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MANAGEMENT INFORMATION SYSTEMS AND PRODUCTION MANAGEMENT: A LOOK AT THE SEVENTIES

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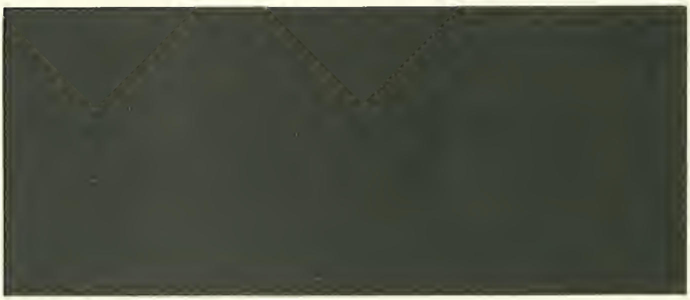

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I. Introduction

The areas of production and inventory control were among the first to experience the impact of computers. Today we find that most large organizations have computerized some facets of their production and inventory control cycle. The sophistication of these systems varies, but even the best are not addressed to the problem the manager faces in his efforts to improve his decision-making process.

The first use of the computers at the production level has been invariably addressed to the processing of accounting data. Efforts to process more disaggregated data and to do it faster, have resulted in systems which clutter the desks of managers with a lot of data but little if any information. In our estimation this is an unfortunate development; because the production manager not only is unable to obtain help from the information system in his attempts to structure and control his problems, but, what is more, he is hampered by the ever increasing quantity of data the computerized system generates. No wonder he mainly resorts to his intuition despite our exhortations to use models and rational analysis.

We believe that the greatest obstacle toward the realization of effective

information systems for production management is not technical but conceptual. We have hardware and software to satisfy our needs economically, if we just knew what to do with them. This is our main problem in the general area of management information systems, lack of articulation.

The purpose of our presentation is to shed some light on the issue of what type of systems we should be looking for in the seventies. To do this we will:

(a) Discuss the ingredients of control of production processes, and at the same time bring to the forefront some of the general characteristics of the major problems production managers face in their efforts to carry out their functions

(b) Outline a framework for general management information system design and specify the dimensions along which such systems may vary, and

(c) Evaluate existing systems across the dimensions discussed under (b) and speculate about the future.

II. The Control of Production Processes

As with any other control situation, there are certain elements which are necessary for managing production operations effectively. The information system, if it is to be useful to management, must provide aid, across each one of the following dimensions all of which are necessary for the operation of a planning and control system.[1]

1. Objectives: The objectives of the production activities of an organization are the result of a whole series of transformations which bring

[1] We view the information system as the set of relationships or links between the various components of the control process. The assemblage of the control process and the management information system we will call management planning and control system.

the overall objectives of the organization to bear on production plans and operations. It is through the transformation or translation of the strategic plans into hierarchical subplans, operations and suboperations, that top level assumptions and subjective value judgments of managers are converted into information. The latter in turn constrains lower-level operations because it is perceived as a set of "facts".

There are several consequences for the information system which emanate out of the hierarchical structuring of plans and operations, and the conversion, in the process, of value judgments into "facts". For the purposes of this paper we will concentrate only on two.

(a) The objectives that filter down to the production level are multidimensional. The Management Information Systems (MIS), therefore, must provide managers with information not only regarding the constraints, but also aid in perceiving changes in priorities and in trading off between conflicting alternatives.

(b) If, in addition to the usual feedback, the assumptions which underlie the constraints and relate value judgments to operating plans were to be monitored, the M.I.S. would be more useful to managers. It can provide signals and dictate actions which could prevent problems from arising. Furthermore, it can help reinforce or point out the necessity for changing held beliefs concerning the relationships between assumptions, objectives, plans, resources, technology and operations. That is to say help the manager test the latter relationships (his model of the world as he sees it), and learn from experience.

Unfortunately, very few if any information systems today provide feedback

across the dimensions identified here. For this reason they are inflexible, and in most cases have to limit themselves to so-called objective accounting data emanating from internal operations. To repeat, our arguments here dictate systems which scan both the internal as well as the external environment across a variety of dimensions, in order to bring to the attention of management opportunities for action. In the process, this feedback will also enable managers to learn from experience by testing their subjective assessments of the relevant environment. Such experience can help the manager build more global models of his operations and derive theoretical inferences either by means of partial optimizations or through computer simulations before he attempts to implement his plans.

2. Controlled Characteristics and Standards: Given that the critical assumptions, constraints, and operational objectives have been identified, there is a need for choosing the appropriate control characteristics across each one of the entities to be monitored. Furthermore, desirable norms of behavior (standards) must be established and projected for each control characteristics so as to enable the control process to function. These standards must be part of the system, and not on a memorandum basis, otherwise one cannot establish close-loop controls to relegate to inanimate systems. In the absence of such a capability one must rely on managers to check on each and every observation and on the basis of their intuitive "feel" of the situation determine whether remedial action is necessary. We must note, parenthetically, that to the extent the transformation process results in a one-many mapping of plans to operations, the demands on the information system, if effective control is to be exercised, increase exponentially as one goes down

to the production level. Also the time sensitivity of decisions[2] increases substantially as we descend the managerial hierarchy and so does the dependence on recent-actual data. For higher level planning assumed or simulated data are more useful. All these are issues which are often ignored or not appreciated, but very critical nonetheless for the design of future systems. Logical deduction shows that on-line, real-time systems are much more useful for production control than they are for long-range planning. For the latter it will be desirable to have on-line capability to allow the managers to build and manipulate interactively complex simulation models. However, we see some fundamental differences in the two situations. In the production control systems of the future, as we will amplify later, the M.I.S. will be collecting data in real time from the manufacturing operations, operating on such data and reporting on those critical deviations the automatic control process cannot handle. It is the incidence of data which will activate the system and the latter will be on line in real time as long as operations proceed. In the case of long-range planning, however, the manager's need will activate the system, and although the responses may be in more-or-less real time the data need not be real-time data.

3. Scheduling: Once standards are established across the chosen control dimensions, scheduling techniques can be used to allocate scarce resources to production. But it is not only physical scheduling which is important. Scheduling of review milestones and feedback indicators, to signal potentially undesirable deviations, are equally as, if not more, critical for success.

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[2] The scope obviously of decisions within an organization decreases as we go down to the operating levels.

The problems faced by the managers in scheduling are well known. Whether the production characteristics dictate "process" scheduling techniques, job-shop, or a mixture, the familiar symptoms of trouble are degeneration of schedules. This is an area where "half a system" is no better than no system at all. The end result in both cases is chaos. Once degeneration sets in, jobs or batches require the full attention of expediters, input resources and over congestion are more prevalent than periods of smooth flow of production. Over-reaction often leads to paralysis, as schedulers develop expensive and complicated manual systems which define finer and finer subassembly levels or smaller and smaller batches. In this way they hope not only to facilitate scheduling but also to obtain diagnostic signals by collecting the appropriate inputs and determining the net value added by the work in process. Manual methods are tremendously expensive, and in many cases impossible, especially in situations where fast feedback is critical. It is not unusual to find cases where the pressure for faster feedback to prevent degeneration (fine subassembly levels and small batch scheduling), leads to falsification of data. When this happens not only the degeneration of schedules and efficiency proceed unchecked, but also the M.I.S. hides from the manager the fact that the organization is approaching a crisis. The first intimations of disaster will normally come from outside the system, from the customers. As we will point out later, we expect future systems to play a very important role in seeing that the scheduling process does not degenerate.

The potential of computers in scheduling has been recognized from the very beginning, ever since computers were introduced in the industrial scene.

Emery (5), Carroll (2) and Holstein (7) among others have reported the course of such activity and the progress made, so there is no need for us to delve on this issue.

4. Comparator-Controller-Effector: The production manager today not only is inundated with a lot of old data but he is also involved in too many low level activities. He serves as the sensor and controller in many situations control of which could be relegated to a system very effectively. Such an involvement, unfortunately, finds him competing against computerized systems in areas where he has a comparative disadvantage. Human beings cannot boast about a time-independent memory with automatic recall capability, nor can we find in people the persistence, rationality, consistency and enormous computational capability of computers. What we decry here is not that computerized systems can perform more efficiently what managers now do. We are rather disturbed by the enormous opportunity cost of managerial time. Because the more the manager spends on low-level activities, the less time he can devote to areas where he naturally has a comparative advantage, such as pattern recognition, generating and testing hypotheses, learning from experience, standardizing, abstracting and planning. We want the production manager to be aware that inanimate systems can take over control of areas he succeeds in organizing and that he can use the released time and the temporary equilibrium in the system to build more global models. What is more, this process can be incessant, moving us toward more all-encompassing models, and more sophisticated and authoritative management planning and control systems.

Our discussion in this section has pointed out, among other things, that we need systems with (a) some characteristics of intelligent managers and (b) ever-increasing capability for "assuming responsibility" authoritatively

for certain tasks which are now in the hands of managers. The next section will be devoted to a discussion of these two observations, and their ancillary consequences, with the purpose of deriving criteria for designing managerial planning and control systems possessing these characteristics.

III. Information Systems: Dimensions of Change

Poensgen and Zannetos (9) have suggested that the purpose of an information system is to provide the manager with data that are selected and structured so as to be relevant in a particular context for a decision. Such data they have defined as "information". They further proposed that the information system must be built up in a way such that it can sequentially acquire more intelligence, as it gains experience, and therefore serve as an extension of human capability. To provide such intelligence a system should have capacity for directed collection and storage of data, processing and transformation of such data and the ability to draw inferences for control from the transformed data.

Many authors have dealt with what we consider "secondary" dimensions on which such a system may be evaluated. Some suggested criteria such as the degree of data accuracy, system response time, and speed of computation. Without under-estimating the importance of the aforementioned criteria, we believe that there are other more critical dimensions across which systems should be evaluated, and which subsume or offer guidelines for determining the necessary degree of accuracy, response time and speed of computation. For these reasons the following discussion will focus on aggregate dimensions of quality of the planning and control models embedded in the system, and in particular, on the degree of "intelligence and authority" of the system. In our discussion of models we

refer specifically to the sophistication of their structure, the extent to which these models are exploited for sophisticated managerial needs, the degree of authority which can be passed on and effectively assumed by the system based on such models and finally discuss certain "ancillary characteristics" of models and data such as "globalness" and recency."

By "intelligence and authority," we refer to the relationship between the system and the manager, in a particular decision area, or the extent to which the decision is automated. As we shall see, models and systems capability are in many instances directly related and improvements in one dimension are dependent on improvements in the other. Indeed, they are both to a large extent dependent on technological changes in the hardware and the software on which the system is based.

We will now talk briefly about the evaluation of systems both in terms of the complexity of the models which can be encompassed and the sophistication of the operations imposed on the models.

1. Model Structure

(a) Storage of raw data; the most rudimentary system might simply be a serial file with each datum individually labeled.

(b) Classification of data; this is the first imposition of structure on the data base. Such structure may greatly simplify data storage and retrieval. The basic system of accounts in an organization would be an example of such a system.

(c) Comparison with an historical standard; the purpose here would be to extract differences for analysis.

(d) Relationships between variables; new variables may be defined as combinations of existing variables. Accounting systems based on

simple linear relations of accounting data would be an example of what we have in mind. As a result of the basic structure of the physical system on which data are being collected for control, we have certain natural inherent relationships between some of the variables collected. Such relationships may be indentified from an examination of the data, and exploited for developing more comprehensive models.

(e) Complex models; the most common model imposed on an operating physical system is the series of linear relationships derived by the accounting system. It is possible to build complex representations of the physical system which more closely capture the underlying structure. Such models may be macro-process flow models that relate many existing pieces of data to predicted future data values. They may be extended to micro-analytic simulations including simulated behavioral relationships.

(f) Model development; up to this point in the discussion, we have assumed that models are imposed on the system by its designer. We now imply that models may be capable of "self-improvement." In a trivial sense, this could be accomplished by allowing re-computation of the parameters of the model. Alternately, the system may "continuously" experiment with a set of decision rules and evaluate their performance. When a decision is to be made a rule is selected probabilistically with the probabilistic weight determined as a function of past experience. An extension of this would be to test at each point for the "best" rule to apply, and on the basis of experience restructure the model to incorporate such knowledge.

2. Operations on the Model

Given the existence of data structure, an information system may create "intelligence" by some series of logical operations.

(a) Data aggregation.

(b) Automatic comparison of data; the system may compare observations from several periods and several organizational sub-units.

(c) Simple arithmetic manipulation; in this category, we include calculations such as cost per unit, percentage, and the determination of statistical relationships between variables.

(d) Optimization; the system embodies an explicit criterion function and algorithms that will seek "good" solutions. The decisions are either automatically implemented or a report is made of the recommended action.

(e) Simulation; in cases where the problem is too complex for optimization routines to be applied, then detailed simulation models may be constructed. The system in this case accepts inquiries from the manager, applies a detailed simulation model to the decision situation and reports the consequences. This allows the manager to test alternative plans across any set of criteria he wishes to impose, introduce his value judgments where trade-offs are necessary, then choose the best plan for implementation.

3. System Authority

Amstutz (1) defines a range of system authority which spans retrieval, review, monitor, recommend, act, predict, learn. Most of these concepts have been included in our category of model structure. The concepts are

related in that a decision cannot be delegated unless a model structure exists that can accept it, and carry it out in an intelligent fashion. For this discussion, therefore, we assume that a model exists and we now categorize the way in which a manager may use it.

(a) The system may announce that a problem exists, based on the violation of a predetermined standard.

(b) The system may announce the problem and allow the manager to select a decision rule for its solution. The system may tailor the routines offered to the technical competence of the manager.

(c) The system may report a recommended solution or solutions and allow the manager to implement one if he chooses.

(d) The system may report a solution only if the consequences of its implementation fall outside of an approved range, otherwise it directly implements the one it chose.

(e) The system is allowed to make decisions but an aggregate measure of system performance is reported. The system is designed to allow the aggregate variable to be controlled without the manager having to directly control the detail decision. For example, an increase in interest rate will directly decrease economic lot size and thus reduce aggregate inventory.

(f) The system may take action and only report if the consequences of the action taken do not coincide with the expected results.

4. Ancillary model characteristics

Carroll (3) has used the term "globalness" to refer to the scope of the data, the decision rules, or decisions encompassed by the system. A purely

"local" decision would involve current data or historical data from the sub-unit immediately effected by the decision. A "global" model in theory would have access to "any" datum that is relevant to the decision, and thus assure that the decisions taken are consistent with system-wide goals and system status. Moreover, "globalness" may refer to the comprehensiveness of the model used.

A final dimension of interest is the concept of "recency" discussed by Amstutz (1). This is simply a measure of the time required to update the model after events have occurred in the system. As we have already stressed, the time-sensitivity of decisions and their dependence on recent data decreases as we climb up the management hierarchy. For these reasons we do not believe that "recency" merits as much priority, relatively speaking, as the other dimensions of model improvement, especially given the present stage of computer technology. The "recency" issue we believe can be satisfactorily handled as a by-product of the development of "associative software." The latter can be used to relate automatically new inputs with existing models, restructure them, so as to introduce higher-level intelligence into the information system, and at the same time update the data bases. (12)

This completes our discussion of the framework which can be used to assess the efficacy of managerial planning and control systems. Now before we turn our attention to systems of the future, we would like to say a few words regarding the hardware technology which will be used to implement these.

Over the years, we have come to expect continuous improvement in the speed of computers, in their cost-effectiveness (cost per calculation) and in the cost of data storage. Improvement in these dimensions will certainly encourage the growth of information and control systems in production operations. Our focus, however, will be on the "conversational" ability of the computer

system, and along with this the availability of various types of terminals to support man-machine interactions. It is our belief that this dimension is important since improvement here will have substantial impact on the quality of decisions managers make.

At present both typewriter and visual display terminals are used. The most common typewriter terminals are inexpensive, but involve substantial time in input and output of data. For "normal" research uses the ratio of console time to central processor time is usually over twenty to one, and the cause of this substantially lies with the speed of input and output devices. With alpha-numeric visual display terminals, the input is essentially the same as with the typewriter, but output is much faster. If this equipment is equipped with a light pen and if the supporting software is developed, certain limited input can also be quite fast. Finally, the visual display terminal with capability for graphical presentations may pictorially convey much more information, such as statistical distributions, and more efficiently than printed output. In the following sections, we will discuss applications of interactive visual display systems in production planning and control systems.

Regarding data collection from operations we foresee extensive use of so-called hybrid[3] systems with data loggers continuously monitoring operations and converting analog to digital signals for direct entry of data into the data base. Feedback is also handled in the same way proceeding from digital to analog for communication with and control of production operations.

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[3] A hybrid system is one which combines aspects of analog and digital systems. It is based on an analog representation of the process it attempts to control, collects observations from the process and converts these into digital signals for direct entry into the information system stream. What we are saying here should not be confused with analog computers.

IV. Evaluation and Extension of Current Systems

Typical production information systems concentrate on the problems of detailed planning and scheduling of production orders. It is usually assumed that product line is determined, the mix of facilities is given and the aggregate constraints on capacity and workforce have been determined. It is true that some information relevant to these problems can be derived from existing systems by special "case studies," but ordinarily this is a time consuming and expensive process. As a result only a few such "cases" may be attempted.

Even in the area of operational control the systems are incomplete. A survey of current systems would show that in the main they are on "batch" equipment and that not all important subsystems are available. The planning and control system used is very elementary, primarily of the type identified as "classification of data", although some simple models may be embedded in such systems. These would include models for lot-size determination, simple forecasting models and structures for parts explosion. Finally, the tendency would be for such systems to be at an extreme of the "authority" spectrum. That is, they simply provide organized data for traditional control techniques by human beings or they are limited to few very structured and local production activities for which they assume complete "operating authority." In the latter case the managers normally make periodic checks of aggregate system performance data.

We must emphasize two points in connection with the above statements. First even such simple systems may provide substantial improvement in control and be cost-effective. Secondly, a few select companies have gone well beyond this level in particular problem areas and even a smaller number are now involved

in developing what they term "completely integrated planning and control systems." Given the constraints of this paper, we will not attempt a complete survey of these progressive systems but rather project some current systems into the future on the dimensions we have previously identified. To accomplish this, we will first discuss problems in the area of operations control (dealing with the day-to-day problems of implementing production schedules) and then turn to problems of managerial control.

Our point throughout both sections will be that there will be strong trends toward more complex model structures, more sophisticated manipulation of these models and increasing authority delegated to the information system. We also expect the rapid development of interactive systems, and in certain applications continuous updating of information. We will now expand on this introduction with specific examples.

A. Operational Control Systems

As we have discussed throughout the paper "recent" information is important for some problems of operational control. For example, if a machine is producing a product that does not meet a quality standard, some immediate action should be taken. In flow processes direct measurements are made of the parameters of the process and this may be followed by automatic adjustment of the control system. It is our belief that control systems for discrete production will increasingly take information automatically from the process and enter it directly into the information system. Not only will the reliability of such data be improved but the overall cost of collection may be reduced. Certainly such a mass of data would swamp a manual system, but given that it is automatically entered and efficiently reduced to the necessary control parameters

by the structure and operations of the information system, it will be manageable. It should also be noted that access to data at the detail level we suggest, would allow models to be created to explain variations at the machine level. In current systems the periodic collection of data may average out interesting interactions between machine performance and other vaiables in the production system, thus suppressing valuable information.

Inventory control systems may also be improved by the availability of more recent data. The computation of lot sizes should depend on variation in demand, changes in the cost of capital to the firm and the changes in the load on the production facilities. In addition to the availability of recent data, we suggest that these decisions will be improved by access to more "global" data. However, to exploit these data substantial improvement in inventory models will be required, beyond the simple E.O.Q. formulas used in many existing systems.

Improvement in models will also be expected in the area of order scheduling and dispatching. The usual scheduling system implicitly assumes infinite capacity for the various machine centers. Order start times and completion times are based on standard production and delay times. We expect that this approach would be displaced by detailed realistic simulation models of the shop. At each point in time the "state" of the simulation model would be as close as possible to the "state" of the real shop. Jobs then could be scheduled within the simulation model and processed through the various shops, using pretested sequencing heuristics, with explicit consideration of the capacity of the available equipment. The estimates of flow times from such a model should be more accurate. Furthermore, by allowing the simulation to advance beyond the current state of the shop, with expected orders, predictions of the future

state of the shop may be generated.

Such a simulation may also be used interactively by a planner to experiment with variations in overtime, reallocation of men, a rescheduling of specific orders to arrive at acceptable production plans. Carroll (2) has studied such a system in operation at the Boeing Company and suggests that the heuristics used by individual planners to solve resource allocation problems may be directly programmed into the control system. To the extent this is true, we may expect the task of setting resource levels, as well as the task of sequencing jobs through machines to be automated in future systems. As was suggested earlier such a system may be introduced in stages moving first from suggested action, to action within a limited range, to complete control. In the latter case management will certainly be interested in certain aggregate performance measures, but not necessarily in the day-to-day process.

B. Managerial Control

When we talk of managerial control we are concerned with the formulation of plans for the allocation of an organization's resources, both human and inanimate. Such resource allocation problems are characterized by (a) conflicting goals held by managers from different functional areas, (b) incomplete information and (c) the fact that managerial judgment is required to evaluate good solutions. The complexity of the problems are such that current models and optimization techniques, may not be adequate. For complex (unstructured) situations, we envision systems which allow efficient interaction between the decision-makers and the planning and control system. Such systems will provide ready access to a global data base, access to the manipulative power of the computer and access to global models. The latter will be supported by ancillary submodels for those segments of the problems that are well structured.

Scott-Morton (10) has described the decision process of the Market Planning Manager in the Laundry Division of Westinghouse, and the impact of an interactive information system, with visual displays, on this process. Evidently within Westinghouse, the planner works with the Marketing Manager and Production Manager to arrive at production plans satisfactory to both mangers.

Using conventional methods the planning process as carried out prior to the new system, required six full days, spread over three weeks of each month. It was based on historical data, a simple simulation model and information from both marketing and production staffs on their future plans. The new system which was designed specifically for the planners is interactive, using graphical display terminal connected to the Westinghouse computer center. By means of this capability, the planners can very quickly access all the data they had previously used and display these in tables or in graphical form.

Although the power of the models used has not been changed, the system is reported to have had substantial impact on both the time required to solve the problem and on the quality of the solution achieved. The implications of each strategy suggested can now be investigated and tested for feasibility so that the entire process is completed in half a day. The speed of each response also encourages them to test more possible solutions and to choose the best of those tested. Thus an improvement in decision-making has occurred simply by giving the planners access to an interactive computer system, although, as previously stressed, the data and models used have remained essentially the same. In general, we expect the development of similar interactive systems for decisions which require manipulation of sophisticated

models and a large data base, and where managerial judgement is required in making trade-offs between conflicting alternatives.

On another dimension, we expect future systems to make more explicit for the manager the implications of his decisions for the detailed operation of the organization, and also allow him to implement there decisions in a rational way. To illustrate this point we will choose an example from the area of inventory control. If, for example, an organization has a severe cash flow problem, then various alternatives may be suggested to ease the situation. As such it may be suggested that limits be established on inventory levels at all locations. If at the operation level detailed inventory control systems exist, then the cost of this suggestion could be quickly estimated. What is more important, the existence of such a system would allow the detailed implementation of that policy. We foresee that system designers will devote attention to the design of "aggregate" control switches to allow managers to exercise their judgement on the control of systems that embody sub-optimal or locally optimal decision rules. That is to say, if the system cannot be trusted to achieve global optimization, then the manager will make those trade-offs and trust the system to implement the plan at the detail level.

A system such as the one described above, will also record the priorities of the decision maker and allow these to be examined. In our inventory example, from the arbitrary limit on inventory it would be possible to calculate the imputed cost of capital used by the manager. If the implicit cost of capital is not consistent with values used elsewhere in the organization, then the system will initiate a process for re-examination of the decision.

Similarly, we envision aid from interactive systems in the area of production control. Scheduling alternatives of manufacturing operations on

the basis of the latest status of shop loading will be evaluated, and the system entrusted with enough authority to monitor deviations and apply remedial action to prevent degeneration of schedules. As we previously mentioned, only in cases where the various prescribed remedies do not work will the system report to the production manager so that he enters into the picture.

In summary then, the system we are outlining through the use of more sophisticated models, global data bases and more direct optimization, will give more flexible and effective control to the manager. Such systems will allow him to test his judgments, and the consequences of his assumptions before he implements them. As we have stated above both the human decision-maker and the computer have their areas of comparative advantage and the future systems that we sketched for production and inventory control will exploit both areas of competence in a complementary fashion.

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