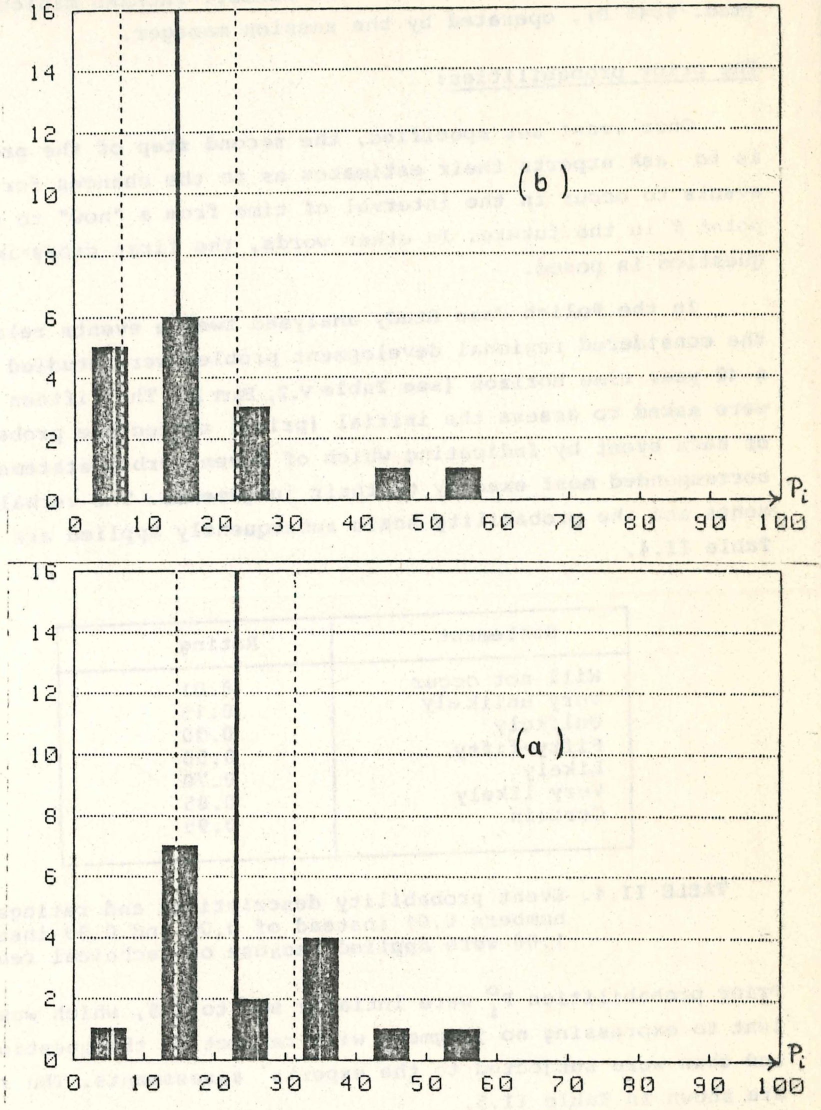

TABLE II.3. An example of distributions of the experts´estimates of threshold value; (a) - two-modal case (1-st Delphi iteration), (b) - unimodal case (2-nd Delphi iteration) Vertical axis - the number of experts; horizontal axis - the threshold values in %.

had been equipped with a computer terminal. The terminal had been set up in the form of Polish electronic calculators ZTR-1 directly connected with the CPU of the HEWLETT-PACKARD minicomputer (mod. 9845 B), operated by the session manager.

The prior probabilities:

Once event set specified, the second step of the procedure is to ask experts their estimates as to the chances for these events to occur in the interval of time from a "now" to some point T in the future. In other words, the first cross-impact question is posed.

In the Polish Case Study analysed twelve events related to the considered regional development problem were studied within a 40 year time horizon (see Table V.2, Part 2). The fifteen experts were asked to assess the initial (prior) subjective probability of each event by indicating which of seven verbal statements corresponded most exactly to their judgements. The verbal statements and the probability scale subsequently applied are given in Table II.4.

Statement	Rating
Will not occur	0.01
Very unlikely	0.15
Unlikely	0.30
Fifty-fifty	0.50
Likely	0.70
Very likely	0.85
Certain	0.99

TABLE II.4. Event probability descriptions and ratings; the numbers 0.01 instead of 0.00 and 0.99 instead of 1.00 were applied because of technical reasons.

Prior probabilities P_i^o were intially set to 0.5, which was equivalent to expressing no judgment with respect to the question posed, and then were subjected to the experts' assessments. The results are shown in Table II.5.

i	1	2	3	4	5	6	7	8	9	10	11	12
P_i^o	.21	.38	.78	.80	.34	.13	.38	.32	.39	.16	.24	.06

TABLE II.5. The prior probabilities of the events e_i (i=1,...,12) listed in Table V.2, Chapter V, Part 2.

Similarly as in the case of evaluating of the threshold values for the events, the group assessment of the prior probabilities was derived through the application of the Delphi technique.

Thus, the probability values given in Table II.5 were calculated on the basis of the weighted average values of the individual subjective estimates; the weights were defined as the compentence indices of paricular experts. It should be also pointed out that the group responses were determined by averaging the occurrence ratio $\Phi_i(P_i^o)$ of each event , and not the probabilities. The group estimate of each prior probability P_i^o has been then derived from the weighted average values of the occurence ratios $\Phi_i(P_i^o)$. The above approach is very often indicated in the literature as the more adequate than the one in which the individual estimates of the probabilities P_i^o are directly averaged (see Kendall, 1977). It follows from the fact that the range of probability estimates that people give is not equally spaced between 0.0 and 1.0 ; e.g. the difference between estimates of 0.001 and 0.010 is more significant than the difference between estimates of 0.501 and 0.510. People tend to think in terms of ratios between the outcome probabilities i.e. in term of odds $O_i = P_i/(1-P_i)$, and this fact should be taken into account when Delphi or any other averaging procedure is to be applied.

The distributions of the experts´prior probability estimates obtained in the course of successive iterations of Delphi exercise applied within the considered Polish Case Study are presented in Figure V.4.1 given in Chapter V, Part 2.

The conditional probabilities:

The next step of the cross-impact procedure is to perturb the experts´view of the system development (or to crate a new view) by telling them to assume that one of the events certainly will (or will not) occur and asking them to reconsider the original probabilities of other events. Thus, the second cross-impact question is posed. In the procedure of assessing the conditional probabilities we assume that the change in the likelihood of occurrence of a given event can be influenced only by the proceding event that "has (or has not) occurred".

As is was pointed out by M. Turoff (1972), "we are faced with a situation analogous to some degree with the problem in quantum mechanics where, in order to measure the state of the system we must physically disturb it". In our case, in the process of setting up an instrument to measure the estimates of an individual´s view of causal relationships among the events, we disturb those estimates.

Evaluating of the conditional probabilities

$$R_{ij} = P(e_i | e_j) \text{ and/or } S_{ij} = P(e_i | \overline{e}_j) \; ; \; i,j = 1,\ldots,N \; ; \; i \neq j,$$

on the basis of the experts´subjective estimates, is a difficult problem. Let us observe that in the considered case we have to obtain $(N^2 - N)$ mutually consistent estimates. For example, in the Polish Caste Study project we have analysed N=12 events, i.e. 132 possible pairwise interactions among these events had to be taken into account.

For the reasons mentioned, before evaluating the quantitative values of conditional probabilities R_{ij} and/or S_{ij}, we ask experts for qualitative estimates of mode and intensity of interactions among events. The question scale which is used in this case is shown in Table II.6.

Rating		Statement
(+3)	-	Very strong positive influence of e_j on e_i.
(+2)	-	Strong positive influence of e_j on e_i.
(+1)	-	Positive influence of e_j on e_i.
0	-	Neutral relation between e_j and e_i.
(-1)	-	Negative influence of e_j on e_i.
(-2)	-	Strong negative influence of e_j on e_i.
(-3)	-	Very strong negative influence of e_j on e_i.

TABLE II.6. The descriptions and ratings for qualitative estimation of causal relationships among events.

The estimates provided by each expert on the basis of this scale form the matrix $\underline{D}$ of qualitative evaluation of pairwise interactions (if any) among the analysed events. In the Polish Case Study we have obtained fifteen such matrices. The example of one of them (Expert No. 7) is given in table II.7.

	1	2	3	4	5	6	7	8	9	10	11	12
1	.	+1	-1	+3	+3	-2	+3	+2	+3	0	+2	+3
2	+1	.	+2	+3	+1	+3	0	+1	+1	0	+2	0
3	0	0	.	0	+3	+2	0	+3	+2	0	0	0
4	-1	+1	0	.	0	+3	0	0	+2	0	+2	+1
5	-2	+2	+3	+3	.	+1	0	+3	+1	+1	+1	0
6	-3	0	0	+2	0	.	+2	0	+3	0	+2	0
7	0	0	+1	0	0	0	.	+1	+3	0	0	0
8	0	+1	+3	0	+3	+2	+1	.	+1	+1	0	0
9	+2	0	+2	+1	0	+1	+2	+1	.	0	+3	+2
10	0	-2	+1	0	+1	+2	+2	0	0	.	0	0
11	-3	0	+2	+2	0	+3	+3	+2	0	0	.	+3
12	0	+3	+2	+3	0	-1	0	0	0	0	0	.

TABLE II.7. The matrix $\underline{D}$ of qualitative assessment of interactions among the events; Expert No. 7.

Once the matrices $\underline{D}$ of qualitative estimates of pairwise interactions between the events are determined, the experts are then asked to provide information on the quantitative assessment of conditional probabilities. In this step they are asked to assume for the sake of analysis that it is certain that a particular event will or will not occur in the time horizon T. Given this hypothesis, the experts provide the resulting new estimates for the probabilities R_{ij} or S_{ij} of occurrence of the other events. Unless they change them, the conditional probabilities are set to the prior probabilities P_i^o .

The session manager informs the experts about the "occurrence" or "nonoccurrence" of an event according to how they specified the prior probabilities, i.e. according to the average values of the group responses on the first cross-impact question:

- If experts had specified the probability P_j^o of event e_j of 0.5 or less; i.e. if $0 < P_j^o \leq 0.5$, they are told to assume that the event e_j occurred and they are asked to estimate the values

$$R_{ij} = P(e_i | e_j) \; ; \; i,j=1,\ldots,N \; ; \; i \neq j ,$$

i.e. conditional probabilities of events e_i given prior occurrence of the event e_j.

- If $0.5 < P_j^o < 1.0$, they are told to assume that the event e_j did not occur and they are asked to estimate the values

$$S_{ij} = P(e_i | \bar{e}_j) \; ; \; i,j = 1,\ldots,N \; ; \; i \neq j ,$$

i.e. conditional probabilites of events e_i given prior nonoccurrence of the event e_j.

The above rule, suggested originally by M. Turoff (1972), is rather arbitrary. It is connected with the tendency to make the maximum perturbation of the experts´initial view of the system development. Let us note that for the purpose of analysis we assume that unlikely events will occur, and vice versa, i.e. that likely events will not occur.

For some technical reasons, the expert is allowed only two-digit specification of a probability which therefore must lie between (and including) 0.01 and 0.99. If he enters a zero or one, it is automatically changed to 0.01 or 0.99, respectively.

At this point, when the estimates of the conditional probabilities R_{ij} or S_{ij} are determined, the computer calculates the values C_{ij} of the cross-impact factors. For this purpose the formulae (II.16) or (II.19) derived in the previous section are used respectively; i.e.

- when the estimates of R_{ij} are determined, from (II.16) we obtain

$$C_{ij} = \frac{1}{1-P_j^o}\left[\Phi(R_{ij}) - \Phi(P_i^o)\right] ; \; i,j=1,\ldots,N \; ; \; i \neq j ,$$

- when the estimates of S_{ij} are determined, from (II.19) we obtain

$$C_{ij} = \frac{1}{P_j^o}\left[\Phi(P_i^o) - \Phi(S_{ij})\right] \; ; \; i,j=1,\ldots,N \; ; \; i \neq j .$$

Once the cross-impact factors C_{ij} are calculated, the lacking elements of the matrices $\underline{R}$ and $\underline{S}$ of the conditional probabilities R_{ij} and S_{ij} are computed from the equation (II.20), i.e.

$$C_{ij} = \Phi(R_{ij}) - \Phi(S_{ij}) \; ; \; i,j=1,\ldots,N \; ; \; i \neq j.$$

Then, the group average estimates of R_{ij} and S_{ij} are calculated.

It should be noted that, similarly as in the case of the prior probabilities, when averaging procedure is applied, the occurrence ratios $\Phi(R_{ij})$ and $\Phi(S_{ij})$ should be taken into account.

The joint form of the matrices R and S of conditional probabilities determined within the analysed Polish Case Study is presented in Table II.8.

The cross-impact matrix:

The following step of the considered procedure is to determine the group response concerning the values of the cross-impact factors C_{ij} and the γ- coefficients:

Once the cross-impact factors C_{ij}^{k} are evaluated on the basis of the expert's estimates; where k is the expert index (k=1,... ...,K) the coefficient γ_j^k can be obtained from the equation (II.21): i.e.

$$\gamma_i^k = \Phi(P_i^o) - \sum_{j \neq i} C_{ij}^k P_j^o, \quad i=1,\ldots,N.$$

The group response is then determined by linear average of the cross-impact factors C_{ij}^k and the coefficients γ_i^k. The values obtained form the cross-impact matrix C being of essential significance for the method considered. As it has been pointed out in the previous section, the cross-impact factors C_{ij} are a measure of the strength and mode (enhancing or inhibiting) of interactions among the events.

The cross-impact matrix C derived in the course of computations carried out within the Polish Case Study project is illustrated in Table II.9. The matrix C presents the relative causal weights (cross-impact factors) of one event (column) upon another (row).

At the end of the procedure, the group average responses concerned with the parameters of the effectiveness of influence Ψ_i and the sensitivity with regard to the influence η_i, η_{ij}, defined for particular events by formulae (II.24), (II.25), (II.26), are determined. The values of these parameters are very often useful for analysis of the resulting scenario of the system development. The details will be given at the end of this section.

I	Po(I)	1	2	3	4	5	6	7	8	9	10	11	12
1	0.21	** **	23 20	23 15	32 3	29 18	20 21	32 16	25 19	37 14	21 21	39 17	28 21
2	0.38	35 39	** **	43 23	56 3	48 33	55 36	43 35	45 35	52 30	47 36	51 34	46 38
3	0.78	76 79	80 77	** **	76 85	90 69	68 79	79 77	89 71	78 78	74 79	79 78	77 78
4	0.80	75 81	82 79	80 80	** **	78 81	82 80	81 79	.79 80	84 77	82 80	79 80	84 80
5	0.34	36 33	49 26	59 1	39 18	** **	38 33	37 32	63 23	34 34	36 34	35 34	36 34
6	0.13	13 13	16 11	14 10	14 10	14 13	** **	24 9	13 13	26 8	20 12	24 11	11 13
7	0.38	41 37	39 37	48 13	40 30	40 37	30 39	** **	40 37	48 32	37 38	40 37	36 38
8	0.32	36 31	44 26	71 0	33 28	72 16	30 32	36 30	** **	38 28	33 32	35 31	32 32
9	0.39	43 38	47 34	49 13	49 11	49 34	50 37	50 33	44 37	** **	44 38	54 35	51 38
10	0.16	17 16	21 13	19 8	19 8	19 15	33 14	19 14	16 16	25 12	** **	22 14	40 15
11	0.24	34 22	25 23	25 21	42 1	25 23	26 24	31 20	26 23	33 19	25 24	** **	39 23
12	0.06	7 6	23 2	7 3	12 0	6 6	10 6	6 6	6 6	13 4	9 6	12 5	** **

TABLE II.8. The matrices $\underline{R}$ and $\underline{S}$ of conditional probabilities determined for the events e_i (i=1,..,12) listed in Table V.2, Part 2. The column $P_o(I)$ includes the prior probabilities. The other columns denote the influencing events; the rows denote the events being influenced. The values of conditional probabilities R_{ij} and S_{ij} are given in %.

I	Gamma	1	2	3	4	5	6
1	-5.57	****	.19	.53	2.86	.65	-.07
2	-5.31	-.16	****	.94	3.65	.62	.79
3	.87	-.14	.19	****	-.56	1.41	-.59
4	1.22	-.36	.21	0.00	****	-.18	.15
5	-6.28	.11	1.01	4.67	1.08	****	.20
6	-4.07	0.00	.39	.39	.43	.13	****
7	-2.64	.16	.07	1.86	.42	.13	-.41
8	-8.34	.23	.83	7.50	.23	2.57	-.11
9	-4.68	.21	.53	1.85	2.04	.62	.51
10	-4.39	.09	.54	.95	1.04	.32	1.09
11	-5.48	.62	.09	.25	4.15	.08	.12
12	-8.31	.21	2.49	.75	3.80	0.00	.64

...C(I,J) i Gamma(I) c.d.

I	Gamma	7	8	9	10	11	12
1	-5.57	.92	.33	1.30	0.00	1.15	.40
2	-5.31	.33	.42	.93	.44	.70	.35
3	.87	.10	1.21	0.00	-.26	.08	-.06
4	1.22	.10	-.09	.45	.15	-.08	.29
5	-6.28	.21	1.76	0.00	.10	.06	.09
6	-4.07	1.21	0.00	1.40	.61	.98	-.20
7	-2.64	****	.12	.67	-.05	.11	-.09
8	-8.34	.29	****	.43	.05	.18	0.00
9	-4.68	.72	.30	****	.25	.80	.52
10	-4.39	.34	0.00	.92	****	.52	1.33
11	-5.48	.57	.16	.73	.06	****	.75
12	-8.31	0.00	0.00	1.39	.52	1.00	****

TABLE II.9. The form of the cross-impact matrix $\underline{C}$ determined for the events e_i (i=1,...,12) listed in Table V.2, Part 2. The first column includs the coefficients γ_i. Plus indicates an enhancing effect; minus indicates an inhibiting effect.

II.4.2. Simulation of the system development state - exploratory scenario.

Given the input data evaluated and/or calculated for the considered cross-impact model on the basis of the subjective experts' opinions, one can proceed to the next stage of the analysed procedure. This is connected with investigation of the scenario which identifies the future state of the system. In other words the next stage is for the computer to present the decision maker with a forecast as to which events will occur. To do this, the Monte Carlo simulation approach for adjusting initial subjective probabilities P_i^o in the light of potential interactions among members of the event set is applied.

In the course of simulation runs the cross-impact relationship given by (II.13), i.e.

$$P_i = \frac{1}{1 + \exp\left(-\gamma_i - \sum_{j \neq i} C_{ij} P_j\right)} \; ; \quad i=1,\ldots,N \qquad \text{(II.27)}$$

is utilized.

The cross-impact factors C_{ij} and the γ- coefficients are assumed to be constant in the considered time horizon T. It is also assumed that the perception of the likelihood of the event occurring produces the causul effect, and not the actual time of occurrence. Taking into account this time independent view, a new set of event probabilities $\{ P_i, \ i=1,\ldots,N \}$ is simulated as follows:

(1) An event is selected from the event set at random and its "occurrence" or "nonoccurrence" is determined using a random number generator so that its probability of occurrence is equal to the originally specified probability.

(2) All other probabilities are adjusted on the basis of the cross-impact relationship (II.27). On the first iteration these are merely the conditional probabilities R_{ij} - if the event is deemed to have "occurred" or S_{ij} - otherwise.

(3) A further event, of the remaining (N-1) events, is randomly selected so that its probability of occurrence is equal to the adjusted probability resulting from the realization of

the Step (2). This procedure is repeated until all events have either "occurred" or "not occurred".

(4) By undertaking a large number of computer simulation runs (Steps 1÷3) and recording the cumulative outcomes for each event (i.e. "occurred" or "not occurred"), it is possible to obtain a revised set of probabilities for the N events, which takes into account the between - event interactions. These probabilities allow one to create a likely scenario of the system development.

The presented procedure is a modification of the Turoff (1972) "cascading perturbation" approach to scenario generation. In the considered Polish Case Study we introduced also some additional extension of the method. Namely, taking into account that the time horizon T assumed for the purpose of the regional development analysis was 40 years, it was divided into four intervals Δt (Δt= 10 years) called <u>scenes.</u>

Let us denote by t-the index of the subsequent scene, i.e. t=1,...,L; where L - the assumed number of scenes. Thus, we have $T = L \times \Delta t$. In the approach mentioned we assume that the prior probabilities P_i^o (i=1,...,N) of the considered events as well as the conditional probabilities R_{ij} or S_{ij} (i,j=1,...,N ; i≠j) are estimated by experts for the first scene (i.e. for t=1) instead of the time horizon T, and that the cross-impact factors C_{ij} and the γ- coefficients remain unchanged in the subsequent scenes t=2,3,...,T. The justification of this assumption is that the cross-impact factors C_{ij} reflect some relative measure of the interactions among events which is constant in time within the considered time horizon T. Also, the γ- coefficients represent constant in time impact of the environment on the analysed system.

Taking into account the above assumptions the computer Monte Carlo simulation of the analysed system development can be carried out in the similar way as it has been done previously. In order to do it, the described simulation procedure (see Steps 1÷4) should be applied sequentially starting from the first scene up to the last one. During this simulation process, the probabilities P_i^t (i=1,...,N ; t=1,...,L) being the adjusted probabilities for the t-th scene are considered as "the input" probabilities for the (t+1)-th scene. For the first scene, "the input" probabilities are merely the prior probabilities P_i^o ; i=1,...,N, estimated on the basis of experts' opinions.

The graphs of probabilities P_i^t (i=1,...,12; t=1,...,4) obtained via application of the described approach within the reported Polish Case Study, i.e. probabilities of occurrence of the considered events in the subsequent scenes, are presented in the Appendix to Chapter V, Part 2.

The presented approach allowing the decision maker to investigate a likely scenario of the analysed system development is in fact directly connected with the so called exploratory forecasting of the future system state. In other words, the scenario generated presents a possible - but not necessarily desirable - state of the system considered. When investigating it, no special policies affecting the likelihood of particular events (e.g. specially introduced investments) have been taken into consideration. In this sense, the analysed procedure yielding a likely scenario of the system development may be called the passive simulation of the future.

The general form of the block-diagram of the simulation procedure described in this subsection is given in Table II.10.

II.4.3. Simulation of the system development goals - normative scenario.

The simulation procedure presented in the previous subsection makes it possible to generate the exploratory scenario of a likely future system state. As it has been pointed out, such a scenario presents a possible "future" connected with the analysed system development. Once a likely future state of the considered system is determined, one can identify the desirable as well as not desirable future situations and then determine the policies (actions) preventing the latter one. This is directly associated with the so called normative forecasting of the system development goals.

It can be done via investigation of the scenario meant for achieving the system goals. In order to do it, the so called active simulation of the system development is to be undertaken.

The first step of this simulation process is specification of the sets of dependent and independent events on the basis of the parameters ψ_i (effectiveness of influence) and η_i, η_{ij} (sensitivity with regard to influence) defined by equations (II.24) ÷

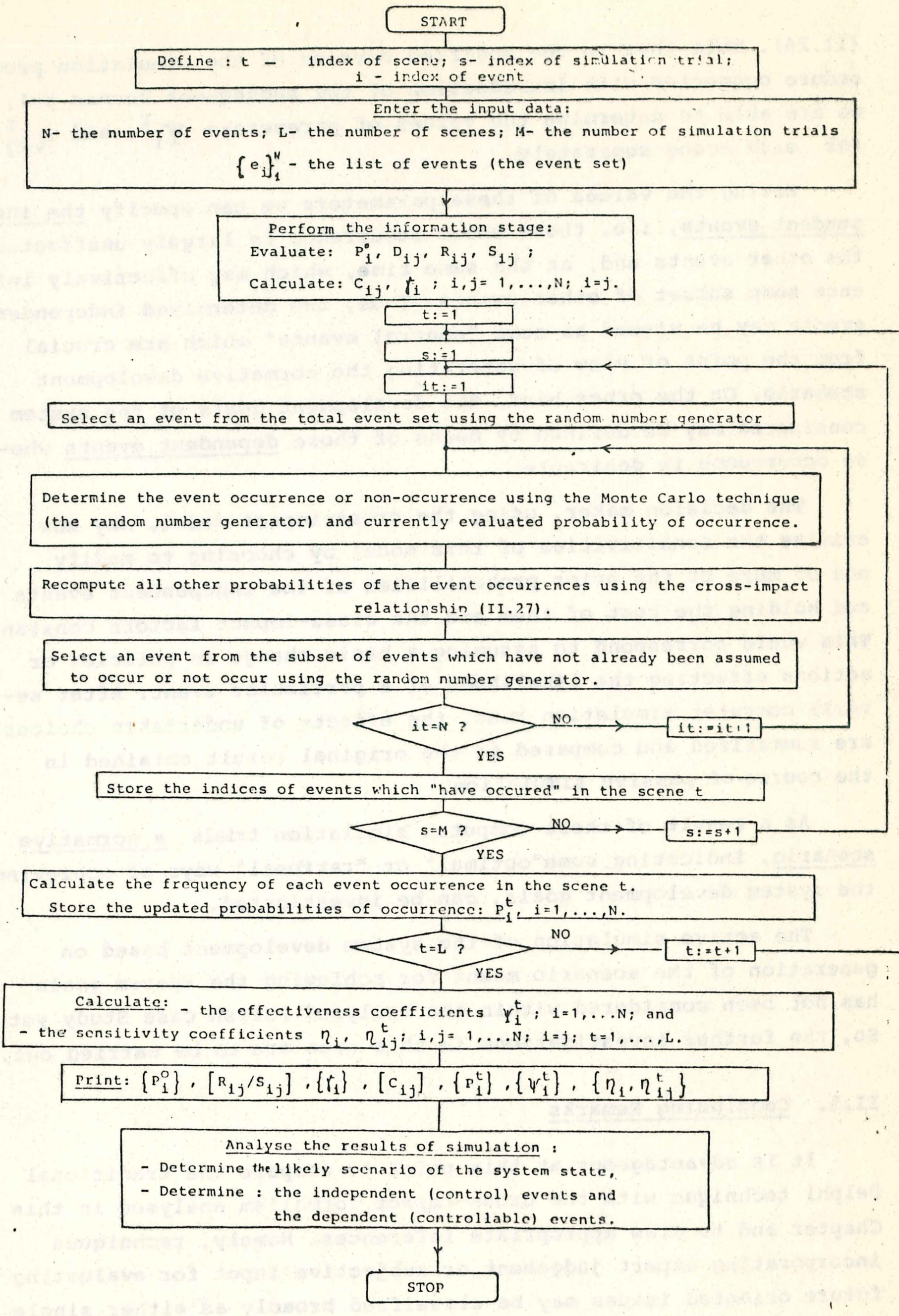

TABLE II.10. The block- diagram of the simulation of the future system state.

(II.26). Note that in the modified version of the simulation procedure connected with introduction of the subsequent scenes t=1,..,L, we are able to determine the values of parameters ψ_i^t and η_{ij}^t for each scene separately.

Having the values of these parameters we can specify the independent events, i.e. those whose occurrence is largely unaffected by the other events and, at the same time, which may effectively influence some subset of other events. Thus, the determined independent events may be viewed as some "control events" which are crucial from the point of view of generating the normative development scenario. On the other hand, the development goals of the system considered may be defined by means of those dependent events whose occurrence is desirable.

The decision maker, using the cross-impact model, may now examine the sensitivities of this model by choosing to modify one or more of the prior probabilities of the independent events and holding the rest of them and the cross-impact factors constant. This would correspond to assuming a basic change in policies or actions effecting the likelihood of a particular event. After several computer simulation runs, the effects of undertaken choices are summarized and compared to the original result obtained in the course of passive simulation.

As a result of those computer simulation trials a normative scenario, indicating some"optimal" or "rational" ways of achieving the system development goals, can be investigated.

The active simulation of the system development based on generation of the scenario meant for achieving the system goals has not been considered within the analysed Polish Case Study yet. So, the further investigations in this area are to be carried out.

II.5. Concluding Remarks

It is advantageous at this point to compare the traditional Delphi technique with the cross-impact formalism analysed in this Chapter and to draw appropriate inferences. Namely, techniques incorporating expert judgement or subjective input for evaluating future oriented issues may be classified broadly as either single event or compound event procedures (see Helmer 1977, Mitchell, Tydeman 1978).

The former, of which the most notable is the Delphi inquiry, involves a group of experts assessing the likelihood of occurrence (and perhaps other measures such as desirability, feasibility or significance) of a number of selected events within certain time periods. Whilst the analyst may then rank individual events in terms of one or more of the measures adopted, a basic limitation is that each event is considered in isolation, i.e. the occurrence of any one event is assumed not to affect of occurrence of any othe

The latter procedure is directly connected with cross-impact analysis approach making it possible to investigate the effect of between-event interdependences in futures research.

From the considerations given in this Chapter it follows immediately that it is useful for an analyst to put these procedures together within the context of a modern terminal-oriented computer - communications system. It is quite feasible to design a computer-aided on-line conference version of the cross-impact exercise which would eliminate delays in processing the group results and allow the conferees to modify their views at will.

Given such a system, an analyst faced with some future oriented complex problem may quickly bring together the group of experts via the terminals to obtain a likely scenario of the future development state and one or more plausible scenarios meant for achieving the development goals. Taking into account the growing availability of terminals, computer hardware and software to support such a conferencing, and the availability of digital communication networks providing reasonable communication costs, it can be expected that the system of the type described here will come into being in the nearest future. In the considered Polish Case Study we have applied only reduced form of the mentioned computer-aided conferencing system; i.e. the so called mini-Delphi inquiry (see Hill, Fowles 1975) has been utilized in our case.

At the end of this Chapter it should be pointed out that, as many authors state (see e.g. Mitchell, Tydeman 1978, McLean 1976), scenario generation is not an "end" in itsef but that it seeks to provide the decision maker with an additional dimension in which he is able to evaluate the efficiency of alternative courses of actions or strategies. In other words, cross-impact is not primarily a technique for predicting the future but rather has its significant advantage in constructing the mentioned context of the futures research.

Thus, the results given in Chapter V, Part 2 , related to the cross-impact study of the Bełchatów-Szczerców regional development case, should be considered in the presented above sense.

The software for the Cross-Impact and Delphi inquiry system proposed has been written in BASIC language for HEWLETT-PACKARD minicomputer (mod. 9845 B). It is available at Department of Technical Service, Polish Academy of Sciences (01-447 Warsaw, Newelska 6, Poland).

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STUDY REPORT

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