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IIASA Working Paper

WP-77-001

1977

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January 1977 WP-77-1

2361
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Preface

The possibility of introducing simulation gaming as an auxiliary, pre-analytical research method is currently under consideration at IIASA. This Working Paper presents a specific approach to simulation gaming that may lend itself particularly well to the study of complex global problems.

Abstract

An approach to simulation gaming is presented, with particular reference to global modeling. The approach is generic in character and can, in principle, be applied to any long-range planning area. In contrast to system-dynamics and to customary econometric models, the proposed "cross impact" gaming permits consideration of events (such as technological breakthroughs, natural catastrophes, and acts of legislation) in addition to trends (such as population growth and energy consumption), and it does so in a probabilistic setting that provides appropriate emphasis for the uncertainties of the future. The so-called cross impacts refer to the effects of events on the probability of other event occurrences and on deviations of trends from their anticipated courses, and similarly to the effects of trend changes on other trends and on probabilities of event occurrences. By including, in particular, actions (i.e., moves by participating players) among the events, it becomes possible to explore both the direct impact and the long-term consequences of alternative policies. In light of this, cross-impact gaming may be considered a pre-analytical approach that may provide intuitive insights valuable for a full-fledged systems-analytical investigation.

A Cross-Impact Gaming Approach to Global Modeling

An area of interest to IIASA that will lend itself well to operational gaming is that of global resources. Several of the ongoing IIASA projects--Food and Agriculture, Energy Systems, Water Resources, and Ecology and the Environment--clearly are devoted to the exploration in detail of large segments of the global-resources problem. Information on these subareas may thus be assumed to be readily available for use in an aggregate global model. Conversely, these projects themselves may well derive some conceptual stimulation and possibly some insights of value from a global-gaming effort, because of the interdisciplinary and interarea connections and influences that such an activity might elucidate.

The best-known modeling efforts in the area of global investigations are those of Meadows, of Mesarovic and Pestel, and of the Bariloche and Linnemann groups. By contrast to these approaches, I propose the use of cross-impact analysis as a means of constructing an interactive man-machine game for dealing with global-resources problems.

The advantages of this approach include the following:

- o It permits the explicit inclusion within the model of events as well as trends. Such events might be technological breakthroughs, natural catastrophes, acts of legislation, treaties, and so on.

- o It is probabilistic in nature, and thus makes it possible to give explicit consideration to uncertainty about the future. This element of realism is particularly important when gaming is used for instructional purposes.

- o It does not limit itself, as is done so often, to the most easily measurable aspects of a given situation but places emphasis on the inclusion of those elements which, from a systems-analytical point of view, represent the most important aspects (even if some of these do not readily lend themselves to direct observation or measurement).

- It is an excellent tool for comparative policy analysis, in that it permits the exploration of the implications of different action programs intended to implement alternative policies.

- It is thoroughly compatible with computer-network gaming; i.e., it can easily be applied in situations where the participants are geographically remote from one another and communicate their input estimates (in the construction of the game) or their moves (in playing the game) via a network of computer terminals.

- Finally, it has a high degree of flexibility in that the structure of the model as well as specific numerical inputs can easily be changed. Among the implications of this last point are the following:

  - The game can be played as an n-player game, for $n = 0,1,2,\ldots$. Here, $n = 0$ represents the case of passively watching the unfolding of a scenario without attempting any intervention. The case $n = 1$ corresponds to one-sided planning (where adversary actions are handled stochastically rather than through explicit intervention by an opposing player), as opposed to $n > 1$, where two or more players interact with one another.

  - A relatively simple--perhaps even simplistic--core model can be constructed first, to which other factors may later be added, either to accommodate the need for greater detail in some subarea or to reflect sensitivities that may not immediately have been apparent.

- Numerical inputs can be adjusted with ease. Consequently, rough judgmental data can be used to start with, to be replaced with more refined inputs when such become available and the sensitivity of the outcome to these inputs establishes the need for such refinements.

- Similarly, the functional relationships between different variables can often be assumed to be linear at first, to be replaced with nonlinear relations when called for.

As for the general procedure for constructing a cross-impact model, it involves a series of steps, as follows:

1. Setting the time horizon.

In the case of a global-resources model for IIASA, an appropriate time horizon might be the year 2026. Although most of our attention is likely to be confined to the next quarter century, it is well to consider, at least initially, a larger time span, such as the next half century, in order to view the developments of greatest interest from the vantage point of a somewhat larger time perspective.

2. Identifying potential developments.

The model to be constructed is concerned with planning for the future. The operating environment for which plans are to be made will differ in many respects from the present environment. These changes can be described in terms of abrupt events (such as technological breakthroughs, acts of legislation, and natural catastrophes) and of gradual trend fluctuations (such as population, pollution, and per capita food supply). To keep the size of the model within reasonable bounds, it is necessary to select only the most important potential future developments, i.e., only those events whose occurrence or nonoccurrence would make the greatest difference to the operating environment and only those trends whose unexpected deviation from their anticipated courses would similarly affect the operating environment most profoundly. Among the trends selected for representation in the model, it is important to include also so-called "payoff trends", that is, trends that can be used to monitor the successful pursuit of stipulated goals. (Examples of such payoff trends might be the quality of life, the per capita food supply, and the per-capita income.)

3. Forecasting the probabilities of event occurrences.

For each selected event, some estimate has to be made of its probability of occurrence as a function of time during the interval from the present to the stipulated time horizon. These preliminary estimates should be understood to be ceteris paribus, or "surprise-free", estimates. (The alteration of such estimates due to the occurrence of contingent, intervening developments is precisely what the cross-impact approach will focus on.)

4. Forecasting the future courses of trends.

Similarly, estimates of the future courses of the selected trends will have to be made. Here, in addition to a median forecast, some indication will also be needed of the uncertainty attaching to the forecasted trend levels. A convenient way to handle this is to subdivide the entire forecast interval into subintervals (called "scenes"), whose length should reflect the desired temporal "resolution". (For instance, in the case of the global-resources model, it may be adequate to subdivide the 50-year planning interval into 10 scenes, each 5 years in length, because a 50-year scenario of the future can presumably be described reasonably well by recording the status of the world every 5 years. If, upon closer examination, it should turn out that this degree of resolution is insufficient, a refined subdivision into 50 scenes of 1 year each could be carried out.) Having stipulated a scene length, it is meaningful to ask the following question: Given the trend level T_i at the beginning of Scene i and a forecast of T_{i+1} for the end of Scene i, what is the 50% confidence interval around T_{i+1}? That is, assuming symmetry, for what value s does the forecaster have a 50% confidence that the true value of the trend will lie between $T_{i+1}-s$ and $T_{i+1}+s$? The value s thus defined will be called the "surprise threshold" (reflecting the intuitive notion that an actual trend value between those limits will not cause surprise whereas a value outside will).

5. Estimating cross impacts among developments.

Developments do not take place in isolation from one another; that is, the occurrence of an event or an unexpected trend fluctuation will affect the probabilities of occurrence of other events and the future courses of other trends. To account for these effects, called "cross impacts", a cross-impact matrix is constructed, with the selected developments (events and trends) listed along both the left and the top:

	E_1	E_2	. . .	T_1	T_2	. . .
E_1						
E_2						
⋮						
T_1						
T_2						
⋮						

Here, for example, the cell where the E_1-row and the E_2-column intersect carries information as to how much, and with what delay, the occurrence of E_1 would affect the probability of occurrence of E_2. (Note that what is being recorded is not a correlation but an estimate of the causal effect of E_1 on E_2. If E_1 occurs in Scene i, its effect on E_2 will be felt in Scene i+1 at the earliest.) In the case of a trend, where "occurrence" is meaningless, impacts are noted instead in terms of deviations from expected values, as measured in surprise-threshold units (see 4 above).

At this stage, the model is ready to be subjected to trial runs; these are passive, 0-player applications. The procedure amounts to deciding by a Monte Carlo random-number process which of the events $E_1, E_2, \ldots$ occur in Scene 1. Depending on their occurrence or nonoccurrence, the probabilities of events and values of trends anticipated for Scene 2 are adjusted in accordance with the entries in the cross-impact matrix. Then Scene 2 is played out similarly, and so on, until the last scene is completed. The result of such a run is a "scenario", that is, a sequence of event occurrences and of trend fluctuations recorded for each successive scene. Several runs will generally produce different scenarios. In a large number of runs, the frequencies of event occurrences and the average trend values should approximately reproduce the input probabilities and trend values.

The scheme lends itself to sensitivity studies. For example, an event can be made to occur in Scene 1 (by raising its input probability to 1), and the average outcome can be compared with that of standard (i.e., unaltered) runs. This opens the door to comparative policy analyses (1-player gaming) and even to studies of the interactions of multiple interventions (n-player gaming). Before entering this phase, however, some additional, preparatory steps are needed:

6. Identifying decision-making agencies.

If the model is to be used for the purpose of a unilateral planning simulation, then, of course, only one decision maker or decision-making agency has to be specified. This single "player" can be a simulated real-world entity, such as a particular national government, the United Nations, or the multinational corporations; or it can be a fictious agency, such as a world government. This latter case may be important for analytical purposes, if it is desired, say, to determine in principle what actions, however unrealistic in a real-world setting, are likely to avert famine. Having thus established an idealized benchmark case, it may then be possible to explore more realistic ways and means, by simulating actual decision makers, of at least approximating the idealized policy. If the interactions of several decision makers are to be simulated, these have to be separately identified. In gaming language this means that they have to be differentially characterized in terms of the moves permitted to them. These moves will consist in interventive actions, which in turn will affect some of the input values of the events and trends included in the model. Thus, operationally speaking, players differ in the amount of influence they can exercise over the developments that constitute a potential scenario.

7. <u>Specifying interventive actions</u>.

For a given play of the cross-impact game, a set of actions $A_1, A_2, \ldots$ will have to be specified that may be taken by one or more of the players. For these actions, an impact matrix will be required:

	E_1	E_2	...	T_1	T_2	...
A_1						
A_2						
⋮						

whose entries indicate to what extent an action A_i will affect the input coefficients that characterize the events and trends. For some actions it may be that they can be enacted at various levels (e.g., capital investments), in which case their impact on events and trends must be stated in terms of the level of enactment.

Two further comments on the role of actions in a cross-impact simulation are indicated. Firstly, a player, when deciding on the next move, may be subject to certain resource constraints. Actions may, in fact, have price tags attached to them, and the player's options may consist in the choices permitted within a given budgetary allowance. Secondly, since the identification of suitable actions often is a matter of inventive imagination, there should be enough flexibility in the rules of the game to provide for the occasional introduction of new actions, together with their associated costs and impacts on other developments.

The type of gaming approach described above should not be looked upon as a panacea. For one thing, the model in its present form still has many deficiencies, only some of which one can hope to eliminate by making the model gradually more sophisticated; cross-impact simulation, after all, is intended to be used primarily in situations where the state of our theoretical knowledge is still inadequate, yet where a systems approach requires that all important aspects be considered regardless of their full scientific tractability.

Even at best the conditional forecasts produced by running the cross-impact model for various policy options are no better than the inputs, which, after all, in many instances are necessarily judgmental in character. However, while firm predictions cannot reasonably be looked for, the model has considerable potentialities in providing insights into how sensitively the future depends on changes in input assumptions and, particularly, on policy changes. Such insights may be especially valuable if, as they are apt to be, they are cross-disciplinary, because the generally unidisciplinary nature of more traditional modeling techniques often fails to elucidate these broader aspects.

The advantages to IIASA of introducing a simulation activity of this kind are manifold. Among the more obvious ones are these:

- It is likely to afford the participants intellectual stimulation, by exposing them to considerations outside their more narrow specialties as well as to the pervasive influence of uncertainty.
- It represents a tool for sensitivity analyses, the results of which will both identify the substantive areas most in need of more detailed examination and determine the direction in which fruitful policies may be looked for.
- It will promote interproject cooperation and collaboration.
- It will permit examination of the effect of near-term national policies (regarding food, energy, pollution, etc.) on long-term global conditions.
- It will facilitate some form of at least rudimentary pretheoretical modeling in subject areas (particularly within the social-science field) where fully reasoned theories are not yet available. While, of course, even purely correlational approaches have occasionally proved fruitful in such instances, cross-impact analysis greatly enhances the opportunity for gaining insights into the causal, rather than merely correlational, relationships between developments.