THE ECONOMICS OF SIMULATION

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ABSTRACT

This paper presents a framework for decision making about simulations before committing resources. The viewpoint is that of a manager who must decide whether to solve a problem by simulation or by some other means. A decision-analysis type model is introduced to allow the manager to determine the minimum cost method of simulation within the operating and policy constraints of his organization. Two case examples using the metholology are presented.

INTRODUCTION

Although simulation is one of the most widely used approaches to solving problems in Operations Research (10) and other fields, little is known systematically about the economics of simulation, either in terms of costs or benefits. We have observed that the decision to undertake large-scale simulations is often made casually, although this need not be the case. It is our thesis that it is neither difficult nor expensive to analyze the costs of a proposed simulation by use of a decision-tree framework nor is it prudent to use simulation unless the anticipated benefits exceed these costs.

We shall take the point of view of a manager faced with a large problem. Simulation has been proposed as a potential method of solution. He must resolve two interrelated questions:

1. How good an "answer" do I need to make the decision?

2. Should I use simulation or some other method of solution (e.g., mathematical programming, Markov models, simultaneous linear equations).

These questions are interrelated because the anticipated costs for a given method depend upon the quality of the solution required. Furthermore, in the case of simulation, the costs are affected by the way in which the simulation is organized.

Generally, the higher level of management at which a decision is to be made, the greater the level of aggregation that is acceptable, and the lower the cost. However, very often very detailed modeling is required because the decision hinges on a very critical detail. Increasing the accuracy required of the model typically results in an enlarged model. A general rule in comparing alternative methods of solution is to fix the level of benefit desired and then compare methods on the basis of cost. However, within each method, the anticipated costs should be minimized.

In what follows, we will assume that the quality of the answer to be obtained is known, and it is desired to find the minimum cost way of obtaining the answer by simulation. Our concern will therefore be primarily with how the costs of a simulation can be predicted. We shall demonstrate that planning a large-scale simulation can be viewed as a multi-stage decision process. At some stages, however, there is uncertainty about the outcome because it is not completely under the control of the decision-maker. The techniques of Decision Analysis (see, e.g. (9))can be applied to determine the minimum cost approach in this uncertain environment. The taxonomy that we present is suitable for evaluating the costs of simulations in general and is not a function of the problem at hand.

OVERVIEW

A common view of simulation costs is to consider only the costs of computer running time, which is readily identifiable from accounting information. However, this cost, although often large, may be merely the tip of the proverbial iceberg. The simulation process has four stages: (1) development, (2) initial operation, (3) modification, and (4) repeated operation. The last two stages may be iterative or, if the project is a fiasco, may never be reached. Each of these stages will be discussed in more detail. Figure 1 shows the activities performed within the four stages, with emphasis on the development stage. This diagram is based on a synthesis of the break-downs given by Apelbaum(2), Emshoff and Sisson (3), Maisel and Gnugnuoli (7), and Naylor et. al. (8). Within each of the blocks, decisions on details are made by personnel at various echelons in the organization. These decisions involve, for example, the choice of language, of programming source (e.g., in house programming vs. job-shop) the computer to be used and the level of detail to be simulated.

LITERATURE

Despite the large number of books, papers, journals and conference proceedings such as one that deal with the technique of simulation, very little has been written about the cost of simulation. A major survey of total cost and total time required for 50 economic and social models and simulations was made in 1966 by Abt Associates (1). Fried (4) presents a cost/benefit and cash-flow analysis (similar to that used for capital investments) for computer projects in general rather than for simulations.

Shubik and Brewer (11) surveyed 132 of the approximately 450 models, simulations and games in the active inventory of the Armed Forces during 1971. The present aggregate data on purposes, operation, use, and cost but do not break out the 46 simulations included in this sample either individually or as a group. One of their major findings is a prevalence of "poor to non-existent cost accounting definitions and procedures."

Most recently, Victor Godin published a paper in Decision Science entitled "The Dollar and Sense of Simulation" (5). He limited himself to twelve textbooks on simulation and to applications of simulation in operations management/industrial engineering. He found the discussion of economics of simulation extremely limited in the standard texts and could cite only 5 applications papers in which costs or benefits are discussed even at a rudimentary level. He concludes that, "Thus, since the texts on the techniques of simulation tend to ignore the concepts of cost, economics, and justification of simulation models, it is not too surprising that the applications articles also omit these points." (5)

Godin's article also contains an interesting table (reproduced as Table 1) showing the resource utilization in simulation in terms of the organizational components involved with simulations.

A MODEL FOR ESTIMATING SIMULATION COSTS

The cost analysis model we present is based on the concept that the simulation development process is the same as the development process for any engineering system. The component of the system, which are shown in Illustration 1, interact to meet a set of requirements which constitute the simulation objectives.

Each of the major components of Illustration 1 can be further broken down into events. These events are usually steps to be taken in a specified sequence. Events often include participation by personnel from more than one department within the firm as well as the use of resources from more than one source, either within or outside the firm. This variety can make selection of a particular course of action wihin an individual event difficult for the decision-maker. Therefore, we have divided events into smaller parts called end items, which are limited in scope to jobs that are the direct responsibility of one supervisor or individual.

Illustration 2 is an example of the detailed structuring of a simulation. Each of the four stages of simulation referred to above (top of Illustration 2) can be broken down into its components. For the development stage, the eleven components are shown in Illustration 1. The first component, problem formulation, can be divided into two events: specifying the problem and defining the objectives. The event Objectives Defined, in turn, consists of three end items: (1) specify objectives, (2) identify output, and (3) specify relevant variables.

A major part of the work in developing a cost model is in developing an exhaustive breakdown of the simulation process into end items. It should be noted that the breakdown should deliberately be exhaustive and that many simulations do not include all the end items we included. Our analysis is necessarily subjective; different analysis will come up with different breakdowns. The important point is that such analysis is feasible and is a useful way of thinking about the problem.

DECISION TREE MODEL

For any particular simulation, the exhaustive model (which includes all end items) can be reduced to a decision-tree diagram that encodes the sequence of steps and the costs associated with each step. The decision tree diagram allows the alternatives available to be specified explicitly and systematically so that the decision-maker can see their implications and make appropriate choices. Decision tree diagrams have been developed extensively by statisticians interested in decision analysis (see, for example, Raiffa, (9)).

Illustration 3 is a decision tree diagram for the simulation development process. The diagram is read from left to right. A path is defined by following the arrows (braches) from problem statement to implementation (left to right). Each path through the tree represents an alternate way of accomplishing the simulation task. The decision tree presents, in time sequence, the alternative available and the information known to the decision-maker as he progresses through any feasible path. The diagram includes two kinds of nodes: decision forks (square on the diagram) and chance nodes (circles). The decision forks are under the control of the decision maker who can select the

Illustration 1

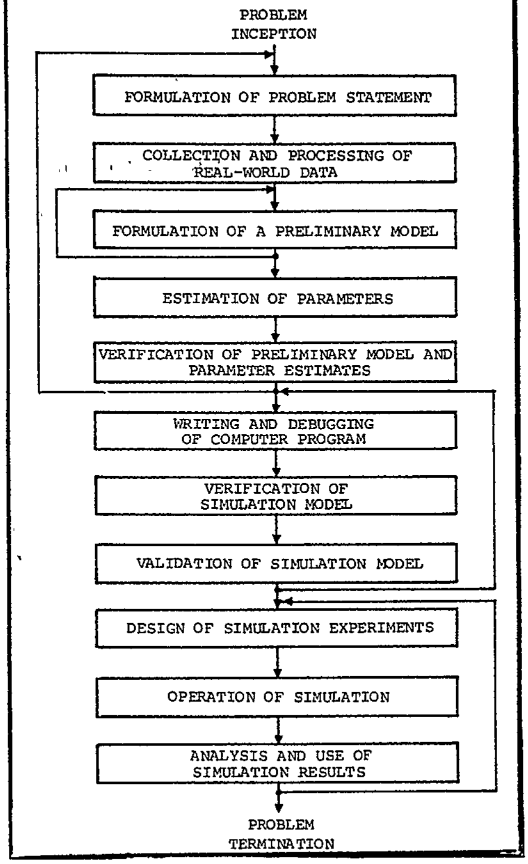


ILLUSTRATION 2

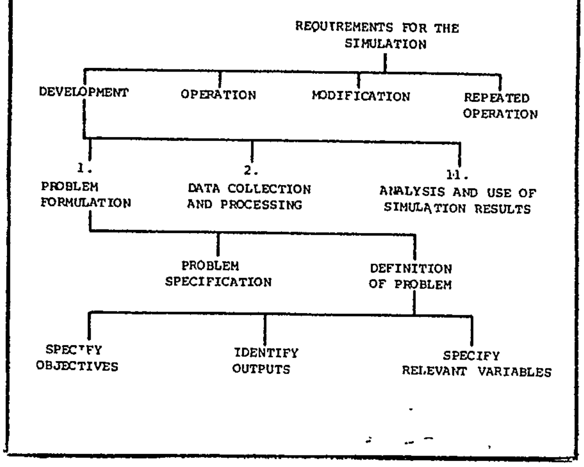


ILLUSTRATION 3

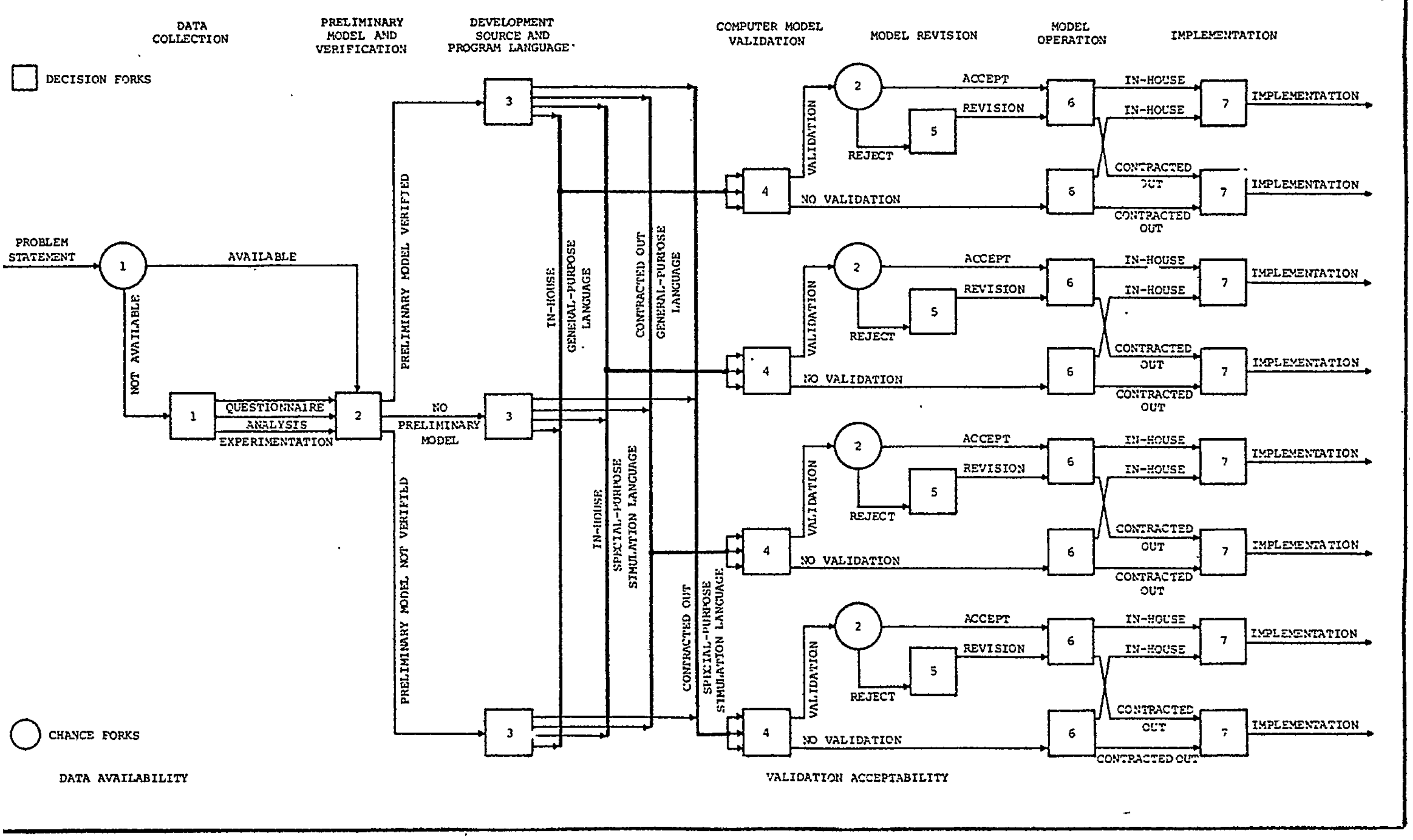


TABLE I - RESOURCE UTILIZATION IN SIMULATION*

	UPPER MGT.	USER DEPT. MGT.	USER DEPT. PERSONNEL	MGT. SCIENCE STAFF	DATA PROCESSING STAFF	COMPUTER & PERIPHERAL EQUIPMENT
MODEL DESIGN AND IMPLEMENTATION PHASE						
Define Problem	X	X		X		
Establish Goals and Objectives	X	X		X		
Formulate Model		X	X	X		
Gather Data		X	X	X		
Flowchart Model				X		
Code Model				X	X	
Keypunch Model and Data					X	X
Debug and Test Model				X	X	X
Validate and Revise Model				X	X	X
Design Simulation Experiments		X		X		
Run Simulation Experiments				X	X	X
Analyze Results		X		X		
Present Results	X	X		X		
Prepare User Documentation				X		
Instruct Users in Model Use		X	X	X		
Prepare Data Processing Documentation				X	X	
Model Use Phase						
Data Gathering and Revision		X	X			
Design Simulation Experiments		X	X			
Run Model and Analyze Results		X	X		X	X
Update Model Logic and Documentation		X	X	X	X	X

*From (5)
DEPT. = Department
MGT. = Management

alternative action he prefers; the chance forks represent nature whose outcomes can be specified initially in terms of probabilities. For each branch a cost estimate must be made (see below). Once these estimates have been made, it is possible to trace all possible paths through the network and determine the costs associated with each path. The optimal path is the one with the lowest expected cost associated with it.

Before discussing the use of the decision tree, we will explain what happens at each fork.

Data Collection Fork. If input data are not available, they will have to be gathered in detail, (e.g., by questionnaire, experiments, or analysis).

Preliminary Model and Verification. For most large simulations, small preliminary models are constructed to obtain a "feel" for the problem. However, this step can be eliminated, at some risk of incurring future costs.

Development Source and Language Selection. Will the program be coded in-house or under contract? Will a special-purpose simulation language or a gneral-purpose language be used?

Computer Model Validation. A choice has to be made as to the extent, if any, to which the computer model will be validated to assure users that it in fact corresponds acceptably to the real-world variables of interest.

Validation Acceptability. This is a chance fork, since the attempt to validate may prove the model to be inadequate and require that it be revised extensively.

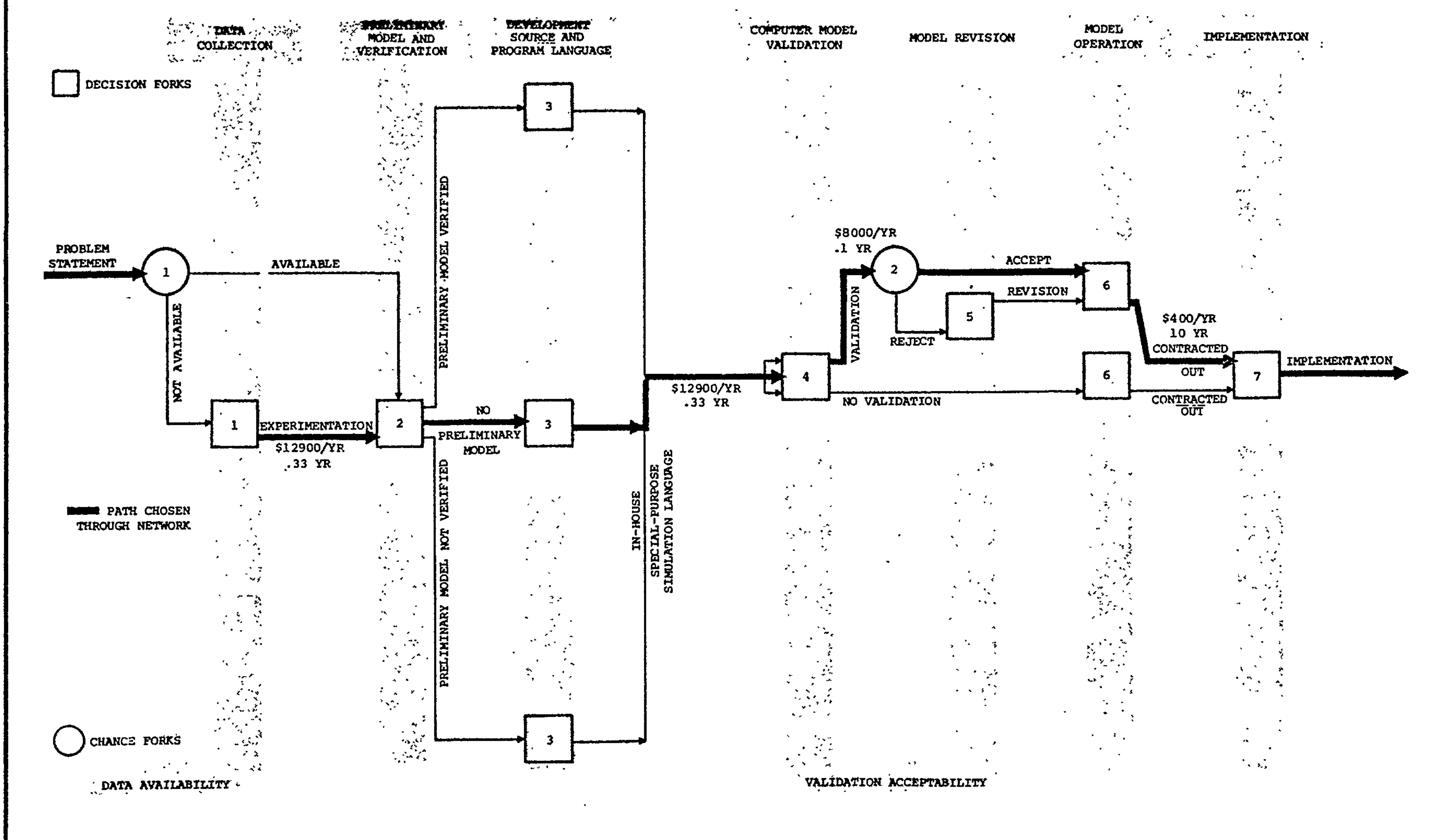
Model Revision. If the model is found to be invalid, then a decision must be made on the extent of the revision required.

Operation Source. Will an in-house or an out-of-house computer be used? Note that this decision will be affected both by the size of computer program and the size of machine available in-house.

Implementation. Once the simulation has been run, decisions must be made on how to implement the results.

The use of decision trees relies critically on the availability of cost and probability information. Typically, cost estimates are obtained

ILLUSTRATION 4



by consulting with knowledgeable people within the organization or by asking for outside bids. Usually the estimates are obtained in terms of anticipated manpower to be assigned, the time the manpower will be used, and the computer running times anticipated. These estimates can then be converted into dollar form. Because time information is also obtained, it is possible to make the calculations more sophisticated by taking into account the considerable time required from initiation to completion of large-scale simulations. As a rule of thumb, expenditures a year or more in the future should be discounted by the company's minimum rate of return to convert all costs into present worths.

Like costs, probabilities can be obtained from people who have done similar problems previously. Usually there is some awareness of the data requirements and the extent to which new data must be gathered. Furthermore, the complexity of the simulation and the degree to which the problem is understood should allow senior programmers to estimate their chances of producing a model that will prove to be valid. They should also be able to estimate the amount of rework that would be required if initial validation efforts prove the model inadequate.

Finding the set of decisions that yield the minimum expected cost path through the network is relatively straightforward (see, e.g., Raiffa, (9)). Ideally, the decision maker should be willing to choose the minimum expected cost solution. However, most decision makers do not operate in this way. For many organizations there are arbitrary policy restrictions that eliminate some alternatives; for example, a lack of in-house programming help or a policy of doing all programming within the company. Thus decision makers tend to seek paths that appear to give the best answer in their own organizational frames of reference, subject to budget constraints. The decision-tree framework presented here, thus, may prove to be most useful as a tool for making explicit to decision makers what alternatives are really available to them and allowing them to select alternatives on the basis not only of cost but also of all the other considerations involved. In those cases where simulation is competing with other methods of solution, the decision-tree framework will lay on the table what the real anticipated costs of simulation are so that these costs can be compared and judged against the anticipated costs and benefits of each of the other proposed solution methods.

APPLICATION OF THE DECISION TREE MODEL TO TWO LARGE SIMULATIONS

To test the concepts just presented, the history of two large-scale simulations was examined. The historical approach has to rely on the memories of individuals. We were able to obtain "oral histories" on these two simulations from the individuals responsible for their development. Each individual responded to a prepared list of questions and his answers were tape recorded. Both the flow diagrams and the associated cost data were obtained from these tapes. We will refer to these organizations as "B" and "R".

CASE 1

Organization B was developing a simulation of a large-scale communication network that they planned to operate. The organization had no policy constraints that restricted the available alternatives. However, they made two choices early in their planning that reduced the size of the decision tree. First, they believed that experimentation was the only acceptable way of obtaining needed input data for Decision Fork 1 (data collection). Second, they wanted to do their programming in-house in a special-purpose language (Decision Fork 3); however, they had no in-house computer that could handle the language.

The reduced decision-flow diagram of Organization B (Illustration 4) indicates that Organization B really had only two decision forks with more than one alternative. Because a previously formulated, small, manual network provided the information generally obtained from a preliminary model, the decision-maker decided against use of a new preliminary model.

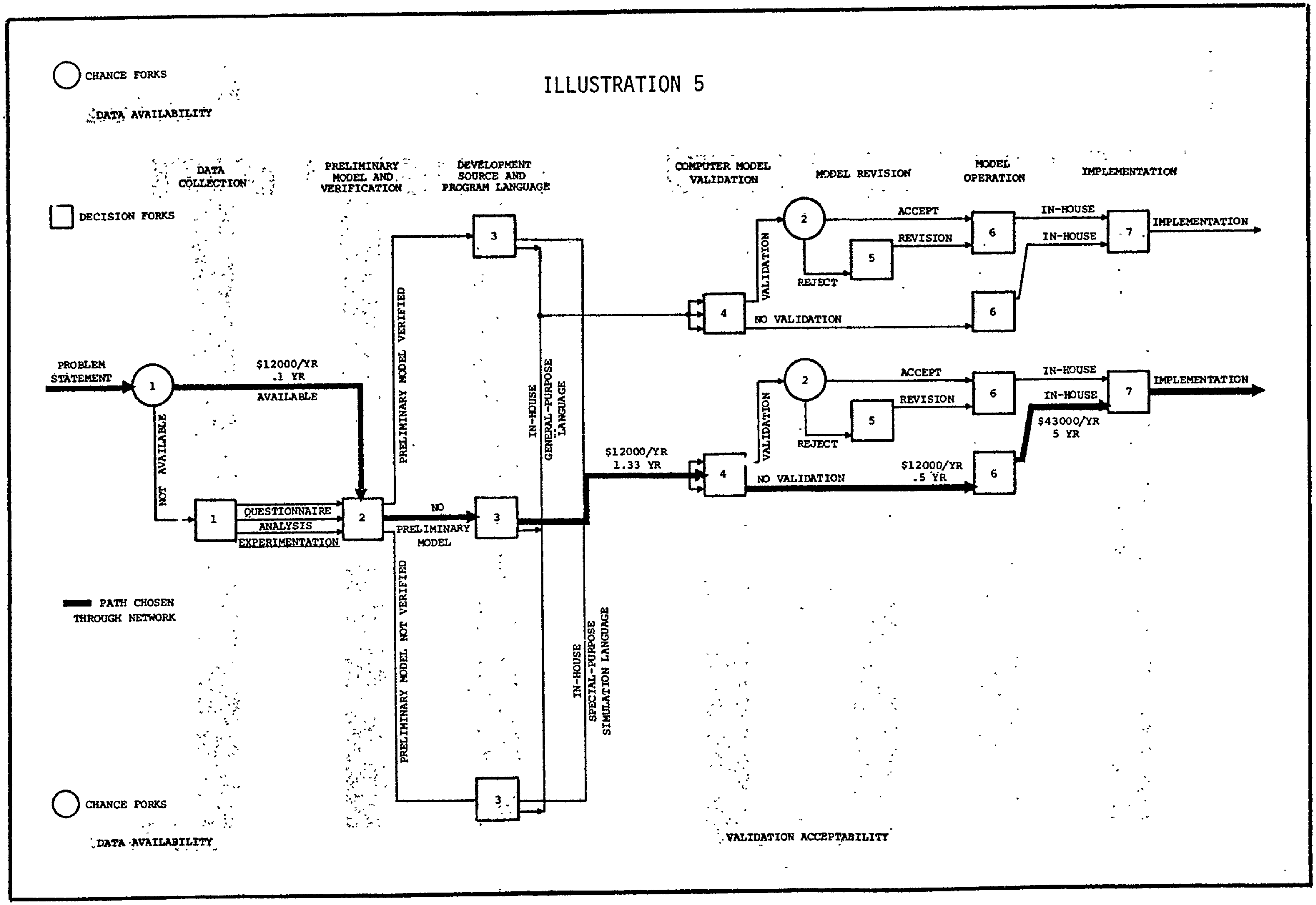
Organization B decided against using sophisticated statistical techniques to validate its model; however, computer results were compared to real-world data. The model was judged to match the real world well enough to be accepted as valid and to be used in simulation studies without revision. The path followed by Organization B through the decision-flow diagram and the associated costs are shown as heavy lines in Illustration 4.

CASE 2

Organization R was developing a simulation of a transportation network that it operates. The organization's operating policies did not permit computer program development or computer time to be bought outside. All other alternatives were available, as shown in Illustration 5.

The input data required for the simulation were available since they were the schedules and other operating data used by the firm in its day-to-day operations. A previously developed computer simulation model provided the information generally gained from a preliminary model; hence they proceeded directly to their large model. The operating group responsible for the program selected a special-purpose language rather than a general-prupose language because they anticipated lower coding costs. Thet did not take computer running costs into account since the computer was a "free good" as far as they were concerned. They felt so confident of their

ILLUSTRATION 5



system that they saw no need to validate their model. Illustration 5 also shows organization R's final path through the network.

DISCUSSION OF CASE EXAMPLES

In both case examples, it was possible to establish a path through the network that represented what actually happened. These paths are not necessarily optimal. In fact, a little analysis shows that a lower cost path could have been selected by Organization R. A critical decision is the selection of the computer language since the language affects programming costs, validation costs, and computer running costs. A very informal survey of several computer software firms led to the following crude, approximate numbers.

	General Purpose Language	Special Prupose Simulation Language
Coding Cost	2	1
Computer Operating Cost	1	8
Validation Cost	1	1.5

Each line in the above table is independent and gives the relative cost for that item. Please note that these values are for illustrative purposes. Readers faced with different cost situations should use values relevant to their own situation). For purposes of analysis, a 10% annual discount was used. Based on the data shown in Figure 4 and 5 and the relative cost factors given above, the present worth of the coding plus operation costs were as follows:

Organization	General Purpose Language	Special Purpose Simulation Language
B	$9,900	$7,500
R	$55,000	$163,800

ESTIMATING THE BENEFITS OF SIMULATION

Estimating the benefits to be anticipated from a simulation is often much more difficult than estimating its cost. In simplest terms, the benefits of a simulation are the present worths of the savings anticipated compared to not having the simulation, all other factors being equal. Yet, all other factors are never really equal. Furthermore, simulations also have intangible benefits such as the better understanding of the problem that results from the model building and data gathering and they often have unanticipated benefits from the continuing use of the simulation after the initial questions for which it was built have been resolved. There is also a logical problem. If the benefits of the simulation are known precisely beforehand, it usually implies that the outcomes of the simulation are known beforehand, in which case the simulation is not needed.

In many cases, simulations are used to help make choices among alternatives. Before the simulation, the outcome is not known; however, it is possible to estimate both the costs that would be associated with each alternative if it is selected and the opportunity looses if the wrong alternative is selected. In such a situation, the expected benefits can be estimated by again using the techniques of decision analysis (9). In the decision theory framework, simulation can be viewed as a method for gathering sample information to reduce the uncertainty in the case of Organization B. For their communication network, they needed to determine whether to use a party-line, switched, partially interconnected, or fully interconnected network. Although they could specify the cost associated with each configuration, they needed to determine which configuration was appropriate for the anticipated message loads.

Because of the intangibles involved, anticipated dollar savings from simulations are typically lower bounds on the total economic benefit. If the dollar savings exceed the dollar costs, then the decision is straightforward. However, if they do not, then the decision process has to involve quantification of intangibles to the extent that they are considered in the go/no-go decision on simulation.

Finally, where other methods of solving a problem (e.g., analytic solution of queues, gaming, econometric models) compete with simulation, incremental analysis should be undertaken. In this case the additional benefits of the more expensive method have to be sufficient to justify the additional costs.

CONCLUDING REMARKS

A large-scale simulation project is a major capital investment for most firms. As such it deserves much careful analysis as any capital budget item of comparable cost. Like capital investments, simulation must be judged on both the benefits and the costs anticipated. They should have an anticipated net positive present worth before commitments are made.

This paper has presented a decision-tree model that enables decision makers to examine the costs of proposed simulation projects prior to comitting resources. The method allows the decision maker to select among alternative ways of obtaining the simulation results so as to minimize project cost. The manpower required for such an analysis, if performed before the fact, will usually be of the order of one or two man-months. If a go-ahead is given for simulation, the analysis will, in fact, provide a plan for carrying out the project.

We have dwelled principally on the cost of simulation and only secondarily on benefits. The complete decision problem involves estimating both the cost and the benefits associated with each proposed alternative solution method. Note that both the benefits and the costs may differ according to which solution method is chosen. For large-scale problems, careful analysis of all alternative solution methods is usually warranted.

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