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THE ROLE OF COMPUTER SIMULATION IN CORPORATE MANAGEMENT: AN OVERVIEW

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Summary

This memorandum, prepared in support of a general study of integrated industrial systems, focuses on the growing use of computer simulation techniques (models) as a means of increasing the efficiency of management systems in large-scale industries. It first examines three significant generalized models or "business games," describing their important characteristics and evaluating their limitations as predictors of "real world" operations. It appears that models providing information feedback offer particular promise for realistic simulation of large-scale organizations.

Next, the author examines the use of simulation models in industry, noting that the most effective applications have been in the fields of transportation, communication, utilities, banking, and, particularly, manufacturing. An important characteristic of firms successfully using simulation techniques appears to be size: historically most practical applications have been in firms with sales in excess of $500 million, although the advent of relatively low-cost time sharing systems appears to be making the use of corporate modelling attractive to firms with annual sales less than $10 million. Typical costs for design and implementation appear to lie in range of $30,000 to $100,000, while elapsed times for full implementation range from six months to as much as three years.

To date, mathematical, rather than econometric modelling techniques have dominated, and have been used effectively in the fields of finance, marketing, production and inventory control. Although short-term forecasting techniques for projections of sales and revenue are in general use throughout industry, broader applications have suffered from a number of limitations in existing models, among the more significant being a lack of flexibility within the model itself and, in some cases, a lack of commitment to modelling on the part of high-level management. Despite these and other limitations, the high degree of risk and uncertainty characteristic of the current economic environment appers certain to lead to greater use of more complex simulation by managers at all levels.

The Role of Computer Simulation in Corporate Management: An Overview

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Point of View

One of the most powerful managerial control devices provided by operations research techniques in recent years is that of simulation. As in other fields involving complex dynamic systems, simulation techniques are highly applicable in the designing, establishing, operating, and modifying of large-scale, centrally planned, and coordinated information and control systems. The experimental use of such techniques has illustrated and reinforced the utility of these techniques for information and control systems problem solving on different levels of management. Within a period of less than five years, computer simulation techniques have penetrated corporations in many countries at the highest possible level.

For our purposes it will be interesting both to analyze the motivations of decision makers and to use simulation techniques in practice. A question for which an empirical answer would be of importance is, "In this field, what is the proportion between research effort on the application of simulation models to large-scale management structures or systems?" Before we attempt to approach the problem and try to present some recommendations, let us examine a few previous studies.

Some Simulation Models of Large-Scale Systems

Simulation is widely used today as a training tool for what are called "business games" or "management games." It usually involves a model of the business with people studying the effects of various decisions under known market conditions. These games are good for managerial training and orientation, but they fail to give any real life control. They are based on stationary systems where past performances are used as guidelines for projections into the future (see Millen and Modie [6]).

Management of a large organization or a corporation should be realized through a dynamic system where various management functions are connected through a feedback and feed-forward control system. Many such studies have simulated a firm or a corporation on a digital computer; an interesting simulation model of this type was developed by Charles Bonini [1]. In his model Bonini asserted that the studies done in the business world have been very narrow minded. His model utilized accepted economic policies and concepts from the behavioral sciences in its representation of a large, hypothetical firm.

The Bonini Model

Bonini recognized that the understanding and control of a complex firm required consideration of a large number of interdependencies and interactions which occur within the firm; this was entered in his model. The modelling of the firm was accomplished by subsystem models of the manufacturing, industrial engineering, accounting, and sales functions. Perhaps the most distinguishing element of the model was that its decisions were not simply the result of applying a single decision rule to a given set of informational inputs. Bonini had specified different decision rules regarding pricing, budgets, index of pressures, and organizational slack. The model thus was able to test propositions relevant to economics, accounting, behavioral science, management, and some of the modern tools of production planning.

The model as well as the decision rules then were a description of a hypothetical firm with strong resemblence to the real world situation. The specific changes considered were:

a) Changes in the external environment, for example, involving uncontrollable parameters like demand or changes in demand;

b) Changes in the information system of the firm, for example:

- changing the information links, that is, the results of changing information flows between the various decision centers;

- changing the content of information, that is, changing the kind, amount, or method of information presentation;

- changing the timing of information flows, that is, the optimum time of reporting whether daily or weekly, etc., or alternatively reporting only if certain events happen.

c) Changes in the decision system, where the system can be altered in two ways:

- changing the decision rules,

- changing the decision parameters.

Bonini has used this model as a controlled laboratory experiment where individuals are replaced with reasonable behavior rules. The objective is to gain insight by varying some factors and replicating various alternatives. The experimentation involved changing eight factors to deal with the changes described above:

1) low versus high variability in the external environment of the firm, or, more specifically, interest in the effect of small versus large standard deviations in the probability distribution for sales and production costs;

2) two different market trends for the firm: one a slow (2% per year) growth upon which is imposed a three-year cycle; the other a fast (10% per year) but irregular growth;

3) a "loose" versus "tight" industrial engineering department in the matter of changing standards;

4) an organization that is susceptible to pressure as opposed to one that is not;

5) an organization in which the individuals are sensitive to pressure as opposed to one in which they are not;

6) an average cost method of inventory valuation versus a Last-In First-Out method;

7) knowledge on the part of the sales force about the inventory position of the company versus the absence of such knowledge;

8) the reliance primarily on present versus past information for control within the firm.

Each of the eight factors had two values with a possibility of twenty-eight or 256 experiments. The actual number of runs made was sixty-four which raises the question of the statistical validity of the model. Another criticism of the model concerns the length of the run. The run is carried out for 108 time periods representing nine years. From this analysis, the time series is averaged out and predictions are made for immediate and short run effects of changes. Nine years seems to be a very long cycle to predict short term changes. Some form of exponential smoothing in which more weight is given to current data over the very old data will represent a much superior predictive model.

The results, although questionable owing to their derivation from an unstable model, definitely show the importance of modelling the firm as a mechanism of interacting decisions. Some more recent models of large scale industrial systems are in one way or the other based on the approach of Bonini.

Although the results derived by this model were questionable, Bonini's method of modelling system components in accordance with behavioral as well as economic and organizational concepts and his attempt to account for personality differences by explicitly including these differences in the modelling of the decision making functions were noteworthy contributions to the literature on large, complex systems simulation techniques.

System Development Corporation Model

Another model has been developed to learn how control is affected by using particular decision rules. The System Development Corporation has constructed an analytical model of a total business system that simulates the production process within an organization (see Jain and Moodie [4]).

In this model, the various activities are divided into tasks and each task is modelled. Each task has an input queue, which holds tasks yet to be done, and an output queue holding completed tasks. The tasks are designed according to the use and availability of resources, and the design considers the specification of queue discipline, methods of performing tasks, and storage and retrieval of information. A group of tasks assigned to an individual makes the person a task center. A set of transactions tie the activity network and task centers together to make an operating system. The modelling of a firm as a task-queue network seems to have validity. The system will be more significant if it can be made more dynamic and put into real time where the manager can sense the environment and change the decision rules, if necessary.

Most analytical techniques which are used suffer from two serious limitations. First, they suffer from the static nature of their techniques, and second, they ignore the interrelationships and interdependencies of various decisions. This results in local optimization of individual functions, which are often conflicting, and results in suboptimum plant operation.

Forrester's Method

Based on the primary assumption that decisions in management and economics take place in a framework that belongs to the general class known as information-feedback systems, Forrester [3] developed a method of analysis and simulation technique for large, complex systems which conformed to a well-defined and proven theory, that of feedback control systems. This industrial dynamics method frees the analyst from the above mentioned two limitations. It can include as many company functions as the analyst thinks are vital and enables the study and implementation of a decision within a dynamic ever changing framework. This is more typical of a real world company's operating conditions: that is, industrial dynamics is primarily concerned with the industrial flows of manpower, materials, money, capital equipment, and information. Industrial dynamics views decisions as the controllers of this organizational flow. The decisions regulate the rate of change of levels from which the flow originates and to which the flow is sent. It defines reservoirs, known as levels, into which and from which these flows pass. It establishes values to control the rate of flow which corresponds to management decisions. The flows of a company are defined by many equations. These equations go into a model which represents the operations of a company. Thus the results of a policy or a decision could be studied for several periods into the future by using a computer.

The process of simulation could be shown here in a couple of steps. In the first phase, a model in the form of block diagram that is the result of an analysis of the firm (or corporation) and of interviews with the top-management people will be constructed. In the second phase, a set of differential equations describing the rate of change of levels and flows will be formulated and a verification of values of constants and variables for the model will be completed as necessary.

As far as a dynamic-mathematical model is formulated in the next step, programming for the computation by using a specialized high-level language, for example, DYNAMO or CSMP will be employed. The results in the form of output summaries and graphs will give the top management, in an easy-to-survey form, a simulated course of the situation in different time series and in different variants and changes of input parameters that are applicable to different spheres of the corporation's activities.

Industrial dynamics is considered as a new and very effective procedure for systems analysis and simulations of large-scale organizations in spite of very serious limitations for decision making and management in practice. For many corporations such a model will serve as an integrated model and methodological standard for an initial approach to the analysis of the corporate structure and the simulation of flows.

Some Considerations for Applying the Present Situation

The following discussion will consider corporate simulation models from different aspects as they were implemented by some significant firms, and it will summarize common features.

Kinds of Users

In actual practice, relatively few firms have managed to integrate their financial, marketing, and production activities into a truly integrated corporate simulation model. Some firms that have successfully developed and implemented a total corporate simulation model include Ciba-Geigy, IU International, Anheuser-Busch, General Electric, Xerox, and IBM. The Ciba-Geigy model is probably the most sophisticated model of a "total company" now in use (see Naylor and Jeffress [8]) in existence today. It is used extensively by corporate and division management to evaluate long-range plans.

The Ciba-Geigy firm is representative of a very large group of other users of corporate simulation models in the manufacturing industry. Manufacturing is one of the most significant fields where practical results have been gained from modelling. Another model-using group is composed of big firms in transportation, communications, utilities, and banking and finance. In contrast, the agriculture, mining and service industries have made little use of these kinds of models.

We can say that before now the rate of sales was very important for a successful implementation of model results; for example, only firms with sales in excess of $500 million per year were of sufficient size that models could bring practical results. It is interesting to note that corporate planning models are now economically feasible for firms with annual sales below $10 million because of the advent of time-sharing computer language which facilitates the development of corporate modelling and gives good results.

Firm sizes are important to our considerations from many aspects. One aspect is the economics of developing models. Most of the existing corporate models were developed in-house without any outside assistence from consultants. Naylor and Jeffress [8] mentioned eighteen man-months at an average cost of $100,000 as an average amount of effort required to develop models in-house (without outside assistance). For those models developed in-house with the help of outside consultants, the average time required to complete the model was ten months, and the average cost was about $30,000. The time horizon necessary for full-functioning implementation fluctuates from six months to three years.

Kinds of Models

Mathematical models play a central role in the work of the management scientists, but this work is by no means limited to model development. The difficulties involved in creating useful mathematical models are, however, sufficiently challenging to warrant some special attention. The process by which an experienced analyst arrives at a model of the management phenomena he is studying is probably best described as intuitive. Indeed, the really effective and experienced people in both management and science typically operate in a largely intuitive manner. This is a reason why econometric modelling techniques are not used very extensively.

By examining model use in the largest corporations in the US, Canada, Japan, and Europe, we can find three basic areas where mathematical models have been successful: financial models, marketing models, and production models.

Financial models are quite easy to develop, require a minimum amount of data, and can be validated against the firm's existing accounting structure. Very good results have been obtained in application areas such as (see Naylor and Jeffress [8]): financial forecasting, financial analysis, profit planning, long-term forecasts, cash-flow analysis, balance-sheet projections, and budgeting.

A very specific area for simulation is found in marketing models. We could say that this area seems to have the most significant gap between research effort and real application. The reason why some sophisticated methods have not been fully accepted reflects the fact that forecasting and econometric modelling techniques are not so well known to corporate planners as the more traditional tools of financial analysis are.

The vast majority of models used are what management scientists call deterministic models; that is, they do not include any random or probabilistic variables. Models which incorporate one or more probability distributions for variables such as sales, costs, etc. are called risk-analysis models. Accordingly, risk analysis models involve a host of statistical and computational complexities which one can avoid by using deterministic models in a wide spectrum (see Splichal et al. [10]).

A different situation is found in production models. In these models, each firm possesses a plant, a work force, and raw materials which form the three basic factors of production. Each of the products that a firm can manufacture requires a different combination of these factors. The availabilities of the three factors limit production. In short, the production model is useable for problems in which mathematical optimization has been used with the goal of maximizing or minimizing an objective function such as profit or cost.

Inventory control was one of the first business areas to be examined mathematically, and it was therefore one of the first areas in which simulation was utilized (see Naylor [7]). Not only has a large body of theoretical work assisted in clearly conceptualizing inventory problems, but inventory problems inherently involve relatively well-defined flows over time which therefore lend themselves to simulation.

Most such simulation models have no capacity to optimize; they simply represent what will happen if a system is set up to operate in a certain way with whatever values are chosen for the decision variables. As a consequence, when optimum values are unknown and the objective of a simulation study is to locate optimum values of one or more decision values in a system, a simulation model is essentially used as a vehicle for search. A simulation model does not in itself produce optimum values of decision variables in the sense that a linear programming model, for example, produces optimum values.

Benefits and Shortcomings of Corporate Models

Many corporations use some form of short-term forecasting techniques particularly for sales and revenue projections. The analysis in this field shows that very popular techniques are oriented toward growth rate, moving average, exponential smoothing, and linear and nonlinear time trends.

The results from using all the above-mentioned techniques are, of course, in direct proportion to the skills and resources expended in developing the corporate simulation model. It is interesting to note, however, that in a significant number of corporations, the benefits of corporate models have been conceded in such control and management improvements as:

ability to explore more alternatives,

more timely information,

more effective planning,

faster decision making,

better quality decision making,

more accurate forecasts and cost savings.

Reservations about the limitations of corporate models do not appear to be so intense as to block model use.

One of the most significant reservations over model use is that a corporate model is not flexible enough. According to the restrictions and dynamic character of the hierarchy of control and management, situations which are very difficult to enter precisely into the model may occur. Such deviants require too much analytical skill and take too long to develop in a running project. Thus, a few deviant situations can increase previously proposed cost levels.

Other limitations can be found in the relationships between the people responsible for construction of the model and those who will use it. We must consider that although suitable models and corporate software are necessary for the success of corporate modelling, they are by no means sufficient. If the top management of the company is not fully committed to the use of a corporate model, then the results are not likely to be taken seriously and the model will see only limited use (see Dutton and Starbuck [2]).

Crucial to the successful implementation of any corporate simulation model is the political support and active participation of top management in the problems both of the definition phase and the implementation phase of the project. The political support of top management can be lost in a situation in which top management, as the model's users, cannot agree with a model's development or its analytic process. Loss of support can occur if the information for the scale of management and control are not flexible for realistic decision making, if the output is not detailed enough, or if the results are obviously inaccurate. This defeats the purposes for which modelling is intended. With the growing participation of management in model development and use, further acceptance of the techniques and the implementation of models at higher levels in organizations is likely to follow.

The Future of Corporate Modelling

In the coming decade, management personnel will be increasingly involved in the development of simulation models to assist them in making management decisions at all levels. Management is turning to these models for reasons which are almost identical to the reasons for implementing centralized corporate planning. Corporate planning seeks the reduction of risk and uncertainty. The degree of risk and uncertainty present in the external environment faced by most corporations is now perhaps at an all-time high. Nearly every firm in most countries in the US and Europe is facing the following problems: 1) energy, 2) inflation, 3) liquidity crunch, 4) shortages, 5) declining productivity, and 6) other economic uncertainties.

In these circumstances, corporations are looking for new techniques such as computer-simulation models to enable them to evaluate the impact of alternative policies, opportunities, and external events on the performance of the entire corporation. A number of firms such as General Electric and Xerox are experimenting with models of the external environment as well as with internal corporate planning models. We see this type of modelling becoming more important during the next decade. Figure 1 is included as an illustration of environmental impact on activities important for decision making and management of an integrated industrial system.

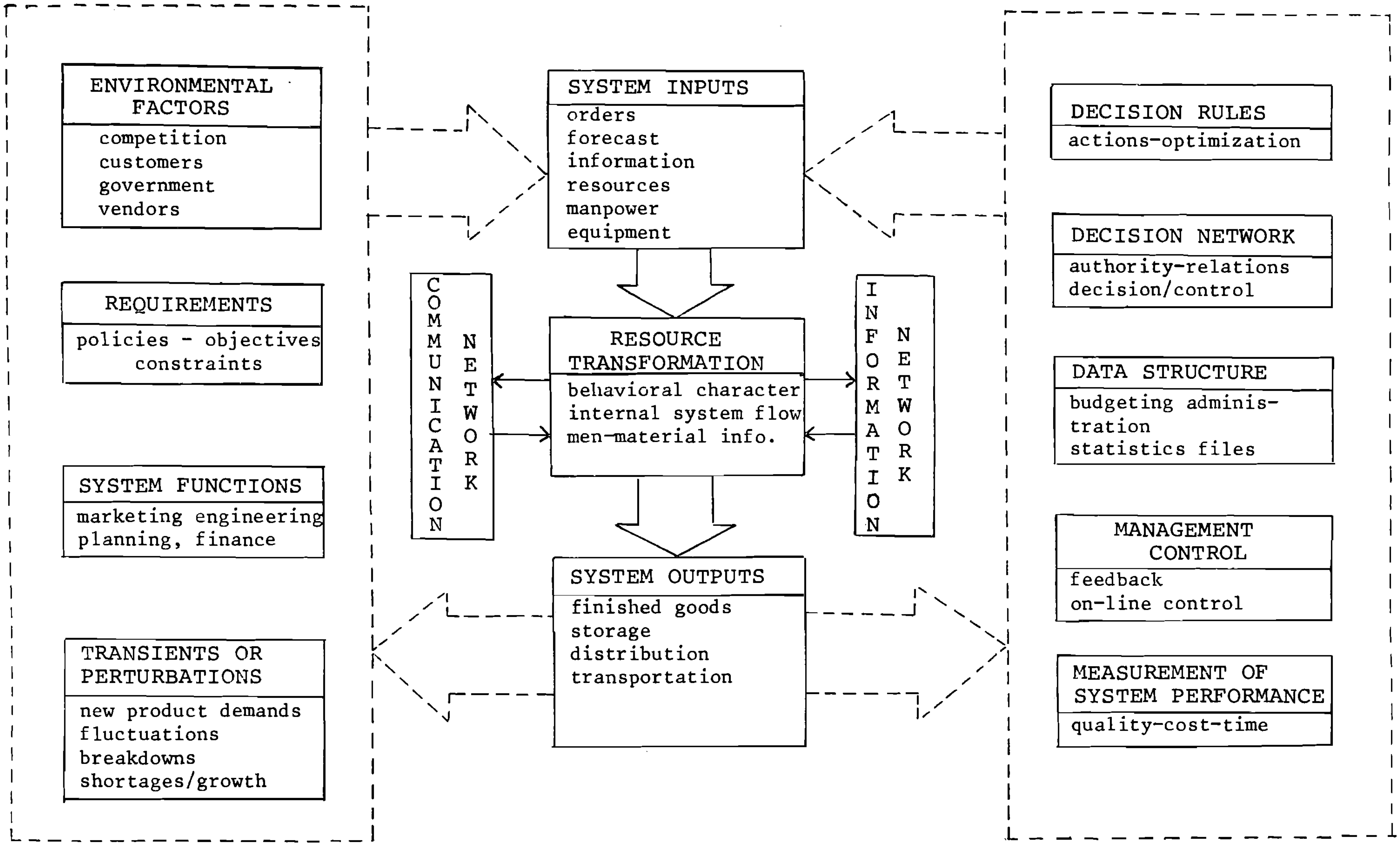

Figure 1. Activities and functions of an IIS.

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