Major extension to cross-impact analysis

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Scenario construction via Delphi and cross-impact analysis

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ABSTRACT

Since its origins, decision makers have broadly used the Delphi method as a collaborative technique for generating important events and scenarios about what may happen in the future. This is a complex process because of the different interrelations and the potential synergetic effects among the relevant events related to a decision. This fact, along with the uncertainty about the occurrence or non-occurrence of the events, makes the scenario generation task a challenging issue in Delphi processes. In the 1960's, Cross-Impact Analysis (CIA) appeared as a methodological tool for dealing with this complexity. CIA can be used for creating a working model out from a set of significant events. CIA has been combined with other methodological approaches in order to increase its functionality and improve its final outcome. In this paper, the authors propose a new step-by-step model for scenario-analysis based on a merger of Turoff's alternative approach to CIA and the technique called Interpretive Structural Modeling (ISM). The authors' proposal adds tools for detecting critical events and for producing a graphical representation to the previous scenario-generation methods based on CIA. Moreover, it allows working with large sets of events without using large computational infrastructures. The authors present sufficient information and data so that anyone who wishes to may duplicate the implementation of the process. Additionally they make explicit a set of requirements for carrying out a Delphi process for a group to develop a set of significant events, collectively make the estimations of cross impacts, and to support a continuous planning process within an organization. They use two examples to discuss operational issues and practical implications of the model.

"Born, troubled, died."
This was their history of Everyman.
"Give me next for my people," spoke the head man,
"in one word the inside kernel of all you know,
the knowledge of your ten thousand books
with a forecast of what will happen next—
this for my people in one word."
And again they sat into the peep of dawn
and the arguments raged
and the glass prisms of the chandeliers shook
and at last they came to a unanimous verdict
and brought the head man one word:
"Maybe."
—from Poem 49 in "The People, Yes" by Carl Sandburg

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1. Introduction

The use of scenarios to study the future is well known as an approach to studying situations that can lead to important changes and in which it is difficult to create explicit relationships among the events. Examples are the merger of two companies, extreme disaster or risk situations, major political happenings and/or the long term impacts of new or changing regulations or policies. All the events in the set are of a binary nature: a merger will or will not occur; a new specific policy will be established or not; a company will or will not go bankrupt; a given technological breakthrough will occur or not, etc. By means of scenario generation methods, forecasters make predictions about the occurrence or not of a set of events in time and/or describe a future story, from the present conditions to a set of plausible futures. In both cases, scenarios have been widely used for exploring the detection of future events together, as well as analysis of the path that leads to the desired future or prevents undesirable futures. That is what we call scenario analysis. In this sense, scenario-generation methods have often been used by decision-makers as an instrument to build landscapes of possible futures. Based on these future visions, decision-makers are able to explore different courses of action [1,2].

Scenario-generation methods combine a set of behaviors that mix qualitative and quantitative, subjective and objective methodologies in different layers [3]. The number of potential scenario methods is increasing as researchers and consultants from different backgrounds use their particular expertise to create new variations [4,5]. The Delphi method is one of the most used techniques for foresight [6–8]. By means of Delphi method forecasters, based on the input provided by an expert panel, can make hypotheses about the occurrence or not of singular events. This success is mainly due to two of the main characteristics of the Delphi method: controlled feedback and anonymous interaction among experts. These characteristics help forecasters to avoid several limitations of traditional face-to-face experts' panels, such as unwanted leadership and high time cost [9]. Nevertheless, the inability of the Delphi method to make complex forecasts in which events are not isolated but interrelated is a limitation for scenario analysis. In a basic Delphi process the occurrence or not of an event was usually considered as if it had no effect on the rest of the event set.

Cross-Impact Analysis (CIA) [10] was developed to address this limitation. CIA is a powerful tool for taking a set of binary future events and examining the potential causal impacts that the expectation or occurrence of each event may have on the others in the set. CIA was designed to calculate the basic impact of a political, social, or technological event on the occurrence probability of other events in the set. Due to this ability of CIA to analyze complex contexts with various interactions, CIA is one of the most commonly-used techniques for generating and analyzing scenarios. Another success factor of the approach in scenario analysis is that it is a flexible methodology that can be combined with other techniques such as Delphi [11,12], Fuzzy [13] or Multi-criteria [14,15] methods to allow true collaborative model building and scenario creation by groups.

CIA is based on cross-impact questions that allow individuals to easily estimate the relationships among n events taken two at a time ($n(n\text{-}1)/2$ comparisons). It is an approximation to the real world where we do in fact recognize the further possibility of relationships among three, four, etc. events. This same approximation assumption is used in many other modeling areas such as measures of association and payoff matrices. For ten events a complete description among all possible interactions into the future of their occurrence would require gathering approximately ten million estimates [16]. This is calculated by following all possible occurrence sequences in a tree-like expansion for all possible sequences of events. No expert, manager, or team of judges would ever be able to undertake such an estimation process by Delphi or any other collaborative methods to do this. Many different approximation approaches to analyzing the more limited matrix model have been proposed such as an approximated Bayesian model [17] and an approximated systems dynamic representation [18]. There are even some very simplified approaches that directly solicit from experts the degree of impact between each interaction on an arbitrary scale (i.e. ++, +, 0, -, - -) and treat this as the degree of impact. Further discussions about different approximations approaches can be found in [12]. At the moment the method proposed by Turoff [16] is the only one that changes nonlinear probability measurement scales to linear interval measurement scales which makes it much easier for humans to view and understand the degree of influence one event has on other events as a consequence of their estimates. We observe that even for interactions among as few as ten events it is very unlikely that a single human can stay consistent when there is no feedback to show the consequences of the individual's estimates of impacts. To then combine the individual's judgments with the input from other estimators is not an activity that will lead to a trusted model of the situation. The need for improved visualization methods of all forms of complex data intended for supporting human decision processes is currently a major field of Information Systems and Science.

In this paper, a new method for building scenarios based on CIA is described. This method is an extension of Turoff's CIA approach [16]. We focus on this CIA approach because of its previously mentioned capability of transforming the nonlinear probability measures to linear interval variables, among other advantages:

1. The estimator supplies a set of probabilities for the n events which are indicative of the non-linear nature of the future occurrence of the events. The estimator is then told to assume the opposite of the initial estimate about each event (i.e. if he or she thinks it is likely, they assume it will not occur) and to indicate how the probabilities of all the other events would change.
2. Among other properties of Turoff's model of cross-impact is the result that all the n equations relating the probabilities to one another are solved for a single consistent set of factors that produces an equation for the outcome of each event based upon the values of all the other events. This provides an inferred consistency from the solution method and allows individuals to see the consequences of their model before it is merged with the data of others.
3. The most critical property is that these equations take the non-linear probability factors between 0 and 1 and convert them to linear factors between each event pair that vary from plus infinity to minus infinity for each pair of events, i and j. This

conversion of the non-linear probability factors to linear impact factors allows the estimator (or group if a collaborative estimation) to see a consistent set of linear relationships representing the degree to which a given event influences the occurrence of another (positive factors) or the degree to which a given event inhibits the occurrence of another event (negative factors).

Specifically we propose combining CIA with the technique called Interpretive Structural Modeling (ISM) [19]. The main goal of this combination is using the previously mentioned linear nature of the cross-impact influence factors in order to integrate the CIA in a smooth incremental iterative manner with the ISM method. This allows the user to determine the stopping point for the condensation of events into scenarios and provides for a linear indication of how much of the impact information has been utilized as well as a graphical representation of the results. There are some antecedents for the application of structural analysis to CIA. Duval et al. [20] suggest that a cross-impact matrix can be structurally analyzed and portrayed by a signed directed graph. Novaky and Llorant [21] propose also an intuitive graphical representation based on CIA concepts. Ishikawa et al. [22] introduce a method for processing CIA outputs and building scenarios based on structural analysis concepts. Godet [23] proposes structural analysis for forecasting the key variables which bear on the future dimension. On the other hand, Martino and Chen [24] combine cluster techniques and CIA analysis in order to create 'typical' scenarios. Moreover, there is some previous research focused on using ISM in order to build scenarios and identify key drivers and actors [25]. In this paper we take these ideas and extend them by applying CIA–ISM for building scenarios.

This new CIA–ISM approach adds tools for detecting critical events and graphical representation to the previous scenario-generation methods based on CIA. Moreover, it allows working with large sets of events without using great computational infrastructures, being a graphical representation of complex systems following a simplified structured process. This fact makes this methodology highly compatible with other complex systems analysis tools such as System Dynamics, Bayesian Networks, and Fuzzy Cognitive Maps. Traditional CIA approaches need great computational infrastructures (i.e. Monte Carlo simulation process and SMIC). If the problem has more that 10–15 events, traditional simulation processes cannot be easily designed nor run in a personal computer. Our model can be run in seconds by using basic spreadsheet software.

The contributions of this paper are:

1. The extension of the original cross impact analysis process by Turoff [16] by merging it with the ISM process developed by Warfield [19]. This allows the users of the cross impact model to decide how to combine individual events into one or more scenarios. This process reduces the complexity of the results and produces a better user understanding of the implications of their estimations in creating the model.
2. The extension of the original model to allow the inclusion of initial condition events or the events which allow a probability of truth to be assigned to initial input events. Further we add output events that measure the degree of accomplishment of certain measures or goals at the end of the basic cross impact time period.
3. We present sufficient information and data so that anyone who wishes to duplicate the implementation of the process as described in this paper and the background theory from [16] will be able to carry out an implementation and have two data sets to be able to check the original model or the extended one.
4. We make explicit a set of requirements for carrying out a Delphi process for a group to develop a set of significant events to apply and point to examples in the literature of how this can be done with either a classical paper and pencil Delphi or a Delphi carried out as a Computer Mediated Communications process on the web.
5. We also make explicit the requirements for a Delphi process to collectively make the estimations in creating the model by the use of experts or knowledgeable people in gathering and verifying with them the resulting estimates.
6. Finally we point out how this new method of cross impact and applications of the Delphi make possible a continuous planning process within an organization.

In order to illustrate the CIA–ISM approach step-by-step application, we use Turoff's original example [16]. This will allow others to check the consistency and mathematics of any effort to implement this process and moreover to demonstrate the ability to form meaningful scenarios out of the original event set, using the method of ISM. Based on this example, operational and analytical issues are discussed. Additionally, a new example is also discussed, in which some major extensions to Turoff's CIA approach are provided. This is new 18 event problem of predicting the outcome of software development projects in very different organizational situations. This problem introduces the methodological extensions to CIA of initial condition events and outcome events as two new event types that make CIA much richer in its potential span of application areas. It is thus possible to tailor a single general model to be able to examine very different situations with different initial properties and different outcome goals. These facts have several philosophical and practical implications which are analyzed at the end of the paper. But, firstly, the basics of CIA and ISM will be presented and analyzed in the following section.

2. Methodological background

2.1. Cross-Impact Analysis

In recent years, CIA has resurged as a powerful tool for forecasting the occurrence or not of a set of interrelated events [12,14,15,26,27]. The main goal of CIA is to forecast events based on the principle that the occurrence of events is not independent.

An individual or a group must come up with a set of interrelated events that might occur in the future. It needs to be a balanced set in that the interrelated subset of events that influence one another are often matched by a subset of external events that are largely not influenced by the interrelated set. Often the analysis itself determines which events the group judges to be external. A pure brainstorming or simple Delphi approach might be used to generate candidates for the model and actual use of the model can be used to determine which events may turn out to be less relevant than others to a final scenario or set determination in an iterative process.

The analytical approach proposed by Turoff [16] was developed specifically for restructuring the cross-impact formalisms in a manner suitable for use on an interactive computer terminal. This requires users being able to modify or iterate their estimates until they feel the conclusions inferred from their estimates are consistent with their views. Moreover, Turoff's approach is based on the idea that an event may be unique in that it can only happen once (i.e., the development of a particular discovery or the outbreak of a particular war). Following Turoff, for this type of event there is usually no statistically-significant history of occurrence which would allow the inference of the probability of occurrence. So, the cross-impact problem is to infer casual relationships from some relationships among the different world views. This is established by perturbing the participant's initial view with assumed certain knowledge as the outcome of individual events. The basic steps in the approach are:

1. Take the events that have been chosen and estimate the subjective probability that each event will occur in some future time frame like five years. Then perturb the estimator's judgments a maximum amount.
   a. For events that have a probability of less than 0.5 (maybe), ask the estimator to assume it will occur and to re-estimate the probability of the other events occurring under this hypothesis.
   b. For events that have a probability of 0.5 or more, ask the estimator to assume that event will not occur and to re-estimate the probability of the other events to occur.
2. Once this set of $n(n\text{-}1)$ estimates have been made for the n events the computer can generate a complete structural model of the estimates.
3. If the individual's working model is available to each estimator, it is desirable to let them experiment with their individual cross-impact model to reach consistency among their own estimates. It is then possible to use the internal influence factors, which are linear, to carry out a more consistent averaging process to obtain a single collaborative model for the group results.
4. If the event set spans many different professional areas, than users are more likely to want only to estimate probabilities for those events and event interactions they are more familiar with. That has to be done as a facilitated process such as in a Delphi.

Following this process, subject estimates actually cause participants to estimate the influence (or causality) resulting from assuming occurrence or non-occurrence of given event to change the outcome of the other events. Analytically [9,16], the correlation coefficients (C_{ik}) can be calculated using a variation of the Fermi–Dirac (i.e. logistic) distribution function by asking subjects about the probabilities (P_i) as determined by this relationship.

$$P_i = 1 / \left[1 + exp\left(-G_i - \sum_{i \neq k} C_{ik}\, P_k\right)\right] \qquad (1)$$

where:

P_i represents the probability of occurrence of the i-th event.
G_i (the gamma factor) is the effect of all (external) events not specified explicitly in the model.
C_{ik} represents the impact of the k-th event on the i-th event. Positive C_{ik} means it enhances the occurrence of the event and negative detracts from the occurrence.

G_i is the constant of integration for each of the n differential equations for P_i, $i = 1, n$ when they are integrated as a solution set. It is the same value constant as the individual products of $C_{ik} * P_k$ which allows us to infer that it collects all other influences for the outcome of a given P_i values which must be the sum of all possible events that were not make explicit in the n events included in the model.

Once a model has been established for the group or for an individual it is possible to vary the initial probabilities on individual events and see the degree of influence that has on the occurrence of the other events. There are also internal measures that express quantifiably to what degree a given event is controlled externally to the set, which indicates either that it is truly external or that events might be missing that should have been included. One can also quickly list which events have the most influence on which other events. For further details see [16]. Given the linear influence factors we can show estimators the consistent relative relationships between any event and those that influence it by plotting these on a linear scale. We can now use a different modeling method, ISM, to analyze the complexity of the resulting weighted influence graph. These linear factors are what are needed to have data that can be used as input to the ISM method. The following extension would allow individuals to receive a graphical visualization of their judgments and improve their ability to make improvements. It will allow a group to receive a linear visualization of their collective results.

2.2. Interpretive Structural Modeling

The basic concept of CIA or ISM is 'structural modeling' where professionals who are knowledgeable about at least some portion of the event set can estimate relationships and/or subjective probabilities. This allows the computer to establish a consistent model for one individual or for a group of individuals. In this sense, ISM is a structural analysis-based technique that enables individuals or groups to develop a map of the relationships among the many elements involved in a complex situation [19,28]. The method is interpretive in that the group's judgment determines whether and how items are related; it is structural in that, on the basis of the relationship, an overall structure is extracted from the complex set of items; and it is modeling in that the specific relationships and overall structure are portrayed in a digraph model [29].

Although this methodology dated from the 1970's, we were able to find several applications in recent years [30–39]. This success is due to its variety of advantages, such as: (1) the incorporation of experts' subjective judgments and their knowledge base in a most systematic manner; (2) the ample opportunity for revision of judgments and; (3) the computational efforts involved in ISM are less for objectives so it can be used as a handy tool for deriving quick managerial insights [35].

The ISM process starts with the analysis of elements (objectives, actions, outcomes, etc.) affecting the complex system under study [40]. This information is in the mental model of the individual/group. Once these elements are determined, the mental model is transformed into a matrix model. By means of the partitioning and extracting of the matrix model, we can obtain a multilevel diagraph. The resultant digraph is converted into an ISM, by substituting the notation of each element with statements. This process admits feedback between different stages in order to compare and correct the inputs of the model. Once the participants are confident with the output the ISM process should be documented (Fig. 1).

This ISM process has solid mathematical foundations. Here we are going to give some basic definitions and concepts based on [19,41] that are necessary for understanding the CIA-ISM. From an analytical perspective, the starting point of ISM methodology is a collection of S events.

$$S = \{s_1, s_2, s_3, \ldots, s_n\}. \tag{2}$$

The Cartesian product $S \times S = T$ is called the working space of the model. The statement 'R is a relation in the working space' can be stated symbolically by $R \subset T$. A relation R is said to be transitive if, given any two edges (s_i, s_j) and (s_j, s_k) in R, it is also true that (s_i, s_k) is in R. Note that transitivity is needed for applying ISM. If a relation R is not transitive, there exists in T some increment ΔR such that the union of R with ΔR is transitive, and such that no edge appears in ΔR that is not necessary to make the union transitive. Then $R \cup \Delta R$ is called the *transitive closure* of R.

The relationships between the elements in set S are binary. From these binary relations we can calculate the adjacency matrix (A), defined as a binary $n \times n$ matrix where the entry 1 represents the direct connection from node s_i to node s_j. The adjacency matrix is a means of representing which vertices of a graph are adjacent to which other vertices. From this matrix, we can obtain the reachability matrix (M), which is a square, transitive, reflexive, and binary matrix:

$$M = (A + I)^k \tag{3}$$

where k is determined such that

$$(A + I)^{k-1} < (A + I)^k = (A + I)^{k+1} \tag{4}$$

and where I is the identity matrix.

Suppose s_i and s_j are elements of the set S. If $M(s_i, s_j) = 1$, this indicates that node s_i and node s_j are connected. If $M(s_i, s_j) = 0$, this indicates that it is impossible to go from node s_i to node s_j. The resulting reachability matrix of 1's and 0's indicates which nodes have links to one another and one may trace any possible paths between the nodes.

Every element in set S can be considered as a node and solved by graph theory in order to obtain a diagraph D(R) of R, where there is an edge in D(R) for every edge in R except those edges of R whose two elements are identical. A walk on a digraph is a directed path on the digraph with an origin and a termination consisting of vertexes of the digraph. A nontrivial walk on D(R) is

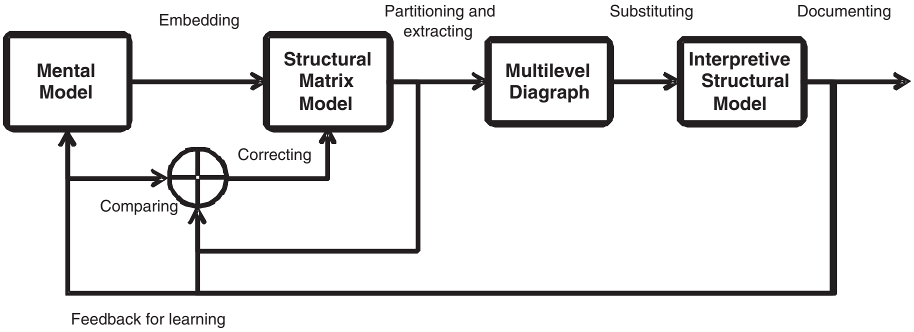

Fig. 1. The ISM process—adapted from [40].

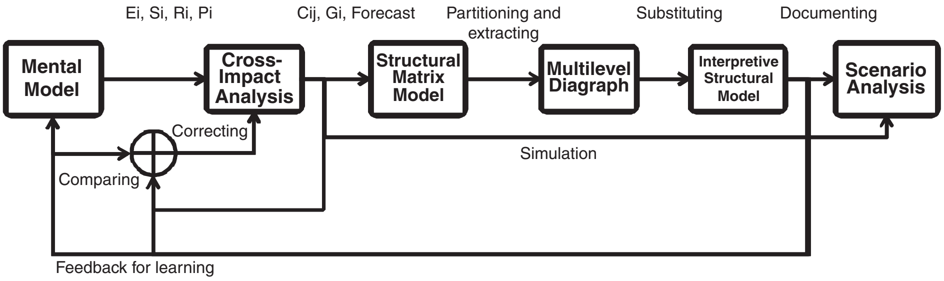

Fig. 2. The CIA–ISM process.

any walk on D(R) whose origin and termination are distinct. A walk $W_1(s_i, s_j)$ of length k_1 is called a path of the diagraph provided the length of any other walk $W_2(s_i, s_j)$ has length at least as great as k_1.

A cycle in S is a universal relation on a collection $C \subseteq S$. A universal relation on a collection C consists of all members of $C \times C$. Suppose s_i and s_j are distinct vertices of a diagraph, and suppose $W_1(s_i, s_j)$ and $W_2(s_j, s_i)$ are walks on the diagraph. Then there is a walk $W_3(s_i, s_j)$ on the diagraph found by the concatenation of walks W_1 and W_2. Such a walk is called a cycle. If W_1 and W_2 are both paths, the walk W_3 is called a geodetic cycle induced by s_i and s_j, since there is no cycle involving vertices s_i and s_j that is shorter in length than W_3. All the vertices contained in a cycle make up a cycle set. This concept of cycle set in very important in our approach since it is the basis of developing micro-scenarios. For a further explanation, see [19,40–44].

3. Bulding scenarios with a CIA–ISM approach

In Fig. 2, our proposal for the methodological merger between CIA and ISM is exposed. In this new approach, the structural matrix model is obtained from processing the C_{ij} and G_i factors. That is, the input of the ISM is the output of the CIA.

The use of ISM is an iterative process in which one takes first the largest absolute values of the influence factors and applies the ISM method until a cluster (cycle in graph) of events or mini-scenario is created. A mini-scenario is a set of events that due to their strong relationships should occur in a specific combination, so they can be treated as a macro-event.

This is presented back to users and more of the lesser influence factors are added to produce additional clusters of mini-scenarios. The resulting process reduces the complexity of the problem, in so that instead of n events we have a reduced number of elements made up of original single events and some mini-scenarios created from a combination of other original events.

For the users, this means they can picture the collapsing process and decide where they want to stop the process to be able to deal with a model that has a lesser number of elements than the original model. If this is being done to develop a plan of action of some type one would not want to have a single cluster or mini-scenario that combined events representing decision actions the organization could take. If they did this it would restrict the ability to treat decision options and independent options in examining future potential outcomes. In this way, an organization can use the resulting model to test the influence of these key decision factors in the planning process by changing the initial probability levels to observe the outcome on the other events.

So, the ISM output along with the CIA simulation output is the base of the scenarios analysis. We are going to illustrate this process using the example of the original Turoff's paper step-by-step[1] [16]. In the original paper, a single economist developed and estimated the cross impact factors for what he felt were the ten critical events for the U.S. economy in the decade following 1971 (Table 1).

Their event numbers in the following analysis will represent these ten events.

3.1. Cross-Impact Analysis

The main output of the CIA process is a cross-impact matrix (Table 2). The calculation process of this matrix is fully explained in [16]. The rows and the columns of the matrix are the events, the cells are the influence factors C_{ij} (Eq. (1)), the diagonal being the overall probabilities (OPV). Note that the cross-impact matrix is associated with the G vector.[2]

The G vector (column) represents the influence of external events on each i-th event. The row for G_i is all zero since the explicit internal events do not influence the unknown external events. Based on this cross-impact matrix we are able to forecast a scenario by means of making hypothesis about the occurrence (or not) of the events E_i. We can obtain this results running the simulation algorithm explained in [16, p. 354]. In this example, we obtain a scenario forecast in which events 1 and 6 are supposed to occur and the rest are not.

[1] An earlier version of this paper dealing with original 1972 problem and Emergency Management applications of forming mini-scenarios was presented at the ISCRAM 2010 conference (http://iscram.org).

[2] Authors' note: There was an erratum in the original paper. The symbol of the gamma factor linked to the 10-th event appeared as positive.

Table 1
Events of the original paper.

Event number	Description
1	The U.S. gets into a trade war with one or more of its major trading partners (Japan, Canada, and western European countries).
2	Comprehensive tax revisions enacted with most present exemptions and exclusions removed, but with rates lowered.
3	Rigorous anti-pollution standards are adopted and strictly enforced for both air and water.
4	The U.S. averages at least 4% per year growth rate of real GNP for the time frame.
5	Defense spending declines steadily as a per cent of the federal government's administrative budget.
6	The U.S. experiences at least one major recession (GNP Decline is greater than 5% for a duration greater than 2 quarters) during the ten-year period.
7	A federal income maintenance system (e.g., negative income tax) replaces essentially all current state and local welfare programs.
8	The oil import quota system is phased out and domestic oil prices allowed to fall to the world price.
9	The U.S. agricultural price support system is dismantled.
10	A federal, -state and local revenue-sharing program is adopted which allocates at least 5% of federal revenues to state and local governments.

Table 2
Cross-impact matrix and *G* vector.

	1	2	3	4	5	6	7	8	9	10	G_i
1	OVP	−0.29	0.00	−0.81	−0.33	1.57	0.00	−0.25	−0.22	0.00	0.23
2	−0.50	OVP	−0.23	0.46	0.00	−0.77	0.90	0.29	0.25	0.42	−1.33
3	−0.41	0.31	OVP	0.43	0.74	−0.58	0.00	0.27	0.24	0.68	−0.30
4	−0.81	0.58	0.07	OVP	0.33	−1.21	0.33	0.25	0.22	0.33	−0.05
5	−0.88	0.58	−0.14	0.81	OVP	−0.31	0.74	0.00	0.00	0.36	−1.02
6	0.88	−0.36	0.00	−2.70	−0.42	OVP	−0.38	−0.31	−0.28	−0.38	0.88
7	−0.41	0.99	0.00	0.88	1.16	−0.29	OVP	0.00	0.00	0.68	−0.91
8	−1.62	−0.50	0.00	0.58	0.48	−1.16	0.00	OVP	0.60	0.58	−0.97
9	−1.49	0.00	0.00	0.93	0.00	−1.07	1.25	1.01	OVP	1.25	−3.29
10	−0.41	0.99	−0.14	0.88	1.16	−0.58	0.68	0.00	0.00	OVP	−0.74
G_i	0	0	0	0	0	0	0	0	0	0	OVP

3.2. Structural matrix model

Our starting point for the structural matrix model is the cross-impact matrix, obtained with the CIA (Table 2). As mentioned in a previous section, ISM needs as input an *A* matrix, that should be square, positive and binary. The cross-impact matrix is a square matrix but is neither positive nor binary. So firstly, we need to transform the cross impact matrix in to a positive matrix; that is, a matrix with all its elements equal to more than zero (Table 3). This is the unfolding of the weighted directed graph cross impact factors (Table 2) into a positive definite matrix where the occurrence and non-occurrence of each event is now a separate node in the graph. This results in a symmetric positive definite matrix in which the properties between the occurrence and the non-occurrence are:

$$+E_i \rightarrow +E_j \text{ implies that } -E_i \rightarrow -E_j$$
$$-E_i \rightarrow +E_j \text{ implies that } +Ei \rightarrow -E_j$$
$$\text{short hand } +i \rightarrow +j \text{ implies } -i \rightarrow -j$$

with events 1 to *n* and −1 to −*n* being the rows and columns we have in the matrix's four areas. The two areas around the diagonal use the $C_{ij} > 0$, and the opposite areas use the $C_{ij} < 0$ in but the absolute values (Table 3).

Secondly, we are going to transform this matrix to binary. To reach this aim, we need to decide what the limit is to consider the C_{ij} as relevant.

In our case, we assume an arbitrary value (0.85) as the lower limit for reachability in order to illustrate the process. The result of this transformation is the *A* matrix (Table 4). From this adjacency matrix, we can obtain the *M* matrix as was previously explained in expression (4).

Table 3
Transforming the cross-impact matrix into positive elements.

	Occurring events (E_i)	Non-occurring events ($-E_i$)
Occurring events (E_i)	$+C_{ij}$	$-C_{ij}$
Non-occurring events ($-E_i$)	$-C_{ij}$	$+C_{ij}$

Table 4
Adjacency matrix for $|C_{ij}|>0.85$.

	1	2	3	4	5	6	7	8	9	10	−1	−2	−3	−4	−5	−6	−7	−8	−9	−10
1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	1	1	0
2	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	1	0	1	1	0	0	0	0	0	1	0	0	0	0
5	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0
6	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	1	0
7	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
−1	0	0	0	0	1	0	0	1	1	0	0	0	0	0	0	1	0	0	0	0
−2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1
−3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
−4	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	1	1
−5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1
−6	0	0	0	1	0	0	0	1	1	0	1	0	0	0	0	0	0	0	0	0
−7	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0
−8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
−9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
−10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0

3.3. Multilevel diagraph

Then, we apply ISM in order to obtain the representation of the multilevel diagraph as explained in [19]. We have to divide the nodes into two sets: antecedents (*Ant*) and succedents (*Suc*).

Suc is of the set construed with element s_i to all that can reach element s_j. *Ant* is of the set construed with all of the elements s_j that can reach element s_i. The intersection between them will give us the intersection set (*Int*) (Table 5). Due to our having two symmetric sets of events, we will obtain two symmetric diagraphs. In order to avoid duplication, we are going to represent a unique diagraph with two groups of events. We will use the term 'group of events' to denote a set of events with the same destiny of occurrence (or not). We have two groups: occurring events ($+E_i$) and non-occurring events ($-E_i$) (Table 3). Regarding the interrelations between events, connections between events of the same group represent positive impacts; connections between events of different groups represent negative impacts. In Fig. 3 events have been classified in to the groups according with the forecast obtained by means of the CIA analysis.

The diagraph expressed in Fig. 3 includes connections between all events except for event 3. This failure of the method to include event 3 in the diagraph is because all impacts related to event 3 are less than the arbitrary value 0.85. Note that we need to discard information when we take the C_{ij} weights and convert them to zero or one. We are going to avoid this limitation by treating the adjacency matrix determination as a sensitivity analysis. By means of this analysis, the clustering process as it occurs among events can be represented sequentially. The users should choose how far down they want to go (Fig. 4, Table 6).

This sensitivity analysis starts with the analysis of the $|C_{ij}|$ distribution. Applying the K-S test, we find that the $|C_{ij}|$ follows a Normal distribution with a reliability of 99% (p value = 0.308). If we take the non-zero $|C_{ij}|$ values and plot the number of them as a histogram from zero to the largest absolute value, we have the |Cij| distribution. Now we are going to apply the structural analysis by taking the k% largest absolute values for C_{ij}. Fig. 5 shows the diagraph for percentile 90.

This diagraph only includes the high impacts between events. That is, in this diagraph events 2, 3, and 5 are not in the representation. Fig. 6 illustrates the diagraph for percentile 80. At this level of analysis, we represent the events 5 and 2 in the diagraph, but not event 3.

The analysis of the percentile 70 is the same as the initial example (Fig. 3), so we go through the diagraph for percentile 60 (Fig. 7).

Analyzing the output of the CIA–ISM for percentile 60, we are able to make a complete forecast about occurrence of the events in the set along with a graphical interpretation of the impacts between them. In other words, we have a complete forecasted scenario. Additionally, we have some cycles in the diagraph that indicate strong connections between some of the events. As mentioned previously, these cycles may be interpreted as mini-scenarios of events that are robustly interrelated in their occurrence. So one may represent the results of Fig. 7 in the following as providing 3 independent events and two independent mini-scenarios:

$$-3,-8,-9,((6,-4),1),(-2,-10,-7,-5)). \tag{5}$$

At this stage, a person or group can decide to what extent they want to utilize these results to reduce essentially the ten events to essentially five events where two of them are really mini-scenarios. We may continue this process of clustering events into mini-scenario by means of treating the adjacency matrix determination as a sensitivity analysis until we found a $|C_{ij}|$ value for which an E_i event has at the same time, as antecessor or successor the occurrence and non-occurrence of an event E_j. We call to this

Table 5
Sets for |Cij|>0.85.

	Ant	Suc	Int	L1	Ant	Suc	Int	L2	Ant	Suc	Int	L3	Ant	Suc	Int	L4	Ant	Suc	Int	L5
1	1,6,−4	1,6,−2,−4,−5, −7,−8,−9,−10	1,6,−4		1,6,−4	1,6,−2,−4,−5, −7,−8,−10	1,6,−4		1,6,−4	1,6,−2,−4, −5,−7	1,6,−4		1,6,−4	1,6, −4,−5	1,6,−4		1,6,−4	1,6,−4	1,6,−4	1
2	2,4,5,7, −1,−6	2,7,9,10	2,7		2,4,5,7, −1,−6	2,7,10	2,7		2,4,5,7,−1, −6	2,7	2,7	2								
3	3	3	3	–																
4	4,−1,−6	2,4,5,7,8,9, 10,−1,−6	4,−1, −6		4,−1,−6	2,4,5,7,8,10, −1,−6	4,−1, −6		4,−1,−6	2,4,5,7,−1, −6	4,−1, −6		4,−1, −6	,4,5, −1, −6,	4,−1, −6		4,−1, −6	,4,−1, −6	4,−1, −6	4
5	4,5,−1,−6	2,5,7,9,10	5		4,5,−1,−6	2,5,7,10	5		4,5,−1,−6	2,5,7	5		4,5, −1, −6	5	5	5				
6	1,6,−4	1,6,−2,−4,−5, −7,−8,−9,−10	1,6,−4		1,6,−4	1,6,−2,−4,−5, −7,−8,−10	1,6,−4		1,6,−4	1,6,−2,−4, −5,−7	1,6,−4		1,6,−4	1,6, −4,−5	1,6,−4		1,6,−4	1,6,−4	1,6,−4	6
7	2,4,5,7, −1,−6	2,7,9,10	2,7		2,4,5,7, −1,−6	2,7,10	2,7		2,4,5,7,− 1,−6	2,7	2,7	7								
8	4,8,−1,−6	8,9	8		4,8,−1,−6	8	8	8												
9	2,4,5,7,8,9, 10,−1,−6	9	9	9																
10	2,4,5,7,10, −1,−6	9,10	10		2,4,5,7,10, −1,−6	10	10	10												
−1	−1,−6,4	−1,−6,2,4,5, 7,8,9,10	−1, −6,4		−1,−6,4	−1, −6,2,4,5,7,8,10	−1, −6,4		−1,−6,4	−1, −6,2,45,7	−1, −6,4		−1, −6,4	−1, −6,4,5	−1, −6,4		−1, −6,4	−1, −6,4	−1, −6,4	−1
−2	−2,−4,−5, −7,1,6	−2,−7,−9,−10	−2, −7		−2,−4,−5, −7,1,6	−2,−7,−10	−2, −7		−2,−4, −5,−7,1,6	−2,−7	−2, −7	−2								
−3	−3	−3	−3	–																
−4	−4,1,6	−2,−4,−5,−7, −8,−9,−10,1,6	−4,1,6		−4,1,6	−2,−4,−5,−7, −8,−10,1,6	−4,1,6		−4,1,6	−2,−4, −5,−7,1,6	−4,1,6		−4,1,6	,−4, −5,1,6,	−4,1,6		−4,1,6	, −4,1,6	−4,1,6	−4
−5	−4,−5,1,6	−2,−5,−7, −9,−10	−5		−4,−5,1,6	−2,−5,−7,−10	−5		−4,−5,1,6	−2,−5, −7	−5		−4, −5,1,6	−5	−5	−5				
−6	−1,−6,4	−1, −6,2,4,5,7,8,9,10	−1, −6,4		−1,−6,4	−1, −6,2,4,5,7,8,10	−1, −6,4		−1,−6,4	−1, −6,2,4,5,7	−1, −6,4		−1, −6,4	−1, −6,4,5	−1, −6,4		−1, −6,4	−1, −6,4	−1, −6,4	−6
−7	−2,−4,−5, −7,1,6	−2,−7,−9,−10	−2, −7		−2,−4,−5, −7,1,6	−2,−7,−10	−2, −7		−2,−4, −5,−7,1,6	−2,−7	−2, −7	−7								
−8	−4,−8,1,6	−8,−9	−8		−4,−8,1,6	−8	−8	−8												
−9	−2,−4,−5,−7, −8,−9,−10,1,6	−9	−9	−9																
−10	−2,−4,−5, −7,−10,1,6	−9,−10	−10		−2,−4,−5, −7,−10,1,6	−10	−10	−10												

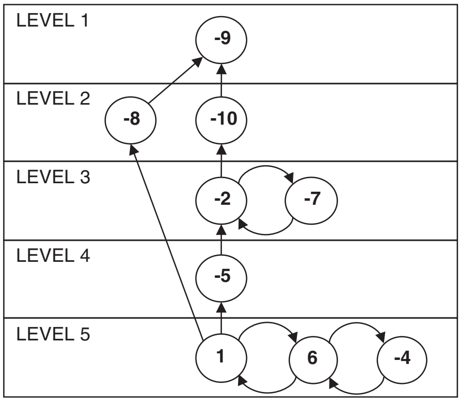

Fig. 3. Diagraph for $|C_{ij}|>0.85$.

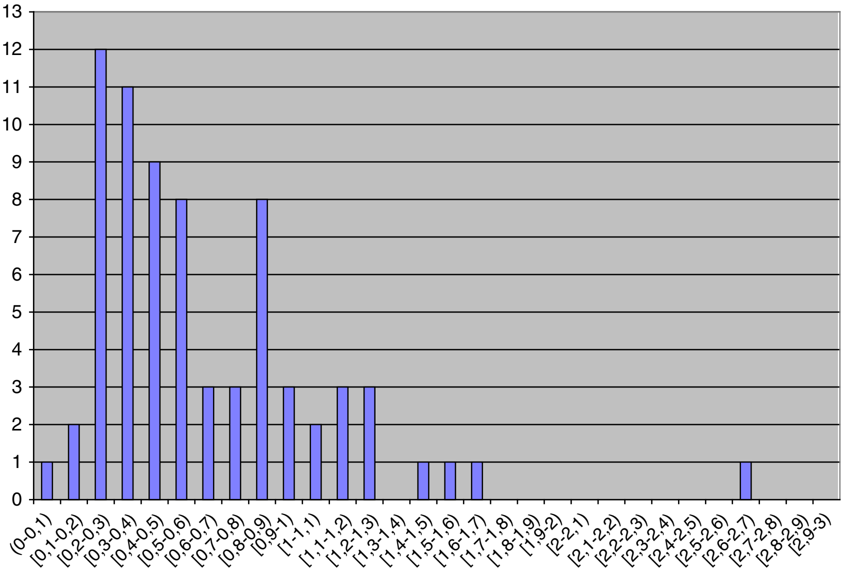

Fig. 4. $|C_{ij}|$ distribution histogram.

$|C_{ij}|$ value the limit of the forecasted scenario. In this example the limit is $|C_{28}|=0.4975$. In next section the scenario for this limit will used as be expressed in the ISM.

3.4. Interpretive structural model

In the ISM stage we replace in each diagram the labels of the events for their statements. In Fig. 8 is represented the ISM for $|C_{ij}|>0.4975$, the limit of the forecasted scenario. Note that in this stage we have represented the group of events $+E_i$

Table 6
Percentiles of the $|C_{ij}|$ distribution.

Percentile 90	1.1581
Percentile 80	0.9198
Percentile 70	0.8109
Percentile 60	0.6450
Percentile 50	0.5389
Percentile 40	0.4132
Percentile 30	0.3409
Percentile 20	0.2950
Percentile 10	0.2508

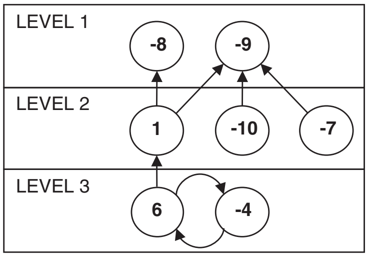

Fig. 5. Diagraph for $|C_{ij}|>1.1581$.

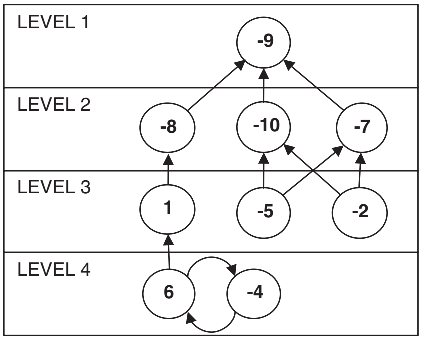

Fig. 6. Diagraph for $|C_{ij}|>0.9198$.

(occurring events) shaded in gray and $-E_i$ (non-occurring events) in white. Based on these results experts are able to compare the ISM results with their mental model and, in case, correcting their initial estimations (Fig. 8).

The main of this feedback process is avoiding any conceptual inconsistency. Once the experts are confident with the results of the ISM the scenario analysis should be carried out.

3.5. Scenario analysis

In terms of reliability, the forecasted scenario (Fig. 8) contains 51.38% of the C_{ij} of the model and over the 75% of their sum. This ISM result is supported by the analytic simulation method expressed in [16] so we can say that the forecast is consistent and includes the greater part of the impacts of the model. Nevertheless, in the process of stepping through the incorporation of more of

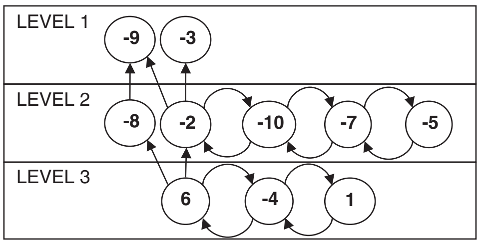

Fig. 7. Diagraph for $|C_{ij}|>0.6450$.

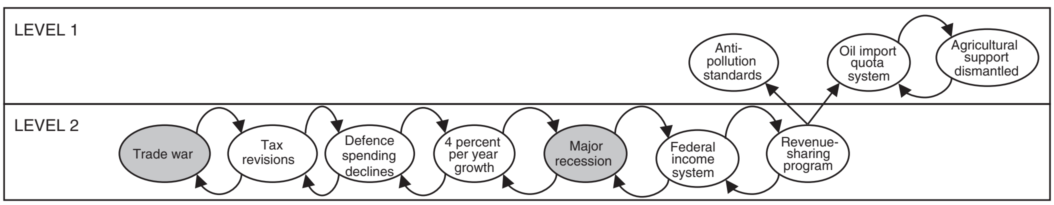

Fig. 8. ISM for $|C_{ij}|>0.4975$.

the larger C_{ij} factors and reviewing the resulting model for all C_{ij}'s greater than (or equal) to an absolute value we are, in fact, ignoring a remaining set of C_{ij}'s below that value. So it is possible to apply an ISM analysis for the remaining $|C_{ij}|<0.4975$ to provide a model of the relationships we have ignored. These interrelations would be easily analyzed by means restarting the process of treating the adjacency matrix determination as a sensitivity analysis as many times as necessary.

While interesting, taking an event set to the limit makes the results too simple to be useful in trying to create a dynamic model to try different variations of initial P_i values to see the impact on the outcomes. Scenarios are useful if they have a meaningful theme. Analyzing the ISM of the forecasted scenario (Fig. 8), we can in principle group any of the level 2 events in to subsets. For example, (trade war and major recession) represents the strongest negative outcome and might well be a negative scenario. Creating other scenarios in this case of say actions that can be taken like (tax revisions and revenue sharing) and consequence scenarios like (high growth and reduction of defense spending) are clearly possible choices. We will discuss this more in the second problem where we will examine sensitivities in a number of ways.

4. Major extensions to cross-impact models

Some important factors allow us to extend the original 1972 model to represent a much wider set of relationships than the original cross impact formalism:

- The Fermi Dirac distribution represents in Quantum Mechanics the distribution for whether an atom is in or is not in an excitation state. This is an event that occurs or does not occur. This is very analogous to the concept of whether an event occurs or does not occur in the future.
- The transformation allowed by this relationship converts a subjective probability estimate, a nonlinear parameter, to linear cross impact factors varying from plus infinity to minus infinity with the zero (i.e. origin) value reflecting a “0.5” probability or an odds ratio of “1.0”.
- The probability concepts in Quantum Mechanics reflect probability estimates of casual relationships that do not follow the probability calculus.

The result of the above is that we conceptually think about the C_{ij} and the G_i as linear influence factors that we may add and subtract to obtain additional measures of influences. What we have done is converted a non-linear scale to a linear one. Not only does the above allow us to employ ISM to recognize meaningful scenarios among the original event set but it also allows us to view this method of CIA [16] as scaling theory for subjective judgment in the sense that Torgerson [45] originally interpreted scaling theory. Being a physicist by training, he viewed Scaling Theory as the investigation and development of measurement instruments for human judgment. To many scientists the improvement of measurement instruments was fundamental to the ability to confirm or disprove theoretical hypotheses as well as creating new theories to explain new observations provided by the instruments. A further observation in the classical probability literature is that the φ_i factors [16] have been interpreted as “weight of evidence (WOE)” [46], which implies an additive (linear) quality. Both probability and the measure of odds are highly non-linear and they do not allow the easy visualization that the linear scale of the C_{ij} provided. For that reason that it is helpful to provide subjective scales for making probability and/or validity estimates (Table 7).

This linear property also allows the meaningful clustering of the events into mini-scenarios. If we accept the above viewpoints as the way to view this particular cross-impact approach, it becomes easy to conceptualize the following characteristics and extensions to the basic model. These are illustrated in the problem we have chosen as an example of these extensions.

Table 7
Subjective scales for making probability and/or validity estimates.

Numeric	Probability	Validity	Odds ratio	Log(odds)	Ln(odds) [a]
	Possibility	Degree of truth		WOE(10)	WOE(e)
1.00 (0.99)	Certain to occur	Certain to be true	99.00	2.00	4.60
0.90–0.98 (0.95)	Very probable	Very probably true	19.00	1.28	2.94
0.80–0.89 (0.85)	Highly probable	Highly probably true	5.67	0.75	1.74
0.70–0.79 (0.75)	Probable	Probably true	3.00	0.48	1.10
0.60–0.69 (0.65)	Likely	Likely to be true	1.86	0.27	0.62
0.56–0.59 (0.57)	Possible	Possibly true	1.33	0.12	0.29
0.45–0.55 (0.50)	Unknown/no judgment	Unknown no judgment	1.00	0.00	0.00
0.41–0.44 (0.43)	Possibly not	Possibly not true	0.75	−0.12	−0.29
0.31–0.40 (0.35)	Unlikely	Unlikely to be true	0.54	−0.27	−0.62
0.21–0.30 (0.25)	Improbable	Improbably true	0.33	−0.48	−1.10
0.11–0.20 (0.15)	Highly improbable	Highly improbably true	0.18	−0.74	−1.71
0.02–0.10 (0.05)	Very improbable	Very improbably true	0.05	−1.30	−3.00
0.00 (0.01)	Certain to not occur	Certain to be false	0.01	−2.00	−4.61

[a] The original work on WOE used log to the base 10 but we really need to use Ln to the base e, natural logs since that is what is used in our distribution function and the calculation of the C_{ij}.

Dynamic Events (E_i): We have always assumed that the dynamic events could or could not occur during a certain time period. Within that time period, the factors we are estimating between E_i and E_j are measures that are valid during that time period. We also interpret the G_i as an expression of the influence on the *i*-th event of all the events we did not make explicit in the model we are creating.

Source Events (I_i): One can also include source events, initial conditions, assumptions, or events that have already occurred for the problem being treated. In this case, all such source events are assumed to be 0.5 probabilities. When the model is applied to a given situation one can decide if the event has occurred or not occurred. No events in the set can influence the source events. Therefore if *k* is a source event all $C_{ki}=0$ for any other event type *i* as does G_k (to give the initial value of $P_k=0.5$). Conversely, the estimator can judge the R_{ik} or S_{ik} for all the other events so that a C_{ik} can be determined [16].

Outcome Events (O_i): These are events that occur at the end of the time period that measure the results of the system that is being modeled. For example, if one is measuring a conflict situation between two entities then one can define a probability of success for one entity which is one minus the probability of success of the other entity. In the example, we have chosen there will be a number of outcomes having to do with performance and cost measures. In this case, any of the source or dynamic events can influence these outcome events; however, the outcome events cannot influence the other events. If *k* is an outcome event all $C_{ik}=0$ for *i* events that are either source or dynamic. Conversely one can judge the R_{ki} or S_{ki} for *k* outcome events and *i* source or dynamic events.

4.1. The problem

Since this will be a one person model rather than a composite by experts, we resort to a topic one of the authors has familiarity with, having taught it for a considerable number of years. The choice of events and the estimates for those events are by Dr. Turoff.

Even today, there is considerable error in the predictions of the cost and performance of a software development process. A large percentage of software development projects end up to be failures in terms of either the non-performance of the desired results for the users, or in much higher than estimated costs. The events of the model reflect a series of lectures to a graduate course in the Management of Information Systems. However, the model presented here does reduce a somewhat larger set of potential events to a set of 4 source events, 10 dynamic events, and 4 outcome events. This represents about 196 consistent estimates that must be made by a single estimator and is about twice the number needed for the original 1972 ten-event set. The problem of collaboratively treating the estimation of a larger set will be taken up after this example. We will only give a few explanations to illustrate the thinking that goes into such an event set. Our major goal here is to illustrate the expanded cross-impact modeling capability. The events below have a short title to be used in listing the analytical results.

4.1.1. Source events

The Source events or the initial conditions that can be judged, usually to be true or false, at the beginning of the time period are:

I1. Evaluation Organization: An evaluation unit exists outside of the existing computer services organization(s) (indicates a time in the past when the computer operation ran amuck and a formal control group had to be established).

I2. Minimal Internal Development: The organization has a general management policy of using off the shelf software where possible (indicates limited ability to develop new applications internally).

I3. Management Computer Literacy: Management is expected to be computer literate in Decision Support Applications (indicates some significant degree of computer literacy for all levels of management).

I4. Technology oriented: The organization deals with technological products and/or services (indicates some significant degree of computer literacy for most types of professionals).

The degree to which each of the above is true or false about the organization gives some much needed background about what types of problems can or cannot occur. By knowing the organization one can reset the 0.5 probability in the final model to higher or lower values and see the impact upon the results.

4.1.2. Dynamic events

The dynamic events are the core of the modeling process and their initial values are chosen to reflect current wisdom about their likelihood. They are also chosen to provide a balanced model where possible negative influences as well as positive influence events are somewhat equally represented. A good cross impact model should reflect a range of outcomes from desirable to undesirable, depending to some extent on choices available to the management of the organization being modeled.

E1: Requirements by Management: A management Committee decides on the final requirements for the system.

E2: Requirements by computing professional: A professional software engineer decides on the final requirements for the system.

E3: Requirements by users: A sizable requirements study effort involving significant user participation determines the requirements.

E4: Modification of existing software by organization: An existing application package is purchased and modified by the organization to meet the requirements.

E5: Modification of existing software by supplier: An existing application package is purchased and modified by the supplier to meet the requirements.
E6: Prototype first: A prototype is developed and tested by the users in parallel with the existing system.
E7: Evolutionary Development: An evolutionary or incremental approach is taken for the development of the system.
E8: Upfront Cost-Benefit study: A detailed cost-benefit study is undertaken before requirements are fully developed.
E9: Cost-Benefit after requirements: A detailed cost-benefit study is done after the requirements are specified.
E10: Evaluation of Existing Applications: Regular evaluation and modification studies are typical of existing software applications in this organization.

Clearly this is a top level set of some of the most important and obvious considerations that affect the outcome of a software development process. There are many more factors that can be brought in but it would really require collaboration where different contributors would focus on the estimates that represent the factors that they feel confident in dealing with.

4.1.3. Outcome events

We have specified two typical negative outcomes followed by two positive ones. These reflect both the effectiveness vs. efficiency paradox and the difference between long and short term considerations.

O1: Development Costs: Development costs significantly exceed original estimates.
O2: Maintenance Costs: Maintenance costs significantly exceed original estimates.
O3: Effectiveness: System is considered a success by both the direct and indirect users of the system's outputs.
O4: Low Life Cycle costs: The life cycle costs are low for this type of application.

In most cases the first two are more likely $P_i = 0.6$ than the latter two $P_i = 0.4$ and you will note the initial values for those reflect that difference.

4.2. Cross-Impact Analysis

Once we obtain the subjective probabilities, we are able to build the cross-impact matrix (Table 8).

In order to get a numerical estimate of the total variability in the matrix of influence factors we examine the following linear sums of C_{ij} for the original C_{ij} matrix

$$|\text{Source Events Influences}| = \sum |C_{iI}| = 103.53 \tag{6}$$

$$|\text{Dynamic Events}| = \sum |C_{ij}| - \sum |C_{iI}| = 213.83 \tag{7}$$

$$|\text{External (unspecified) Event influences}| = \sum |G_i| = 30.69. \tag{8}$$

Table 8
Cross impact matrix and *G* vector.

	I1	I2	I3	I4	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	O1	O2	O3	O4
I1	OVP	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
I2	0.00	OVP	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
I3	0.00	0.00	OVP	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
I4	0.00	0.00	0.00	OVP	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
E1	−1.08	4.47	−2.70	−1.08	OVP	−0.39	−3.44	0.74	0.59	−2.63	−2.79	2.26	0.98	−2.48	0.00	0.00	0.00	0.00
E2	−0.46	−0.96	−1.53	−1.53	−1.10	OVP	−3.09	2.86	−0.64	0.56	−1.28	1.37	0.42	0.85	0.00	0.00	0.00	0.00
E3	1.53	−0.43	3.16	1.53	−1.46	−1.26	OVP	0.00	0.00	3.31	3.52	−2.67	1.13	2.62	0.00	0.00	0.00	0.00
E4	−1.39	3.58	0.00	4.28	0.00	−0.68	−1.25	OVP	0.00	−2.11	0.00	−0.59	−2.28	−1.39	0.00	0.00	0.00	0.00
E5	−0.58	6.59	0.96	1.80	0.00	−1.69	−3.82	0.00	OVP	−2.92	−3.54	0.34	−3.54	−2.16	0.00	0.00	0.00	0.00
E6	2.42	−1.27	0.93	0.93	−1.90	0.71	3.29	0.00	0.00	OVP	2.68	−3.44	3.15	0.99	0.00	0.00	0.00	0.00
E7	1.62	−1.96	3.12	1.62	−0.77	1.25	3.44	−1.63	0.00	3.26	OVP	−4.78	1.78	3.98	0.00	0.00	0.00	0.00
E8	0.00	0.96	1.39	0.96	0.36	0.74	−5.07	0.80	0.00	−2.29	−3.11	OVP	−5.99	−2.76	0.00	0.00	0.00	0.00
E9	1.29	−0.80	1.80	0.84	−1.17	1.38	0.00	0.70	0.00	1.23	−0.81	−0.81	OVP	−1.32	0.00	0.00	0.00	0.00
E10	−1.62	−2.70	1.49	1.49	−3.72	1.15	5.07	−1.35	0.00	4.22	6.43	−3.47	3.26	OVP	0.00	0.00	0.00	0.00
O1	−0.88	1.62	−1.96	−0.88	0.58	−1.51	0.68	0.00	1.08	0.52	−2.24	0.54	−1.47	−1.39	OVP	0.00	0.00	0.00
O2	−1.96	3.58	−1.96	−1.96	0.58	−1.51	−1.25	1.35	1.08	−1.47	−2.24	0.54	0.00	−1.39	0.00	OVP	0.00	0.00
O3	1.96	−1.62	1.96	3.58	−0.58	0.68	2.76	−1.35	−1.08	2.11	2.24	−0.54	1.47	1.99	0.00	0.00	OVP	0.00
O4	3.58	−1.62	1.96	3.58	−0.58	0.68	2.76	−1.35	0.00	1.47	3.25	−0.54	0.00	1.99	0.00	0.00	0.00	OVP
Gi	0.00	0.00	0.00	0.00	0.68	2.35	−1.64	−0.03	1.85	−2.99	−2.19	3.95	−1.54	−1.42	1.75	1.35	−3.95	−5.01

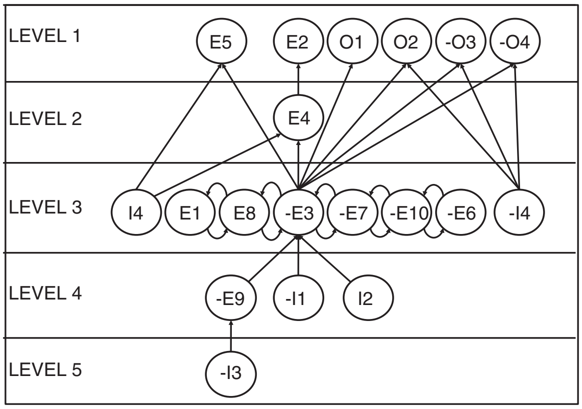

Fig. 9. Diagraph for $|C_{ij}| > 1.69$.

In the original model the total of all influences is

$$|\text{Total Impacts}| = \sum |C_{ij}| + \sum |G_i| = 348.07. \tag{9}$$

This allows us to calculate the relative fractions or percentages of the impacts due to each type of event.

$$|\text{Source events impact}| \,/\, |\text{Total Impacts}| = 0.30 = 30\% \tag{10}$$

$$|\text{External events Impacts}| \,/\, |\text{Total Impacts}| = \sum |G_i| / \left(\sum |C_{ij}| + \sum |G_i|\right) = 0.09 = 9\%. \tag{11}$$

Therefore, only 9% of the influences are due to the events we did not specify. The dynamic events make up 61% of the influences. We see that the source and the unknown external events account for 39% of the influence and the dynamic events of the model account for 61% of the influence.

4.3. Scenario analysis

By applying the CIA–ISM approach described in Section 3 we can represent the forecasted scenario by means of a diagraph (Fig. 9). The limit of this forecasted scenario is $|C_{ij}| = 1.69$, so it includes the 42.77% of the C_{ij} and the 61.97% of the linear sums of C_{ij}.

We obtain the same result by means of the simulation when we make the probability of the source events I1 = 0.01, I2 = 0.99 and I3 = 0.01 (Table 9). Regarding the source event I4, it can be easily checked by using the simulation algorithm explained in [16] that we obtain the same result when the probability is I4 = 0.99 or I4 = 0.01. That is, we obtain the same result of the graphical

Table 9
Forecasted scenario—simulation for I1 = 0.01, I2 = 0.99, I3 = 0.01 and I4 = 0.99.

Events	Pi	STEP1	STEP2	STEP3	STEP4	STEP5	STEP6	STEP7	STEP8	STEP9	STEP10	STEP11	STEP12	STEP13	STEP14
I1	0.010	0	0	0	0	0	0	0	0	0	0	0	0	0	0
I2	0.990	1	1	1	1	1	1	1	1	1	1	1	1	1	1
I3	0.010	0	0	0	0	0	0	0	0	0	0	0	0	0	0
I4	0.990	1	1	1	1	1	1	1	1	1	1	1	1	1	1
E1	0.700	0.993	0.999	0.999	0.999	1	1	1	1	1	1	1	1	1	1
E2	0.650	0.603	0.883	0.915	0.917	0.917	0.917	0.917	0.918	0.918	0.918	0.918	0.918	1	1
E3	0.350	0.050	0.009	0.004	0.004	0.004	0.004	0.004	0	0	0	0	0	0	0
E4	0.600	0.994	0.998	0.998	0.998	0.998	0.998	1	1	1	1	1	1	1	1
E5	0.750	0.995	1	1	1	1	1	1	1	1	1	1	1	1	1
E6	0.150	0.018	0.001	0.001	0	0	0	0	0	0	0	0	0	0	0
E7	0.200	0.008	0	0	0	0	0	0	0	0	0	0	0	0	0
E8	0.850	0.838	0.998	0.999	0.999	0.999	1	1	1	1	1	1	1	1	1
E9	0.450	0.157	0.141	0.172	0.178	0.179	0.178	0.179	0.179	0.179	0.179	0.179	0.179	0.196	0
E10	0.010	0	0	0	0	0	0	0	0	0	0	0	0	0	0
O1	0.600	0.916	0.970	0.959	0.955	0.955	0.955	0.955	0.955	0.954	0.954	0.954	1	1	1
O2	0.600	0.967	0.996	0.994	0.994	0.994	0.994	0.994	0.994	1	1	1	1	1	1
O3	0.400	0.163	0.010	0.009	0.009	0.010	0.010	0.010	0.009	0.009	0.009	0	0	0	0
O4	0.400	0.079	0.008	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0	0	0	0	0

resolution. This seems to verify the simulation approach as providing a valid analysis of the influence implications for final outcomes.

$$\text{Ocurring Events Summary } I2, I4- > E1, E2, E3, E4, E5, E8- > O1, O2. \tag{12}$$

Table 10 is useful for understanding the graphical results and also for the estimator to understand better the implications and consistency of his or her estimates.

The estimator (in this case) feels that a company that does little internal development is likely to use this approach to such an extent that the initial condition I2 is about twice the influence weight (4.47) as the second most important factor, that of doing a Cost-Benefit Study before there are any user or detailed requirements (2.26). The next three positive influences are all less than 1/2 the magnitude of this.

The negative influence factors start with E3 (−3.44) which is clearly contradictory to E1 and is followed by many items that would influence alternatives to develop requirements. Note the only events not involved, by definition, are the outcome variables which have zero influence factors on all the other events, as indicated by blanks for values to allow better visualization. The second column shows the actual weight applied because of the values for P_j multiplying the influence factors. This does not change the relative amounts much for the positive influences but makes the third negative influence most important. The idea is that computer literacy on the part of management might change their minds about designing the requirements without inputs from the employees that are going to actually use the system.

The other example is a negative outcome variable (Table 11): Large Development Costs (O1). This is still almost a majority of the outcomes in the development of new applications. This outcome did not show up in the diagrams until after 30% of the largest influence factors were used. What we can see is that the positive influences are low and when one multiplies by the initial probabilities, all the values of $C_{ij} * P_j$ are less than 1.0.

A manager trying to insure that development costs are kept in line is really involved in somewhat of a coin toss and has to control a lot of different things to make sure costs don't grow beyond the project budget. It is not possible to focus on just one or two reasons for runaway software development costs. It is easier to understand runaway maintenance costs, at least in the view of the one estimator of the inputs to this model.

4.4. Clustering summary

Looking at the first three graphs in the ISM analysis, we have the following cluster possibilities:

$$(((E8, E1), (-E10, -E7)), (-E3, -E6)). \tag{13}$$

If one is trying to replace the original ten internal events with a simpler model, then one can choose to cluster any of the three doublets, one four event inner model and a doublet, or all six events into one mini-scenario. The decision to do this in the case of this management problem should depend on the following:

- Are any of the possible mini-scenarios independent of management control or actions? If so, there is no reason not to create the mini-scenario to reduce the complexity of the overall problem.
- Are any of the possible mini-scenarios influenced by the same influencing events? If so, they can also be turned into mini-scenarios.
- Management can decide to take actions that make the events in the chosen mini-scenarios to be true, whether the events consistently occur or don't occur according the combined scenario.

Table 10
E1—requirements by management (ordered influences table).

J event ID	Short title E_j	C_{ij}	$C_{ij} * P_j$
I2	Minimal internal development	4.47	2.23
E8	Upfront cost-benefit study	2.26	1.69
E9	Cost-benefit after requirements	0.98	0.44
E4	Modification of existing software by organization	0.74	0.44
E5	Modification of existing software by supplier	0.59	0.44
E2	Requirements by computing professional	−0.39	−0.25
I1	Evaluation organization	−1.08	−0.54
I4	Technology oriented	−1.08	−0.54
E10	Evaluation of existing applications	−2.48	−0.25
E6	Prototype first	−2.63	−0.39
I3	Management computer literacy	−2.70	−1.35
E7	Evolutionary development	−2.79	−0.56
E3	Requirements by users	−3.44	−1.20

Table 11
O1—large development costs (ordered influences table).

J event ID	Short title E_j	C_{ij}	$C_{ij} * P_j$
I2	Minimal internal development	1.62	0.81
E5	Modification of existing software by supplier	1.08	0.81
E3	Requirements by users	0.68	0.24
E1	Requirements by management	0.58	0.41
E8	Upfront cost-benefit study	0.54	0.41
E6	Prototype first	0.52	0.08
E4	Modification of existing software by organization (no impact)	0.00	0.00
I1	Evaluation organization	−0.88	−0.44
I4	Technology oriented	−0.88	−0.44
E10	Evaluation of existing applications	−1.39	−0.14
E9	Cost-benefit after requirements	−1.47	−0.66
E2	Requirements by computing professional	−1.51	−0.98
I3	Management computer literacy	−1.96	−0.98
E7	Evolutionary development	−2.24	−0.45

Note that in the final model and the forecasted model the only dynamic event influencing the full scenario above is E9 (Cost benefit after requirements). The other influencing factors are three of the Initial Conditions. I3 does influence E9. Changing initial conditions is usually a strategic decision that may take more time and effort than the internal events that are controllable.

If a new reduced cross impact model is to be composed it will treat each chosen mini-scenario as a single event. It may also be that the user or users of this model decide they need to create some new events to describe potential increased control over the outcomes of the model. This would be normal in terms of any use of the model in a continuous planning process.

4.5. Outcome events analysis

We use the process of the perturbation simulation to calculate the outcome of all the events. We take each source or internal event and set each one in turn to a value of 0.01 and then to a value of 0.99. In the simulation model approach [16] this causes that event to either occur or not occur first in the sequence, causing the other events affected to change their values and then take the one closest to 0 or 1 to next occur. The process continues until all the outcomes are determined (Table 12).

The outcome events are divided into two bad outcomes (O1 and O2) where development costs and maintenance costs greatly exceed the forecast amounts. The good outcomes (O3 and O4) are user acceptance and low life cycle costs. The following table shows for each event whether the occurrence or non-occurrence of that event causes the good outcome or the bad outcome to occur. This is a summary of a large number of different runs of the model. Note that certain events do not matter and these are E2, E4, and E5. Reviewing Fig. 9 helps to understand the specific influence paths and underlying logical clusters or mini-scenarios leading to this result.

We note from the final diagrams that E2, E4, and E5 are essentially behaving as a set of three outcome variables, so that it is not strange that they do not behave in the same manner as the other variables. They have no direct influence on the outcome variables.

Table 12
Outcome events analysis.

Event	Good outcome	Bad outcome
	+O3 and +O4	+O1 and +O2
	−O1 and −O2	−O3 and −O4
Source/initial events		
I1. Evaluation organizations	+I1	−I1
I2. Minimal internal development	−I2	+I2
I3. Management computer literacy	+I3	−I3
I4. Technology oriented	+I4	−I4
Internal events		
E1. Requirements by management	−E1	+E1
E2. Requirements by computer professional		+E2 −E2
E3. Requirements by users	+E3	−E3
E4. Modification of existing software by organization		−E4 +E4
E5. Modification of existing software by supplier		+E5 −E5
E6. Prototype first	+E6	−E6
E7. Evolutionary development	+E7	−E7
E8. Upfront cost benefit study	−E8	+E8
E9. Cost-benefit after requirements	+E9	−E9
E10. Evaluation of existing applications	+E10	−E10

It is clear that the estimator did not adequately express himself with respect to E4 in this model because doing all the software in the organization can be a bad thing, indicating that the organization does not have the internal talent to do successful outsourcing of the software that is not strategic to the organization's mission. There should have been a separation of software types into the software that is common to most companies and the software that is strategic to the company being modeled. This extension of the event set would have required a number of additional events to deal with this complication in order for it to become explicit in the model.

After we established this demonstration problem, we discovered a Delphi paper in the recent literature that tried to itemize all the "events" that represent risks to software development projects [47]. This is the sort of group study that should precede the development and use of a cross-impact model. This organizational planning effort would derive the potential events in the three categories of initial condition events, dynamic events, and outcome events. This study focused on two expert groups: senior executives and project managers of software development efforts in China. It reported on an earlier study based upon thousands of IT projects started in 2006:

> *"only 35% were categorized as successful, 19% were outright failures, and the remaining 46% were completely over-budget, behind schedule or failed in some way to meet user requirements"* [48].

In Liu et al.'s [47] study, there were 34 project managers and 30 senior executives, with a mean of over five years of experience for all 64 participants. The collective group came up with 57 risk factors and then the two different expert groups ranked the importance of each factor. The independent group was asked to select the ten most important and the project managers selected 14 factors and the senior managers selected 13. The overall list was compared with two earlier studies to show which factors were repeated and which were unique to this study. In this study, there were significant differences between the ratings by the two expert groups. Only seven of the twenty top items were common to the two expert groups. The resulting 20 unique factors did not include explicitly initial conditions or outcome events. In fact, a significant number are expressed as outcomes and not process causes.

If the exercise done in this paper were repeated for a real group it would be interesting to incorporate most of these 20 factors into this model as dynamic and outcome events. However, none of the top 20 risks of the Chinese study dealt with outsourcing, organizational evaluation processes, development policies, who does requirements development, or actual programming. These three areas are the main emphasis of the model made explicit in this paper. The lack of outsourcing in Chinese organizations is a contrast with the U.S. that is not surprising.

If we consider the prior example using the set of ten economic future events for the U.S. back in 1972, we note it had a lot more potential different mini-scenarios. The nature of broad economic events is that many possible influence relationships can be conceptualized and rationalized. What the estimator in that case learned by the estimation process was that one event had tremendous influence on good outcomes that eliminated a majority of the negative outcomes. This event was a major simplification of the income tax which is even more complex today. He did not explicitly perceive how critical this event was until he played with the model that he had created from his estimates.

With respect to the new cross-impact problem we have introduced, it is a process within an organization that is taught in many courses dealing with the management of software development. It has been extensively studied and investigated and as a result, there are certain well recognized influence relationships that are fairly direct and strong. While many different factors can make the development process go wrong there are many strong principal and direct relationships that show up in the resulting relationships diagrams produced by the use of ISM that reflect the cognitive model of the estimator.

4.6. Requirements for associated Delphi processes

The cross-impact methodology we have presented requires two different collaborative activities if it is to be a useful part of the foresight process. The first is a group that creates the event set in a process where they may propose events and then evaluate their significance for inclusion in building the model. The second is the group process to make the estimates of the cross-impact relationships. We will discuss each as potentially two different undertakings that may or may not involve the same members.

The first process is a straightforward one of compiling a suggested list of events by members of the group and having the individuals judge their significance. An example of a classical Delphi approach to doing this is the Chinese Delphi dealing with software development [47]. However, one would expect in a company that a database of events would be created and updated on a continuous basis by inputs from professionals and managers throughout the organization. One example of designing such a database for emergency management applications of scenario development is described in a recent paper [49]. There have been a number of general online Computer Mediated Communications based systems to allow the asynchronous gathering of any list of items and continuous voting (and vote changing) on entries in the list on either an anonymous or non-anonymous basis [50–52]. The purpose of voting in this type of Delphi is to expose the existence of disagreements and to give the participants an opportunity to expose and discuss the reasons for this disagreement. There is an excellent voting method for rating the significance of the items in a single list of items, "Thurstone's Law of Comparative Judgment" [50,53,54]. In an organization that wants to run a continuous planning process one would expect that anytime a professional has read something that stimulates a new idea for a meaningful future event, he or she could put it in the corporate database.

A problem-solving dynamic Delphi process, such as the one developed by [54], is a good example of what is needed. It uses Thurstone's Law of Comparative Judgment to convert the rank orders of the individual participants into a single group interval scale. This allows one to observe the most important clusters of events so that a subset can be chosen for applying the cross-impact approach by the same group or a related group. The version of this technique described in the prior paper [54] allows the process to proceed without everyone voting on all the events and to change their votes based upon the discussion.

The second collaborative process that is needed is the actual solicitation of the cross-impact process. The largest cross-impact event set that one of the authors has actually experienced as the facilitator was for a company that wanted to look at the impact of future government regulations on its services and products. This set had about eighty events and data were gathered by professionals coming into a room with large tables having pieces of the matrix laid out, and they would do a subset individually of the interactions. There are also related cases using this manual type technique for large PERT charts for construction type projects. However, it is difficult in such an effort to really investigate differences of judgment. It is our view that a system has to be designed and implemented that has the following properties:

1. The user can designate the subset of events he or she feels confident about for making estimates of the cross-impact probability factors.
2. There should on the average be at least three estimators for every cross-impact cell that is non-zero.
3. If there is any disagreement about the direction of impact between two events this must be communicated to the current estimators in a manner where they discuss the disagreement, preferably in an anonymous or pen name mode on an online discussion system.
4. If agreement is not reached on the direction of impact, one needs to bring in additional estimators capable of judging that particular interaction and/or a wider discussion is introduced to involve more of the participants.
5. Once there is agreement on direction of the relationship between any two events, one should also check that the estimated probability values for a single interaction are all in one of the following alternative ranges for probability: 0.6 or greater (likely), 0.4 or less (unlikely), or between 0.4 and 0.6 (uncertain). One might want to allow a discussion in some cases when there is not this level of agreement.
6. One should use Dalkey's [55] (expression (14)) derived Bayesian relationship to calculate a better group probability for a specific interaction as opposed to using simple averaging of the estimates.

$$P(J/R) = \frac{\Pi_{i=1}^{n} Ri}{\Pi_{i=1}^{n} Ri + \Pi_{i=1}^{n}(1-Ri)} \tag{14}$$

where:

J represents an event
R are the estimations
N represents the number of estimations.

Some of the same considerations should be applied when there are disagreements about the initial values of the probabilities of the cross-impact events for the individual events. Dalkey [55] also points out that you want to have confident estimators that will be definitive, and to avoid the 0.6 to 0.4 range unless it is truly a consensus agreement that the event outcome is highly uncertain under the conditions specified.

Once we have an event set it should be given to a group to apply the cross-impact modeling. For small event sets or subsets all participants should have access to develop their own model and examine the consequences. The consistencies and inconsistencies the model provides can allow them to change their initial inputs to make them more consistent with the inferences the model provides as they modify their estimates of the individual event probabilities and see alternative outcomes for which events occur or do not occur. Once the individuals feel they have done the best they can for creating their world view of the future, the results can be averaged to produce a group model. This can be done in the following way:

1. Average each C_{ij} and each G_i for the group as a whole. Plotting these in terms of the frequencies of estimates for values along the *x* axis around 0 in the plus and minus direction gives a good description of how consistent the group is. One would hope that there is agreement about the direction of influence of the *j*-th event upon the *i*-th event. If this is not the case one needs to engage in a discussion among the participants about why there is such a significant disagreement. Resolving this can send the participants back to their individual models to change the associated estimates.
2. At this point one can apply ISM and start reducing the number of events by the formation of tightly coupled doublets of events and, at some stage, decide on how far to go in reducing the initial *n* independent events into a smaller total number of events and scenarios. This can bring about a significant reduction in the complexity of the results.
3. After the choice of reducing the event set complexity, one can ask the same set or a new set of participants to re-estimate a new set of probabilities to develop a new model for the reduced event set.
4. An alternative option is to recalculate averages of the probabilities using the theory of least squares via the geometric mean, or using the Bayesian formula given in Dalkey's 1975 paper for averaging probability estimates among a group of experts (expression (14)).
5. A final option is to use the calculated cross-impact factors to set up a game by assuming initial probabilities of 0.5 for all events, adding event sinks which are goals and objectives that are influenced only by the internal explicit events and do not in turn influence any of them. In this case, the model determined by the factors reflects the choice of different options by two players or

Table 13
Required estimators.

Initial conditions	Dynamic events	Outcome events	Estimates	Required estimators
4	10	4	186–200	3–5
10	30	10	1570–1620	24–40
10	50	10	3550–3620	64–90

teams who use resources to buy improvements in a subset of events by buying an improvement in a given event having a higher probability of occurrence. This is viewed as a learning game in that the players should, from repeated plays of the game, get a feel for the impact of the internal structure of the model which was developed by the collaboration of a group of experts in that field [56].

The collaborative development of models is still a major challenge in the Delphi area and the various options described above deserve further exploration and experimentation. The number of estimations needed basically depends on the size of the event set and the number of the different types of events, as has been discussed previously. Regarding the number of experts, theoretical and practical arguments claim that Delphi expert panels should be between 5 and 20 members [7]. Nevertheless, in some cases a panel of three would be enough. That is, if three experts agree on the direction and the estimates are in a small range rather then spread out it should be sufficient. If not one must give the three estimators a chance to discuss and to consider adding two more experts. Five as a collaborative group is the first size that allows for a minority vote (2 to 3) so one can try to avoid the “Asch effect” [57]. The above is consistent with 3–5 experts in any area being a rule of thumb in Delphi.

In the example discussed in Section 4, the average range of estimates for the 18 event set was 186 to 200 based upon whether the initial P_i values are estimated or assumed to be an initial value. It took two iterations of seeing the results of the estimates to feel the model was a true reflection of the views of the estimator. We assume that a person can make estimates of about 200 values if he or she is an expert in the area and can pick out 10 to 15 events in a larger set to provide estimates for. We also assume the number of estimators needed varies from 3 to 5 for each estimate. This results in the following approximated table (Table 13).

What is difficult to estimate is how many non-interactions exist as this can reduce greatly the number of estimates for large event sets. The above ranges for required estimators are reasonable from past experience with Delphi exercises dealing with complex foresight problems. It is definitely what is needed to produce collaborative models of complex situations which require interdisciplinary inputs.

4.7. Interaction

Once a model has been established for the group or for an individual it is possible to vary the initial probabilities of individual events and see the degree of influence that this has on the occurrence of the other events by means of computer interaction. There are also internal measures that quantifiably express to what degree a given event is controlled externally to the set. This indicates either that it is truly external or that events might be missing that should have been included. One can also quickly list which events have the most influence on which other events.

Due to the ladder (i.e. examine the consequences of each step before proceeding on or stepping back to fix one's balance) nature of the model, it is possible to build subsets of mini-scenarios of which two, three, or four events always seem to happen or not happen in combination. One can then create a new event set made up of compound events and in fact reduce the complexity of the problem from n different events to a much smaller number of mini-scenarios including the extreme result of one scenario made up of all the events. However, this should be done with the help of someone who knows the internals of the CIA model well enough to be able to use the internal parameters to present a sensitivity analysis for the user group as a whole. Since probabilities are highly non-linear variables, understanding of the model's consequences and the estimations by those without a good understanding of the mathematical properties does require some guidance for most user groups. This is the case at least the first time they go through using the model as an input to planning. The most powerful benefit in the long run is to reduce very complex situations to simpler ones by developing summary scenarios that express the most likely futures. This is based on some of the decision options and actions that are contained in the initial event set.

5. Philosophical issues

In the earlier paper [16], Turoff discussed the paradox of cross-impact probabilities not following the probability calculus and not being a Bayesian approach. One way of working around that is to restate the events so that the question clearly asks the estimator to make a causal inference. The following is a possible rewording of the cross-impact questions.

Estimates for the basic types of events:

- Initial/source events: What is the probability that each of the following statements are true now, at the beginning of the time interval, about our entity of concern?
- Dynamic events: What is the probability that each of the following statements will be true at some point in the following interval of time from now to time “*t*” years in the future?

- Outcome events: What is the probability that the following statements well be true at the end of the time period indicated above?

These are all events that represent the consequences of the model and its structure just as the probability of an atomic excitation in represented in physics by a calculation of the Schrödinger equation (i.e. equivalent in quantum Mechanics to Newton's Laws in the world as we perceive/sense it). There is no reason we have to assume it is a Bayesian probability. The critical question to be asked of the estimator is the one that deals with the relationships among the above events.

Estimates for the cross-impact influence relationship:

- Given that statement *X* is assumed true (or false), what is the degree of influence on statement *Y* being true (or false)?

Use a numeric estimate between 0 and 1 with 0 being completely false, 1 being completely true, and 0.5 being completely uncertain or "maybe."

We can also view this as a formulation of fuzzy set relationships among these probabilities. One must recognize that one of the assumptions about the cross-impact approach is that the events are unique in that we are talking about an application to unique organizations, situations, governments, etc. They only occur once and, for instance, we do not believe one can calculate a probability of a World War III based upon two prior events that have occurred and are called World War I and II. However, we can try to determine what will influence today and in the future, what may bring about a World War III. It is also clear that a World War III would have very different initial conditions and outcome consequences from World War I or II. In the development of fuzzy set models it is quite common use the concept of something being true or false to a certain degree measured on a scale between 0 and 1. Fuzzy mathematicians also use Possibility Theory rather than Probability Theory [58].

The 1972 paper talked about causal relationships and the analogy between atomic excitation states where an electron is either in the excitation state or it is not and future unique events that either occur or do not occur. It proposed, therefore, the use of the Fermi–Dirac distribution (i.e. also the logistic distribution) for the relationships among the cross-impact events. However, this was an argument by analogy and not a derivation from an energy conservation relationship.

There is another alternative view provided by Torgerson's original concepts of the meaning and objective of Scaling Theory [45, chapter 1]. He strongly believed that the objective of Scaling Theory was to develop measuring instruments for human judgment. Accomplishing this goal would allow the behavioral sciences to move "ahead" just as improved measurement procedures allowed the physical sciences to advance with new theories and empirical proof of their degree of correctness.

From the point of few of scaling theory the significant outcome of this approach to CIA is as follows. One can take an estimate of probability or influence which is in the range of 0 to 1 (or the odds ratio in the range of 0 to infinity) and transform it to a linear scale of "influence" in the range of −infinity to +infinity with zero being the point of no influence on the relationship between two events. This is exactly what we have done by creating the C_{ij} factors that are linear measures on this scale. We have converted a nonlinear representation to a linear one.

This also has the great advantage of allowing a clear visualization of the results in terms of the transformation from a direct weighted graph to a non-directional graph of 0,1 weights. The results are the reachability matrix that creates resulting influence diagrams for the problem of concern. This in turn allows the estimator or the group collaborating on the estimates to see the consequences of their examination of a very complex problem and decide, when necessary, how to reformulate the problem and to re-estimate the relationships.

As described in a previous section, the C_{ij} factors are actually the result of a calculation that is called the "Weight of Evidence (WOE)" in Probability Theory. It is used to apply weights to different items of evidence in a probabilistic situation [46]. The WOE is defined as the log (likelihood ratio) and as a result is a linear additive quantity behaving the same as the equations expressed in [16] for C_{ij} as reflected in Eq. (13) for $\varphi(P_i)$ and for C_{ij} in Eqs. (19) and (22), putting C_{ij} as equations based upon P_i and S_{ij} or R_{ij} (the relationship influence factors) [16].

The WOE concept goes back to the Greek goddess of justice: Themes holding a scale for the weight of the two sides of an argument [46]. Benjamin Franklin used the related T Method to make a decision by listing all the pro and con arguments and determining which view has more of them. Related work in this area seems to be the Dempster–Shafer theory and the ability to describe belief functions derivable from representations of incomplete knowledge, belief updating, and evidence pooling [59].

For all the work that behavioral scientists have done over the past century, there is an important and serious distinction between their primary objectives and those of us working in foresight, forecasting, planning, and particularly in Delphi Design. They are trying to find scientific truths about human behavior. They assume that psychological measurements are constant beyond some early age. The only exception is marketing and advertisement where the objective is to change the views of individuals so they will be inclined to buy a given product. In our case, we want to expose the individual and the group to the consequences of their judgments and make explicit underlying disagreements among the group members. The goal is to offer them a chance to view the implications of their estimates and be able to improve them and in turn those of the group composite as well.

In terms of the causality of the transitions of two-state variables (0 or 1, such as excitation states, unique events that occur or do not occur, or validity states of true or false), the concepts of possibility and validity are the same with respect to the underlying distribution function and the descriptive measures. One might also hypothesize that the increase of communications, at all levels in our society, has made the self-fulfilling prophecy a modern reality for unique events. The marketing professional community has always intuitively understood this. The resulting degree of beliefs about a plan or a future must, to a real extent, be validated by the degree of competence of the estimators. This is something generally true of all Delphi studies.

6. Concluding remarks

The days of discrete, periodic long term plans and short term plans are numbered. Planning today for most organizations has to be made a continuous process. One needs to integrate the type of model described here into a complete planning environment. This would provide the following:

1. A system for professionals in the organization to evolve and update the event set that could be used in various models to evaluate various options for major decisions such as new or improved projects, mergers, investments, etc.
2. Participating groups of experts throughout the organization could enter their estimates about the interactions of the events for which they feel confident in making such judgments.
3. Improving both subjective estimates and the models that events contain as new information provides improved intelligence for the estimators.

Given the growing complexity of our world, the problems of dealing with a world economy faced with growing threats to required resources and financial interactions that can lead to unpredictable results, we do need greatly improved methods to build and evolve models that can exhibit the requisite variety to cope with such challenges. We have seen the fallacy of using highly paid executives to make decisions based upon the intuition of one person who cannot, because of his or her status and pay, ask for serious help from other humans. This might well explain the retreat from some of the promises of strategic planning methodologies of the past by most non-technological corporations during the last twenty years.

In this sense, planning should not be a discrete event in an organization; it must be a continuous process that is integrated into the fabric of an organization. Planning must also be a highly participative process by all the professionals that represent the professional community of the organization. The current understanding of the strengths and weaknesses of the organization must be understood by all the levels of management and this can only occur if the information of the professionals that carry out the functions of the organization flows freely into the planning process. Given the speed at which things happen in our very highly computerized environment, there is not an option to interrupt and put off work on short or long term plans. The distinction between the two becomes meaningless.

The inputs of the events and initial conditions and the outcomes will be continually modified and evolved by an efficient Delphi process to allow hundreds to thousands of professionals to supply and interpret new information for generating new options and considerations to be incorporated into an organizational-wide model forming the basis of the planning process. The ability to test future options by choosing to implement them within the model and see likely forecasts of the outcome consequences becomes the essence of a continuous planning process with organizational wide participation. Collaboration and recognition that one of the consequences of the network integration now possible of all the views of the contributors in the organization is what has brought about a new age in society: The age of participation[3] [60]. Communications in any type of organization will allow collaborative planning on an organizational wide basis. The communication structures to allow many minds to contribute to the examination of complex problem solving and complex model construction are the major challenge in the design of future organizational systems.

To contribute to this aim, a new scenario generation methodology has been proposed. The CIA–ISM approach aims at allowing researchers and practitioners to (1) handle complex systems; (2) obtain a set of plausible snapshots of the future; (3) analyze interaction between events; (4) detect critical events. This scenario-generation method might have several potential applications in scenario-planning, foresight, technology assessment, information systems and management. The main strong points of the authors' proposal are:

1. a strong theoretical background for the techniques on which the proposal is based;
2. the possibility of working with large sets of events;
3. tools for analyzing the key drivers of the scenarios;
4. specific software is not needed for making the calculations (e.g. Excel);
5. graphic output that gives a clear representation about the forecast;
6. compatibility with other techniques such as the Delphi, fuzzy or multi-criteria methods.

Additionally, the introduction of the merger of cross-impact with ISM is a major extension in allowing the collaborative development of scenarios out of much larger event sets and this ultimately reduces the complexity of foresight. In the typical large scale event sets approaching a hundred events or more, estimation by groups will usually result in the need to subdivide the estimation process among different areas of expertise. It is generally true in Delphi that one should encourage participants to estimate or judge only those areas they feel confident in judging. We have provided an intelligent approach to the evolution of scenarios from event sets which augments human judgment in an integrated manner for the direct construction of a structural relationship model through the use of a computer in a true direct augmentation process without the need for intermediaries to implement computer programs [19,44].

[3] This was originally proposed as 'the age of collaboration' by Dr. Turoff but after discussion with Dr. Roxanne Hiltz it was felt that obtaining that was still uncertain and what we do have at least is an 'Age of participation'.

7. Future research

There are a number of different activities we will be undertaking in the near future that are direct follow-ons to the work we have done here. The first is extending the current program we have developed to include the next step in the use of this modeling approach.

Once the users have agreed on what is the combination of mini-scenarios and basic events that should make up a model of reduced complexity, we can take the original C_{ij} matrix and the G_i's and actually combine events two at a time to form the reduced C_{ij} matrix by adding together the two rows and two columns for each event pair and the respective two G_i values until we create all the chosen mini-scenarios. This would build a new model with a reduced set of events. It would be a foresight model that could be used in a large number of different ways to create a conditional forecast or plan for the future.

Clearly we need to demonstrate larger models on the order of 50 to 100 events where different contributors would pick out the subset of events they feel confident about and only estimate the interactions for that subset. The Chinese Delphi [47] is a good example of needing that range to have a comprehensive representation of the problem we were treating here as an example. Demonstrating a larger problem based upon professional inputs from a group is our second major objective. We welcome input from others that have a set of events and can provide group inputs to further experiment with this modeling method.

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