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Evaluation of Management Information Systems

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The economic evaluation of Management Information Systems may be based on the following theories and techniques: Control Theory, System Dynamics, (discrete-event) simulation, and gaming. Applications of these approaches are summarized. Advantages and disadvantages of the various approaches are presented.

1. INTRODUCTION

TRADITIONALLY the emphasis in computer science and information science (called 'informatica' in Europe) has been on the evaluation of the *technical* performance of computer systems, measured by such criteria as throughput, response time, CPU (Central Processing Unit) utilization, (see, for instance, [7]). Only a few attempts have been made to model the *economic* performance of computerized information systems—or MIS (Management Information Systems)—measured by criteria like profits, sales, inventories etc. In this paper we shall evaluate economic evaluation studies based on System Dynamics models and 'discrete' simulation.

2. CONTROL THEORY

Control Theory highlights the role of feedback and feedforward information. Negative feedback means that information on a variable is compared to some desired goal value, and in the case of deviation between the actual and the goal value, corrective action is taken. Feed forward means that predictions or forecasts are made, such as sales forecasts. The advantage of Control Theory over techniques such as simulation is that it provides more general conclusions. The disadvantage of Control Theory is that it must introduce drastic simplifications in order to keep the mathematical problems within manageable limits. Hence its models are usually continuous, i.e. a very aggregated view of the world is maintained. The models are also linear in order to simplify analytical solutions (using Laplace transformations). Steady-state solutions are relatively easy to obtain so that transient behavior tends to be neglected. Deterministic models are simpler to solve than stochastic models. Hence bias but no stochastic noise was examined in the study by Politzer & Wilmès [9] which we shall discuss below.

Delays are modeled through, e.g. *first order exponential delays*. The effects of such delays are illustrated in Fig. 1: In the upper part the input shows a temporary increase (pulse) and in the lower part the input shows a permanent increase (ramp function). The reaction of the output depends on the order of the delay function, as the figure illustrates. These delay concepts correspond with a *continuous* view of the world as is maintained in electrical engineering. For a critical discussion of such delay functions (also used in System Dynamics) we refer to Riethmüller & Schreiber [10]. In Kleijnen [6] several sources of delay in MIS are discussed, such as update interval (say, weekly versus

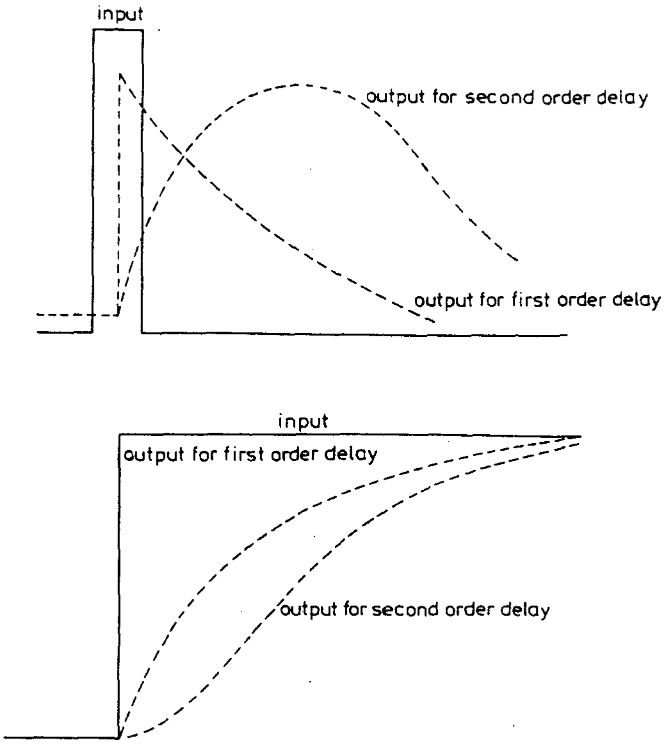

FIG. 1. *Delays of first and second order*

monthly processing), retrieval delay in real-time-systems, decision delay (time to reach a decision and to affect the physical system) etc. These sources of delay would require non-continuous, non-linear, stochastic models if we want a realistic model. So Control Theory is far removed from the mental models used by System Analysts and most users in data processing. It remains possible that at higher levels of decision-making a more aggregated view as proposed by Control Theory, becomes more appropriate.

Politzer & Wilmès [9] applied Control Theory to the evaluation of a MIS. They restricted their study to a classical model for planning inventories and production originated by Holt *et al.* [5] and known as the HMMS model. This model assumes simple quadratic cost relationships. The authors derived a steady-state solution based on a continuous version of the HMMS model, and they studied the effects of (exponential) 'delay' and bias. Gross value was found to react asymmetrically to multiplicative bias, i.e. overestimation had a different effect compared to underestimation. Delay was found to have an optimal value larger than zero, i.e. on-line systems do not necessarily yield higher gross benefits. However, remember that these conclusions were derived under a number of restrictive assumptions!

If the Control Theoretic model cannot be solved analytically then we may resort to simulation, especially System Dynamics simulation.

3. SYSTEM DYNAMICS

System Dynamics (SD) or Industrial Dynamics has as its philosophy that each socio-technical system can be looked upon as a dynamic system with (negative) *feedback*. Since it takes time to collect and process data on the output, to compare the resulting information to the norm, and to adapt the decision variables, *time lags* are created which make the model dynamic. Delays in information transmission may cause fluctuations within the company, as opposed to externally caused business cycles. The computer language that has been developed especially for this SD approach is DYNAMO, but other languages can also be used, e.g. FORTRAN or the simulation language CSMP.

There has been considerable controversy about the usefulness of the SD methodology. SD may tackle any problem, ranging from some subsystem within a company to such world problems as world energy resources. The approach does not pretend to give exact numerical predictions but it does show the dynamic properties of a system [1]. Thissen [13] examined a variety of techniques for improving the understanding of complex SD models. Nordhaus [8] emphasized that in SD relationships and variables are not based on empirical data—in contrast with traditional econometrics—while changing an assumption may drastically affect the model's outcome. Compared to other simulation approaches, SD has the advantage of being more than a technique. However, the very advantage of being a framework means that the modeler has to adopt a world view (with levels and rates) that is not spontaneous, but requires learning (or indoctrination?). For instance, a discrete-event simulation of a queuing system is a direct representation of the spontaneous, intuitive way such a system would be described by 'anybody'. Unfortunately, such a discrete-event description is too detailed for 'large' systems. Note that if one is willing to adopt the SD view of the world, mastering the SD technique needs practice in the *art* of model building.

Of special interest to us is the concept of *delay* in SD. As in Control Theory SD uses delays of first order, second order, etc; see Fig. 1 above. We find a discrete view more compatible with the MIS world view (see section 2).

Though a great many studies have been performed using the SD methodology, only a few of these studies concern the explicit study of information systems.

Swanson [12] investigated the effects of error, distortion (bias), delay, and sampling (update interval). He modeled the control of manpower, production, and inventory, based on information on sales and inventory. Swanson found that delay had the largest effect, while error had the smallest effect. His conclusions, however, are not based on solid statistical methods: only two simulation runs per case with no interactions measured.

At Philips Industries a series of studies was performed under the acronym IPSO: Initiating Production by Sales Orders [3, 14]. This studied the effects of delays in information and examined the scope of the IS. In a chain of production processes—or more generally, a network of production processes—a process may be provided with information on the demand from the next process. Alternatively, this information may be augmented with marketing information, i.e. the demand by the ultimate customers of the company. Extending the scope of the data base so that besides 'local' data 'global' data are also available, was found to dampen the oscillations in the company's inventories and activities. Note that this series of studies combined a number of techniques and ideas ('models'). The models were strongly influenced by System Dynamics. The simulation experiments were combined with analytical results derived for simplified models, e.g. Control Theory models. Analysis suggested which SD models to simulate, and simulation results were used to test analytical approximations.

In conclusion, SD is an extremely popular method. It is much more than a technique; it is a world view. SD is best known for its study of large scale systems: World Dynamics, Urban Dynamics, etc. For such large systems an aggregated view seems necessary. At such high levels of aggregation ('the' pollution, 'the' world consumption) continuous models may be adequate: flows, rates, exponential delays. However, at the level of MIS we prefer more detailed models with discrete events, aperiodic decisions, and realistic representations of information attributes. A technique permitting such a level of detail is simulation together with its extension, gaming. Note that the derivation of adequate decision rules (policies) is assisted by SD modeling. Especially when the MIS is integrated (e.g. coupling the production and the inventory system), then large systems must indeed be managed.

4. SIMULATION

The *structure* of simulation models can be different in the following respects. The system may be modeled by *difference equations* so that at *equispaced* points of time the state of the system is computed. An example is a corporate simulation model based on balance and profit & loss account relationships. Slightly more complicated difference equations are used in System Dynamics: a set of recursive difference equations with variable coefficients (rates). In *discrete event* simulation the model is a most detailed representation of the real-world system in so far as individual events are represented. Many languages have been developed for this approach, e.g. GPSS and SIMSCRIPT. In this section the term 'simulation' will exclude SD simulation models.

Simulation permits the most realistic models. Moreover, the user—the client of the model builder—can better understand a simulation model. A disadvantage is that it may take much effort to build and run a simulation model, while the responses are, strictly, valid only for the specified values of the input variables and parameters. In Kleijnen [6], however, we have explained how statistical techniques can be used to generalize simulation results. Next we shall present an example of a simulation study on the value of information.

Boyd & Krasnow [2] performed an interesting *discrete-event* simulation study on the timeliness of information in the context of a hypothetical manufacturing company. They investigated periodic decision-making, tactical decisions being made less frequently than operational decisions. They also varied the processing delay (turnaround time). The delays affected the speed with which decisions could react to changes in the environment such as changes in demand. This lead to fluctuations in both profit and physical variables like inventory. Reductions in the various delays improved profit significantly.

Note that Welke [15] criticized the *ad hoc* character of simulation studies such as made by Boyd & Kranow [2]. He proposed a general framework for the simulation modeling of information systems. His framework supports a user's view, as opposed to the traditional technical data processing view. The framework can be applied to a particular system in order to generate a descriptive model, which can next be evaluated using a discrete–event simulation package. We refer to Welke [15] for more details.

5. GAMING

In gaming or man–machine simulation one or more input variables is determined by human participants or 'players'. Let us briefly compare gaming to pure computer simulation including System Dynamics simulation. The relative advantage of gaming is its *behavioral realism*: Decision-makers may have multiple—possibly vague—goals. They may use heuristic—possibly inconsistent—decision rules. They may form competing or colluding teams. They may show learning behavior or fatigue and boredom, and so on. The disadvantages of gaming relative to pure machine simulation, are lack of *experimental control* and certain practical nuisances. If the purpose of the game is to reach general conclusions rather than to train people, then human participation creates much noise. For instance, a player can show inferior performance not because he is supplied with poor information but because he lacks 'feeling', gets bored, is confronted with superior opponents, etc. General conclusions require repeated runs with the game. But repeated runs are expensive or may even be impossible because of lack of players and computer time. Moreover, repeated runs are not completely comparable since the players show learning, fatigue etc.

This brief discussion was not meant to decry gaming as a useful research instrument, but to warn against possible pitfalls. A general reference on gaming is Shubik [11].

The *'Minnesota' gaming experiments* were performed at the University of Minnesota's MIS Research Center during the period 1970–1975. In these experiments relationships were investigated among

(i) the information system itself;
(ii) the decision-maker: psychological characteristics, experience;
(iii) the decision environment: operational versus strategic, etc.

Dickson *et al.* [4] summarized nine different gaming experiments. The experiments taken together, showed that effects did occur when changing the experimental factors, i.e. information system, decision-maker, environment. Unfortunately, no simple general relationships could be formulated.

6. CONCLUSION

The evaluation of the economic benefits of MIS forms an underdeveloped area. In order to make progress in this area, we need *theory plus tools*. Theories provide framework, clues, guidelines, ideas, etc. Tools provide numerical results. In the context of MIS relevant theories seem to be: Control Theory, System Dynamics, Bayesian Information Economics. Useful tools are simulation, gaming, and—more generally—mathematical modeling and statistics. A new management style, fostered by more scientifically trained managers, might stimulate the acceptance of formal models. This paper surveyed a number of formal theories, models, and techniques. Their practical application remains as the major task.

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