MODELING OF DISTANT FUTURES

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Summary

This paper introduces some techniques that have been found useful in studying preliminary and simple models of future developments. These techniques rely on joint model building in which many experts participate. Such joint participation has helped to eliminate most of the personal biases of a single model builder and has led to a greater degree of acceptance of the finished product. The models described here are simple. The paper concludes with a discussion of the problems encountered in making such models more sophisticated.

Introduction

All decisions seek to influence the future. The decisions that attempt to improve the probability of achieving favorable outcomes are always based on a set of beliefs about the characteristics of the situation within which a decision is to be made--i.e., the model of it. Unfortunately, major decisions about the future of our society have been and for a long time will continue to be made with only the vaguest notions of the underlying phenomena. Most often, a model of the situation does not exist or was not even attempted. When it was attempted, it was not believed. Perhaps the reasons for a widespread scepticism of models as predictive tools or for decision making are their complexity and the amount of internal assumptions. Complexity often makes the model intelligible only to its author, and it is then very difficult to examine its assumptions. At the Institute for the Future, one of our objectives is to develop better tools for decision making concerning the long range future of our society.

Preliminary Identification of Model Components

An important part of model building is the selection of its components, or of variables that ought to be included. On first examination, there appears to be an almost endless list of known factors that, to a greater or lesser degree, affect the future outcome of the situation. An expert in any field can list these factors at length, and all of them are more or less relevant. In addition, it is recognized that new factors, previously unknown, may emerge. One of the insights of decision analysis[1,2,3] is to establish several criteria for determining the relevance of such factors. If a pilot model is available, each variable can be swept over its range to determine whether the outcome is affected by its value.* Similarly, the stochastic sensitivity is determined by noting whether the outcome (or the probability distribution of the outcome) is affected by a change in a given variable while all other variables are assigned conditional probabilities. Finally, the strictest test can be applied--would outcomes change enough to change the decision if some of the variables were eliminated from the model?

Each of these tests requires a model, at least a pilot model, of the situation. Therefore, there appears to be a need to determine the initial selection of component variables before model construction. The approach of decision analysis is to focus on the decision and then to build the supporting structure by asking the decision maker about the outcomes he would like to improve by a decision. In considering the future problems of our society, it is not at all obvious what is the decision to be made--in fact, generation of policy alternatives is one of the reasons for model building. Also, there is no one convenient "decision maker," nor is there any agreement on what should be optimized or favored. There is no single value model.

To clarify the selection of relevant factors, several techniques are being explored at our Institute. One technique is to ask leading experts a question such as the following: Assume that you were away from the United States and unable to obtain any information about a particular situation that concerns you. If you were to arrive in, say, 1985 for the briefest of visits, what 10 topics or 10 developments would you ask about? Notice the underlying constraints: the expert is given limited resources to acquire information (10 questions); the time frame is specified (1970-1985); and the questions focus on the importance, or the utility,** of the outcomes to him.

We have found that when such a question is put to several experts, there is a substantial overlap (as much as 70 percent) between the developments quoted. Because such preliminary determination of relevance focuses on outcomes and not on the underlying factors, or state variables, the next stage may be: (1) to construct a model that attempts to connect directly the important developments or outcomes or (2) to determine the state variables needed to build an analytical model underlying these outcomes.

The Cross-Impact Model

The first of these approaches "short-circuits" the distinction between the state variables, the model, and the outcomes. We call this technique the "cross-impact" analysis. It is a static, probabilistic tree-type of model, in which the stochastic dependence of developments or events, hopefully nonoverlapping, is considered--two events at a time. The prior probability of a key development is encoded first, followed by the likelihood ratios, i.e., the change in the odds of this development happening given presence or absence of another development. The basic approach has been described by Edwards[4] but modified by us as follows: if the sequence of developments can be estimated, this technique can be extended to make a tree of joint probabilities of many developments. These joint probabilities are probability assignments to a static "scenario" composed of jointly occurring, independent events. Such a tree is shown in Figure 1, and the required computations are described in Appendix A.

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* However, in dynamic models with many feedback loops, this check may fail.

** The term "utility" is used here in the sense of classical economics.

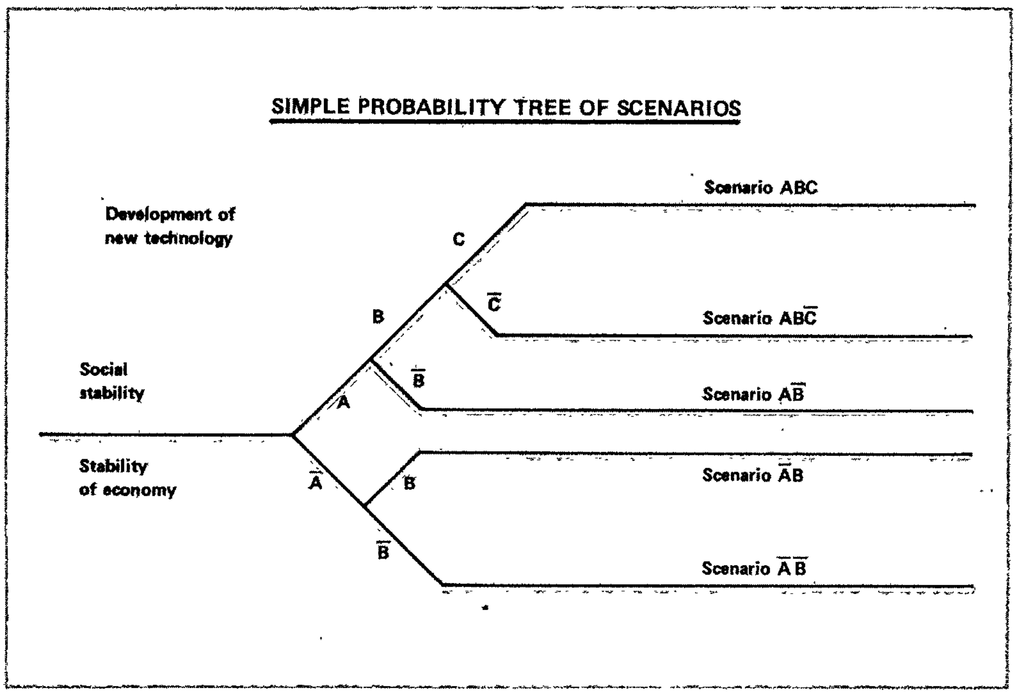

Figure 1

A profile of such scenarios can be constructed from information obtained from a single expert or from many experts. We have used the Delphi technique* for such joint model building.

Determination of State Variables

The second approach, in which state variables are "extracted" with the help of outcomes, is also conveniently done by anonymous, interactive interviews such as Delphi. During an early round of a written interview, we supply a respondent with a description of an event (see Figure 2) and ask him to determine what factors, or what other developments, made him assign a given probability to this particular event.

We also may ask him to determine the importance of this event in accordance with a specified scale of importance. Then, in subsequent rounds, the factors brought out by the majority of the respondents are themselves assigned probability and importance. Whatever approach is used, after the first round of questionnaires, enough information is available to begin evaluating a set of events, or developments, with respect to their information content. The value of information that would be derived by the resolution of uncertainty of many events of different importance is suggested by information theory to be a product of their uncertainty and importance** (or utility).

* Delphi is a form of an iterative, anonymous conference of experts, typically conducted by written questionnaires.[5]

** Both importance and utility are typically defined with respect to the objective of the study. For example, it may be the importance of the event to the communications industry, and "important" event may be defined as one causing a change of more than 10 percent in the industry's revenues.

After the first round of the questionnaire, both of these assignments may be available (for example, as medians of experts' opinions), and therefore a preliminary crude ranking by the product of uncertainty and importance can be made, and an arbitrary cut-off point can be established that limits the events, or variables, to a manageable few.*** When thus limiting the size of the model, a rough idea is obtained of the value of the information that is being discarded. For example, the first 10 questions may contribute products of importance and uncertainty that add to 100 units; the eleventh question may contribute no more than five units, and additional questions even less.

Building a Profile of Scenarios from Delphi Responses

The direct approach of cross impact leads to a preliminary or prior evaluation of the probability of different events. The results of interviews can also be used to re-evaluate the probability assigned by us to a static scenario composed of many events. These events may have been suggested by the earlier cross-impact analysis. We are building a profile of future scenarios in a study of future communications developments by applying Bayes's Rule to the voluminous information collected during written interviews with many experts from many disciplines. One variable of interest in the study is the utility, or attractiveness, of different futures of communications to a decision maker, and we would like to obtain the "lottery profile"****

*** It is recognized that the product of uncertainty and importance offers but a preliminary guide to the relevance of each event, and this is because the probabilities are not all-exhaustive (they do not add to one). Hopefully also the importance is on the same scale of utility.

**** Here the "lottery profile" is used to describe an all-exhaustive subset of outcome space.

SAMPLE OPINION ABOUT A HYPOTHETICAL EVENT

	Probability of Event					Future Importance of Event				Familiarity with the Subject			
Hypothetical event	Highly likely	Quite likely	As likely as not	Not very likely	Unlikely	Very important	Important	Little importance	Unimportant	Expert-working knowledge	Quite familiar	Casually acquainted	Unfamiliar
A time division switch for telephone service, or telephone and wideband service, will be placed on trial in one of the large metropolitan offices where the exchange trunks have been all converted to the T-1 and T-2 carrier systems.	✓					✓				✓			

Figure 2

of such futures over the range of their utility to him. Ranking of the scenarios according to their personal utility is not very easy, nor is it really essential, but it results in an intuitively acceptable lottery, from "worst" to "best." The "prior" lottery, or the probability distribution of future scenarios prior to collecting experts' opinions by means of the interviews, is the distribution of scenarios obtained through the cross-impact analysis. Bayes's Rule specifies that, to update our probability assignment, the prior lottery (or strictly the probability density assignment) be multiplied by the likelihood function. The likelihood function is our personal assignment of probability of obtaining an experimental result (the distribution of the Delphi responses) for each "state of nature," or scenario.* If possible, the likelihood function should be obtained by experiment.

When a group of experts makes a statement about the future, at least two components of the likelihood function are involved: (1) the likelihood (assigned by us) that a group of perfect or "clairvoyant" experts would understand and answer the question precisely enough to form a perfect consensus, and (2) our opinion of their ability to forecast the value of a future variable, if they are not clairvoyant.

With regard to the first component of uncertainty, experiments conducted at the Institute suggest that, even if the facts are known, the ambiguity and vagueness of the English language contribute to a measurable dispersal of answers. Typically, a distribution of answers is as shown in Figure 3, which shows how different respondents interpret the term "widely" in the following context: "Picturephone® transmission circuits will be widely used for broadband local area service." Thus, we can assign a probability that each respondent's answer would have been placed elsewhere than recorded, if his and our definition of "widely" had been aligned. The second component of the likelihood function is estimated by us from the actual, measured expression of the experts' uncertainty. In the typical Delphi interview, this uncertainty is approximated by the spread of the answers of individual experts (see Figure 4). The complete likelihood function, thus estimated, is then a convolution of these two distributions across the variable of interest, which may, for example, be the utility of the individual scenarios. Appendix B shows the computations required.

A typical question may be phrased as a statement. For example: "By 1985, riots in the United States will occur as a matter of course in at least one major city each month." We may ask the respondent to estimate the likelihood of such an event and to select one of the five intervals of probability, the lowest interval being 0-10 percent, and the highest 90-100 percent. If the riots were actually to occur, presumably some respondents, selected because of their knowledge of underlying social trends and external factors, would assign a reasonably high probability to the event.** A typical distribution of answers concerning the probability of an apparently "certain" development is shown in Figure 5. However, even if the experts were clairvoyant or the social developments were perfectly understood and deterministic, we know that there will be no consensus of opinion as to what is meant by "riots." As a result of experience of dealing with experts

* An "outcome," "state of nature," "hypothesis," and "scenario" are all terms that have been used to describe discrete points in outcome space.

** This belief of ours is based on a feeling that there is an underlying logic to social developments and that they are not, therefore, merely due to chance. The "matter of course" phrase is designed to eliminate the effect of chance.

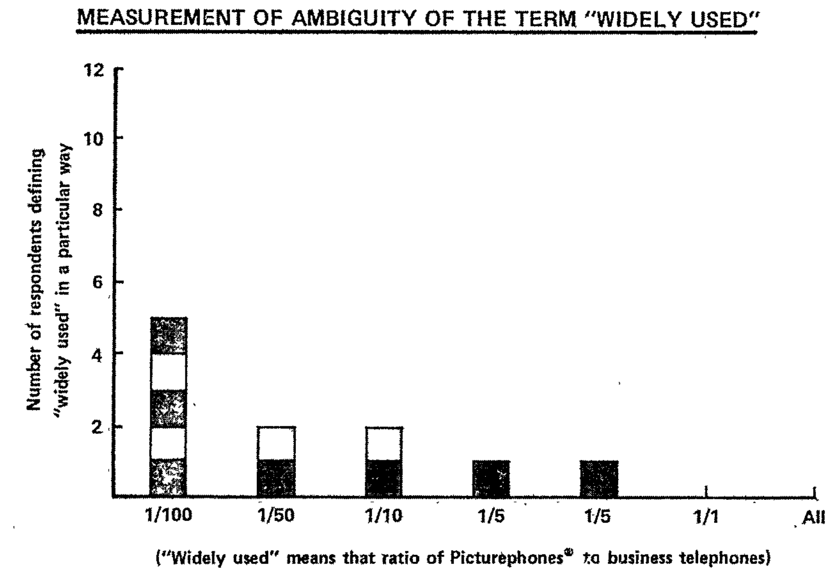

Figure 3

in such an ill-defined area as social developments, we assign a probability of, say, only 0.7 that even a clairvoyant respondent's answer would actually fall in the category of highly likely (or more than 0.9).

Jointly Occurring Events (Static Scenarios)

In practice, Bayes's Rule can be applied as follows: For each scenario, its prior probability assignment can be multiplied by the probability assigned by us that the experts' consensus would be as given, were this specific scenario true. This probability assignment is basically equal to a fraction of the respondents that gave an answer corresponding to the high probability of the event, except that the distribution of experts' answers is "smeared" to account for errors due to vagueness and ambiguity of the question. Since each scenario is composed of many jointly occurring events, the calculation evaluates the joint probability that many

TYPICAL DISTRIBUTION OF ANSWERS CONCERNING THE PROBABILITY OF AN APPARENTLY "CERTAIN" DEVELOPMENT

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        1.10 02    GOVERNMENTS (AT ALL LEVELS) WILL ENACT LEGISLATION RESTRICTING
                   INDUSTRY PRACTICES RELATIVE TO WATER AND AIR POLLUTION.

                                                                              LIKELIHOOD
   75 PCT - 0.75    1 3*3*3*3*2*2*2*2*2*2*2*2*2*2*2*2*2*2*2*2*2*2*1*1*1*
                    2
   MEDIAN - 1.00*   3
                    4
   25 PCT - 1.25    5

        P - 0.95
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Figure 4

SAMPLE DISTRIBUTION OF ANSWERS OF INDIVIDUAL EXPERTS

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      4.11.02    THERE WILL BE A PROLIFERATION OF MICROWAVE CARRIERS PROVIDING
                 BOTH LONG HAUL AND SUBSCRIBER-TO-SUBSCRIBER SERVICES

                                                                   LIKELIHOOD
 75 PCT = 2.74      1 2*2*
                    2 3*2*2*2*1*
 MEDIAN = 3.95 *    3 2*2*
                    4 3*3*2*2*2*2*2*2*2*2*2*2*
 25 PCT = 4.55      5 3*3*2*2*1*1*1*1*

      P = 0.31
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Figure 5

separate questions have all been answered in a particular way.

We ask questions on a broad range of topics, such as the future state of the economy and a possible revolt against technology. Here the probability that respondents would forecast the joint occurrence of riots, depressed economy, and a revolt against technology is the product of the individual likelihoods that, for a given scenario, the distribution of answers to each question would contain that fraction of the respondents' answers in the column corresponding to the "highly probable" estimate that was actually recorded. We are only too aware that such an approach to assigning a likelihood function to a distribution of answers is highly speculative and begs agreement of whether anyone can forecast future developments, even though we ask for conditional forecasts. A less ambitious objective would simply be to collect diverse opinions without an attempt to consolidate them in one profile of "futures." However, no one is satisfied with that, and we all intuitively create such profiles in our minds.

The resulting posterior probability distribution of scenarios is, of course, but a first step in the quantitative perception of the future. The difference between the prior distribution and the posterior distribution of scenarios tells us how the interviews may have contributed to a re-evaluation of our initial probability assignments.

Limitations of Simple Models of the Future

The techniques described here attempt to extract some meaning from many experts' forecasts of a very complex, dynamic reality. Whenever one attempts to capture elements of reality in an analytical structure, a criticism is sure to be raised: "But such and such detail, impact, event--you name it--was omitted. Therefore, the model is no good; it does not represent reality."

The answer is simple: compare the proposed model with our current approach to decision problems, which most often does not employ any analytical models of the situation. An explicit model, no matter how simple, that encourages the preliminary identification of decisions and outcomes is usually better than relying on intuition. However, useful building of models requires an appreciation of the necessary compromise between simplification for tractability and acknowledgment of reality. We have encountered a few general cases:

- Where a probability assignment to one variable, or one event, is of paramount interest, the emphasis is placed on computing the probability of that event across the spectrum of all scenarios.[6] For example, one may be interested in the probability assigned by the experts from many fields to the end of the United States as we know it today, no matter how it may happen--through civil war, military take-over, or atomic holocaust.
- When interested in discrete scenarios, one is generally concerned with either those very undesirable or those very likely. The focus of concern is possible actions that may modify the probability of such a scenario. It is then necessary to obtain from the experts a sequence, or at most a few probable sequences, of events. Otherwise, the computations become impractically complex.
- Where the dynamics of the problem is of prime interest, then the complexity or the probabilistic features should be given secondary consideration.

Regardless of the modeling compromise adopted, my personal view is that the model builder's contribution

COMPUTATION OF THE PROBABILITY OF A SCENARIO

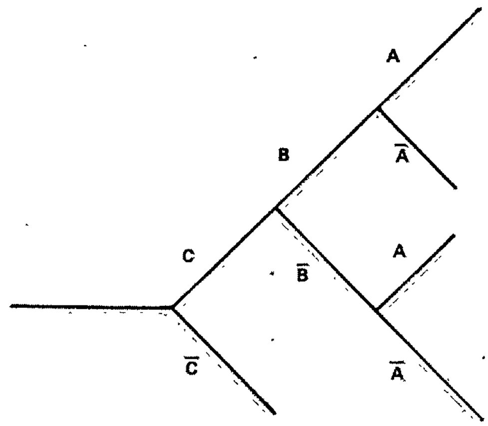

Figure A-1

should terminate at a stage where a better understanding is developed. Let someone else, or even a group, inject their own value model and try to optimize what they feel is important. Model building, like any other structure, inevitably reflects the personality of the principal builder. When problems are highly quantifiable and deterministic (i.e., when there is only one number to describe a given variable), it is possible to check up and identify disagreement with the "architect's" data. But if the situation is more typical of social developments, that is, a mixture of "hard" facts, presumptions, and estimates, the model builder's sins of omission, commission, and buried assumptions are very difficult to identify and are justly suspected. Buried assumptions may reflect value judgments as well as estimates. In a pluralistic society, such as ours, a possibility of one set of value judgments creeping into the model structure is understandably very disturbing to groups whose value judgments are different. For example, we are aware that there is a wide disagreement as to the time preference, or the social "discount ratio," of the young and the elder. Also, the utilities of many of the outcomes once thought desirable are being questioned. Therefore, our efforts should concentrate on developing, jointly with many experts, preliminary models of the future. We hope that these efforts might stimulate research in joint modeling, and lead to a more informed discussion of the key issues that confront us and eventually to building of models that might be used with confidence for decision making.

Appendix A

$$\Omega(A|B,\varepsilon) = \Omega(A|\varepsilon) \cdot L(A;B)$$

where: $\Omega(A|B,\varepsilon)$ are the posterior odds on A given B

$\Omega(A|\varepsilon)$ are the prior odds on A, and

$L(A;B)$ is the likelihood ratio of B given A and its negation

Similarly, the odds in the lower fork can be computed:

$$\Omega(A|\bar{B},\varepsilon) = \Omega(A|\varepsilon) \cdot L(A;\bar{B})$$

The posterior odds on B are:

$$\Omega(B|C,\varepsilon) = \Omega(B|\varepsilon) \cdot L(B;C)$$

The process can be continued until we arrive at the main trunk (fork C,$\bar{C}$ in Figure A-1). For the odds on C we simply use the initial odds, $\Omega(C|\varepsilon)$.

After all the odds are computed, the calculation of joint probabilities of many events in tandem is straightforward.

Appendix B

Computation of the Probability of an Event Given Delphi Responses

Let:

y'_k = fraction of the total number of respondents whose answer was recorded in a particular column z_k, where k=1,n

y' = distribution of y' along z

y_k = fraction of the total number of respondents whose answers were recorded in columns z_1 to z_n but would have been recorded in a column z_k, were they not confused by the ambiguity and vagueness of the question

y = the distribution of y along z

x = a utility of a future scenario, development, or event ("state of nature")

ε = experience (obtained from previous experiments, sometimes intuition)

m = an auxiliary variable denoting the number of the column along z where the answers are recorded (m=1,n)

Then
$$y_k = \sum_{m=1}^{m=n} y'_k \cdot \left\{ z_k | z_m, \varepsilon \right\}$$

where $\left\{ z_k | z_m, \varepsilon \right\}$ encodes the probability that the respondent's answers are dispersed along the z axis because of ambiguity and other errors,

and the final computation is:

$$\underset{\text{POSTERIOR}}{\{ x | y', \varepsilon \}} = \frac{\overset{\text{PRIOR}}{\{ x | \varepsilon \}} \cdot \overset{\text{LIKELIHOOD FUNCTION}}{\{ y | x, y', \varepsilon \}}}{\int_x \{ x | \varepsilon \} \cdot \{ y | x, y', \varepsilon \}}$$

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