*A method of representing the gross characteristics of an information system within a dynamic model of the firm is presented.*

*The performance of the firm and, indirectly, that of the information system is measured in accordance with usual financial accounting practice.*

*The procedure is demonstrated by simulations (programmed using a general purpose simulator) conducted with a specific model of a hypothetical manufacturing firm.*

# Economic evaluation of management information systems

**by D. F. Boyd and H. S. Krasnow**

The evaluation of data processing systems has traditionally rested upon the notion of cost displacement. This approach is a natural outgrowth of viewing such systems as essentially productive. However, significant economic benefits of many recent systems accrue from the so-called intangible benefits to management. Thus, the nature of current information systems suggests that they be viewed, for purposes of economic evaluation, in a broader context than that of a producing machine.

Here we view the contribution of an information system in maintaining control over a business system operating in a changing environment. This view implies a criterion of evaluation related to the dynamic performance of the firm. We hypothesize that better information will lead to better control which in turn will yield improved total performance. The control objective of the firm is to respond to the environmental demands in an economically efficient manner. The effectiveness of an information processing system in satisfying this objective may be evaluated by:

1. An accounting measurement of the financial performance of the firm over time in the face of changing demand (environment).
2. The accuracy, completeness, and timeliness with which that demand is satisfied.

These measures, being more complex, are more difficult to estimate than cost displacement and require an adequate model of the firm itself.

The objectives of the current study were, first, to define a method suitable for the economic evaluation of information systems when viewed in this manner; and second, to demonstrate its technical feasibility by applying it to a hypothetical firm.

## Description of the method

The importance of the dynamic behavior of the firm to its own well being has been shown and it has been demonstrated that this behavior can be simulated.[1] Advanced information systems, which are often intimately and extensively involved in control, have also been successfully simulated. The problem then, is to relate the mechanics of the information system to the dynamics of the business firm within a single model.

**physical system**

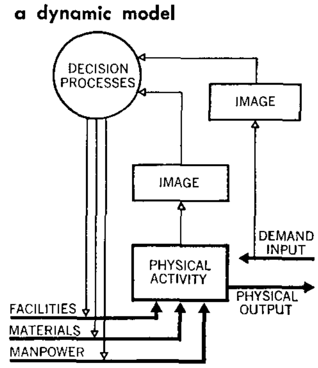
The simple firm performs an economic function upon which its existence is based. (The modern corporation, of course, often performs many such functions.) A minimal set of activities is required in order to perform this function: we designate this set and its interrelationships as the *physical system*. In a manufacturing firm the elements of the physical system are the production processes and the resources which produce the end product. In a service firm, the physical system is composed of those activities and their associated resources which directly provide the customer with service.

**information processing system**

A total representation of the firm requires, in addition to the physical system, a second part referred to as the *information processing system*. The latter encompasses all activities of the firm whose direct or indirect function is to control the physical system (Figure 1). In a real firm there are, of course, activities which do not fall within either of these two categories (for example, janitorial services). These activities are of little interest for the purposes at hand, and appear only as fixed or variable cost elements within the accounting structure.

The information processing system is broader in concept than any existing data processing system, the latter serving as a component of the former. The information processing system can be represented by the following basic elements and their interrelationships:

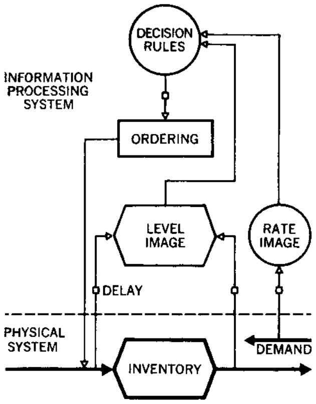
**Figure 1 Elements of a dynamic model**




*Sensor.* This type of element originates all data input to the information processing system. It includes both manual and machine-generated input. It reports the occurrence of an event within the physical system (or perhaps within the environment).[2] A segment of a physical system is shown in Figure 2. Sensors record all possible events, the receipt of material into inventory, disbursements from inventory, and the receipt of requisitions (demand) for inventory.

*Input transmission.* Sensed data are subject to delay and/or distortion during transmission. All delays associated with input

**Figure 2 Segment of a dynamic model**




are imagined to occur at this point (i.e., sensing alone is complete, accurate and instantaneous).

*Image.* The end result of data input and most conventional processing, whether machine or manual, is an image. In Figure 2, the image of the true inventory is the inventory record. Images can be classified as levels (e.g., inventory) or rates (e.g., the arrival rate of inventory requisitions). If applied to continuous flow measurements, level images would be the time integral of one or more rate images. With appropriate sensors, images can be provided which describe any activity within the physical system. However, they are distorted as a result of input transmission delays and may be biased by the random or systematic loss of sensed data during transmission.

*Decision process.* This is a crucial element of the information processing system. The term is used in the broadest possible sense to encompass all decision making related to the control of the physical system. Decision processes can function with the aid of much or little information; with information which is accurate or distorted, timely or outdated. The information upon which the decision process depends (all of the information available to it) is contained in images. The decision process has no direct contact either with the physical system or the environment. In the example of Figure 2, the decision to order additional material for inventory utilizes images of the current requisitioning rate and inventory level.

*Output transmission.* The result of a decision is a command which will ultimately produce some change in the activities of the physical system. A single time delay is associated with both the decision making process and the transmission of its commands. In Figure 2, the command is in the form of an order for additional material. More generally, commands take the form of an adjustment to the resources committed within the physical system.

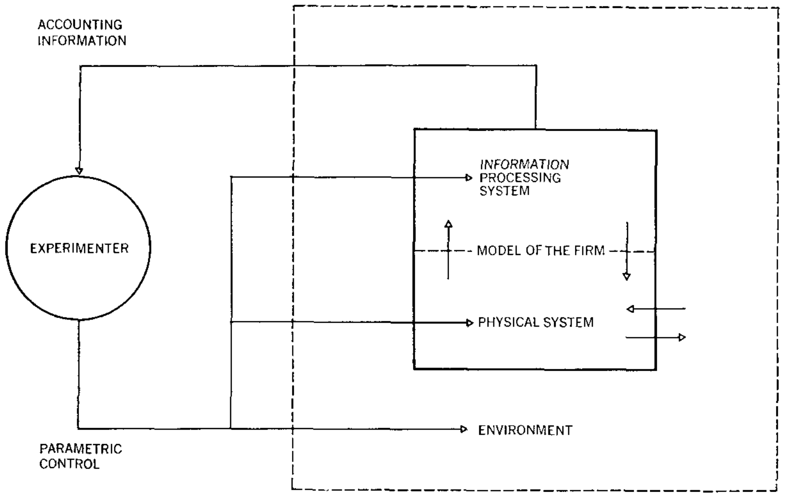
**environment**

In addition to representing the firm in this manner (physical system–information processing system), a complete model requires explicit recognition of the interaction with its environment. In particular, it recognizes certain basic requirements (demands) which the environment places upon it and which it undertakes to satisfy. One basic measurement of the performance of the firm is the adequacy with which it satisfies these demands. The environment may also provide information inputs to the information processing system relevant to the future demand pattern. (It should be noted that for purposes of model building, the interface between the firm and its environment is somewhat arbitrary. The crucial distinction is between that which can and that which cannot be controlled by the firm. The former is classified within the physical system; the latter within the environment.)

**accounting structure**

Figure 3 suggests that the representation of the firm has two interfaces: one with its environment, and one with the experi-

Figure 3 Interfaces in the simulation




menter. This figure also suggests the experimenter may change the parameters governing the environment and the information processing and physical systems. In order to measure the results of these changes, he must make comprehensive observations regarding the performance of the simulated firm. The mechanism for accomplishing this observation has been designated the *accounting structure* because of the central role of financial accounting for performance evaluation. Cost is a critical element of performance and must be considered in any over-all evaluation. Conventional accounting procedures are introduced for this purpose. The complete accounting structure is capable of providing any desired data concerning the operation of the model, including data which are entirely independent of cost. No errors or time delays are introduced. In this sense it is perfect and provides an accurate and unbiased appraisal of the performance of the firm.

## A specific model

We will now describe a specific model of a simple, hypothetical manufacturing firm.

**physical system**

The physical system of the model shown in Figure 4 incorporates as much as possible of the dynamic complexity found in a typical manufacturing operation within a nominally simple model. Thus, a basic assumption is made that the general dynamic characteristics of a system can be adequately represented without the introduction of the large number of individual elements actually present. The components of the physical system are now described.

Two end products are manufactured, designated as Products 1 and 2. Both products are assembled and shipped to customer order. Three finished parts (Parts A, B, C) provide all of the components for the assembled products, in accordance with the Bills of Material shown in Table 1.

Table 1 Bills of material

| | *Units* | | | |
|---|---|---|---|---|
| | *Part* | *A* | *B* | *C* |
| Product 1 | | 1 | 2 | |
| Product 2 | | | 1 | 1 |

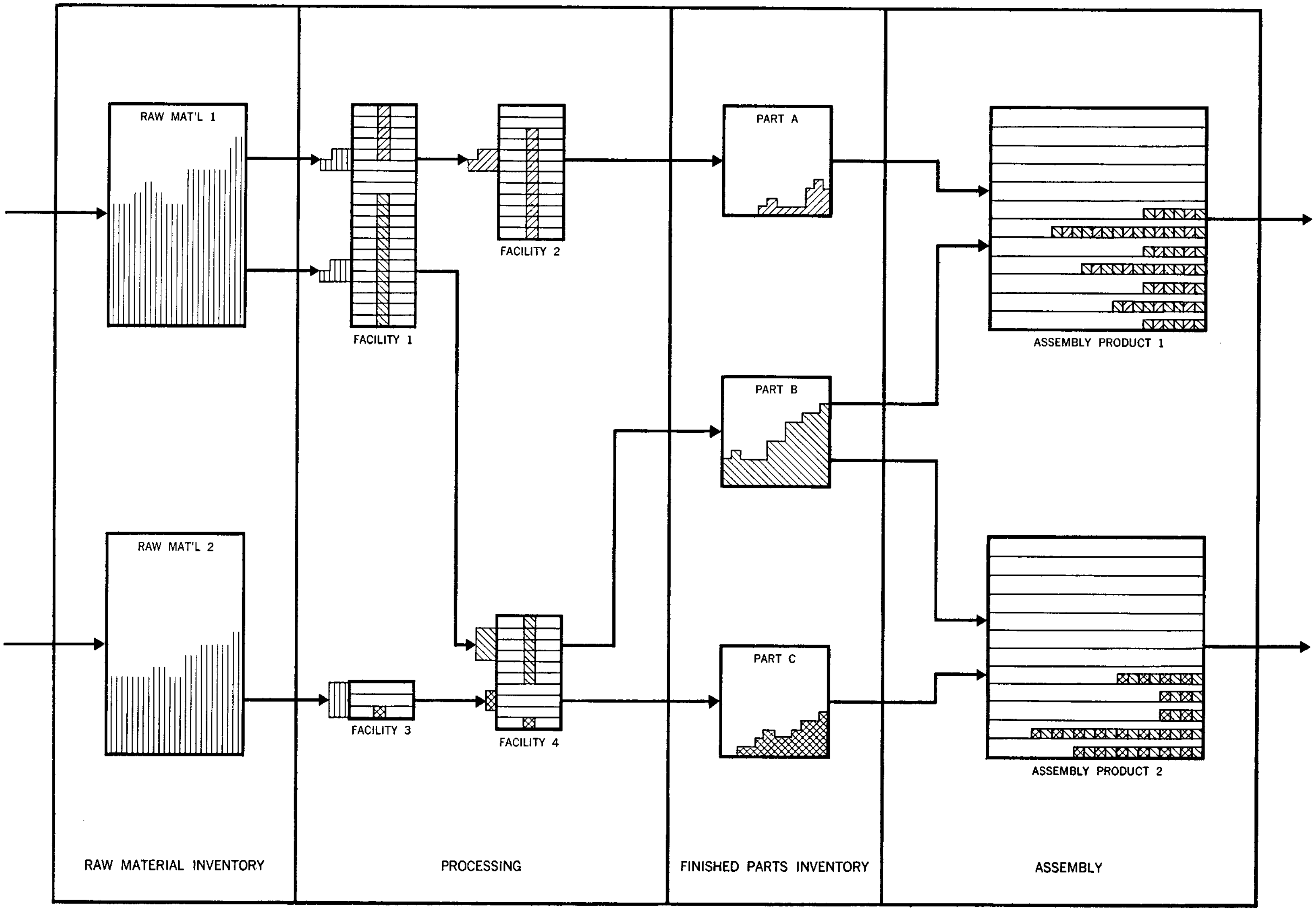



**Figure 4 The physical system**

It can be seen that Part B is common to both products, introducing a conflict situation (with its related decision problems) of the type often found in practice.

The activities of the physical system are distributed over three stages of manufacturing: raw material procurement, parts processing (fabrication), and assembly and shipping. This introduces much of the dynamic complexity of the model, since overall response is dependent upon actions taken somewhat independently within each stage. Accurate control will require good planning to coordinate the activities within different stages. These activities are:

*Raw material procurement.* Inspection, receipt and storage of raw material.

*Processing.* Requisitioning of raw material. Setup of a facility unit for processing a particular part. Processing a part on a facility unit (fabrication operation). Scrapping a part on a facility. Movement of partially finished parts to next operation. Movement of finished parts into inventory. Storage of finished parts in inventory.

*Assembly and shipping.* Requisitioning of finished parts required for assembly of an order. Movement of parts to assembly area. Assembly. Scrapping of parts during assembly. Requisitioning and movement of replacement parts. Shipment of completed orders.

The scale of an activity (e.g., time to perform, rate of occurrence, etc.) is either dependent upon other activities and therefore determined by the simulation (for example, number of parts in inventory); or it is a parameter of the physical system controllable by the experimenter (for example, time to assemble one unit of Product 1). In the latter case, the value may be specified determinately as a constant or a function, or stochastically as a random function.

The performance of an activity requires the commitment of one or more resources. Several activities have been structured so that they compete for the same resources, thereby creating typical conflict situations which can only be resolved by rational decisions. The resources available in the model are:

*Processing manpower.* Men within the processing stage are entirely interchangeable, and may work on any valid operation, or remain idle.

*Assembly manpower.* Men within the assembly stage may assemble orders for either product. However, no transfer of men between the assembly and processing stage is permitted.

*Processing facilities.* Each facility within the processing stage possesses a discrete number of units of capacity. A processing operation commits one man and one unit of facility to the processing of one part. The facility units must be set up prior to processing, however successive units of the same part may be processed on the same setup.

*Material.* The finished parts used in the assembly of the two

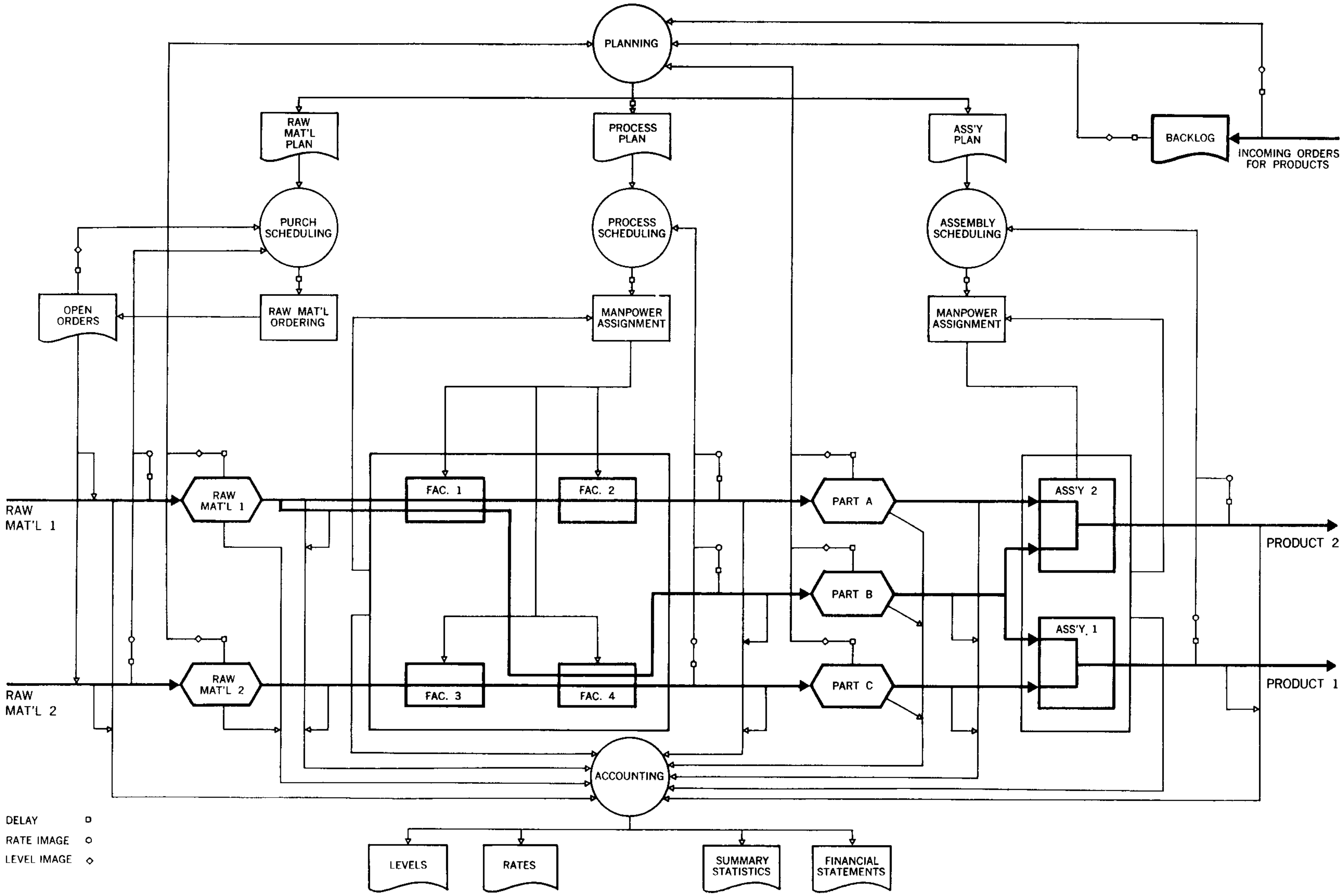



**Figure 5 Schematic of the model**

products are fabricated from two raw materials. Two of the finished parts (Part A and Part B) compete for Raw Material 1.

**information processing system**

The prime objective in constructing the information processing system was to provide sufficient capability to permit effective dynamic control over the physical system. Within this context, the emphasis was placed upon building a conventional structure which could plausibly incorporate a range of data system types. Figure 5 is a schematic of the complete model depicting, among others, all of the major features of the information processing system.

Hierarchical aspects of an information processing system in the large firm are included. Decision making occurs at various levels within the organization with considerable interaction between levels. Operational control, at the lowest level, responds to events on a fairly rapid time scale, in a highly constrained manner. At a higher level, tactical decisions are taken whose effect may be only indirect, leading to direct action at the operational level. These decisions are less frequent than those at the operational level, as well as more complex.

The physical system, as previously described, is also included in Figure 5. In the model, sensors are included at all points on the interfaces between the three stages of manufacture, and on the interface within the environment. The sensors are assumed to exert no direct influence on the physical system. It is believed that this generates a reasonable amount of data for this type of system. Additional sensors, placed within each stage (e.g., recording material movements between operations in processing), would suggest a rather highly advanced information system. Fewer sensors placed, say, only on the interface with the environment (e.g., recording orders and shipments) would probably not permit effective control over the physical system. The precise configuration shown in Figure 5 is arbitrary, and could be readily extended or curtailed. The sensors could be inserted at any point at which an event can occur.

Figure 5 also indicates delays associated with information transmission, the resulting images of the sensed data, and the decision processes which utilize these images.

Decision rules are themselves parameters of the information processing system, in the sense that they can be individually detached and replaced. However, only one set of decision rules has been utilized in the model thus far. These are designed to achieve reasonable control even under fairly poor information flow conditions. In practice, of course, the decision processes and the quality of the information flow are highly related. Improved flow may be ineffective if not accompanied by improvements in decision making; conversely, major improvements in decision making (e.g., utilization of mathematical techniques) may be impossible without parallel improvements in information flow.

The set of decision rules for the model relate to planning, purchasing and manpower assignment. Descriptions follow:

*Planning.* This is the mechanism which permits the model to adjust to, and perhaps anticipate, systematic changes in customer demand. The crucial element in planning is projection of shipping requirements for the next two months, based upon the past pattern of orders and the current backlog of unstarted orders. Exponential smoothing is employed to generate the forecast of future orders, and the backlog is distributed to future requirements in an exponential manner. Once shipping requirements are established, they are used as the planning base at all three stages of manufacture. An assembly plan is produced from the shipping requirement by adjusting for assembly lead time. The processing plan and the raw material plans are generated from the assembly plan by the necessary parts explosions, adjustments for excess inventories, lead times, and scrap losses.

*Purchasing.* The raw material plan provides the basis for ordering raw material. Orders are placed periodically, at a time determined by the availability of a new plan. This time is later than the nominal date of the plan, due to the delay implicit in the planning process. (For example, the plan stating requirements for the months of January and February might not be available until the second week in January.) Before ordering, therefore, the plan must be updated for material received since the start of the month, and for any currently open orders. Allowance is also made for the possibility of receiving defective material. The actual order quantity is determined so as to cover requirements through an entire period (month) until the expected receipt of the next order.

*Manpower assignment.* In the processing stage, the plan is used once each week to generate a scheduled load. The plan is first adjusted for parts produced since the first of the month, and is then extended in accordance with the work content (standard time) remaining in the month for each production operation. The available work force is then assigned to each operation (part to be processed on a facility) in proportion to the computed work loads and subject to the limitations set by facility capacities. Existing setups are not considered in arriving at this decision. The implementation of the decision will permit reassigned men to complete the operation on which they are currently engaged before moving to their new assignment. In the assembly stage, the assignment procedure (between products) is identical except that there are no facility constraints to be observed. Each stage makes assignments based on its own work force, with no exchanges permitted. The planning process is insensitive to local conditions prevailing "on the floor." As a result, it is possible for assignments to be made to operations for which material is perhaps temporarily unavailable. In such cases, it is desirable to consider reassigning the men to other idle facilities for which material may be available. The decision determines the number and location of idle men, and reassigns them in sequence to the remaining operations to the limit of facility capacity. In the assembly stage, this decision merely transfers idle men to the alternate product unless idleness is observed for both products.

As previously noted, the commands associated with the foregoing decision processes consist of purchase orders, which generate new material, and manpower assignments. All of the decisions are time triggered, although it would be equally straightforward to utilize event triggering. The lengths of the planning period (month) and the manpower assignment review period (week) are fully adjustable, as are all of the delays associated with decision making and implementation.

**environment**

The interactions between the firm and its environment are limited. They consist of the following items:

*Customer orders.* An input to the physical system. The properties of an order are: it is for a single product; it specifies the quantity (number of units) required; it is held within the physical system until filled.

*Product shipments.* An output of the physical system. No partial shipments are made. Orders are shipped as soon as completed.

*Purchase orders.* An output of the information processing system. Each order is for a single raw material, specifying the quantity desired.

*Receipt of raw material.* An input to the physical system. The environment imposes a delay (lead time) upon the filling of purchase orders. At the end of this delay, material is entered into the physical system.

**experimenter**

The nature of the interface between the model of the firm and the experimenter is indicated in Figure 3. Communicating the results of the simulation is the role of the accounting structure. It provides a wide variety of data needed for evaluation. Cost factors are a critical element of performance, and are incorporated in a fairly complete set of conventional financial statements. Direct data are also provided on all relevant features of the physical system (e.g., inventory levels, manpower utilization) and of the information processing system (e.g., shipping requirements, scheduled loads by operation in man-hours). Some of the data are provided as a function of time (i.e., periodically), some as a single aggregate measure for the entire simulation period.

The experimenter exerts control over the simulation by setting parameters for the physical system, the information processing system, and the environment. He is also free to independently set the cost elements (e.g., labor rates, material prices) of the accounting structure, which govern the absolute level of the financial results. The major controllable features of the model are summarized in Table 2. For stochastic variables the parameters are in the form of a probability distribution.

In addition to direct variation of system parameters, the experimenter may introduce more basic changes. Decision rules can be modified or entirely replaced without disturbing other

Table 2 Parameters which can be controlled by the experimenter

| *Sub-system* | *Parameter* | *Stochastic* |
|---|---|---|
| Physical | Setup times | Yes |
| | Processing and assembly times | Yes |
| | Material movement times | Yes |
| | Rejection rates | Yes |
| | Size of work forces | No |
| | Facility capacities | No |
| Information processing | Input transmission delays | Yes |
| | Command delays | Yes |
| | Decision parameters | |
| | Planning | |
| | Length of period | No |
| | Fcs't smoothing constant | No |
| | Backlog distribution constant | No |
| | Processing & ass'y lead times | No |
| | Inventory safety margins | No |
| | Planned manpower assignment | |
| | Standard times | No |
| | Purchasing | |
| | Scrap allowance | No |
| Environment | Purchase order lead time | Yes |
| | Customer order arrival rate | Yes |
| | Customer order quantity | Yes |

parts of the model. It is also possible, though not quite as straightforward, to modify the structure of the physical system. For example, the flow of parts in the processing stage could be changed, or the material usage specifications could be altered.

## Description of the simulation runs

The experimental approach that is chosen depends entirely upon what one wishes to learn about the total system. It is possible to vary the parameters of the information processing system in order to evaluate the relative worth of a spectrum of data processing capabilities; or evaluate alternative decision processes. Alternatively one can vary the parameters of the physical system to suggest the range of industry characteristics for which a given information handling capability is worth while. As in all simulation work, a systematic approach to experimentation is desirable. In particular, statistically designed experiments offer the best prospect of achieving soundly based conclusions at minimum cost in computer time.

We turn to the second purpose of this paper, which is to demonstrate the feasibility of the method for the economic evaluation of certain "intangible" benefits of improved information systems. For this purpose six simulation runs were selected.

**key parameters**

These runs were based on manipulating two aspects of the information processing system: first, the length of the planning period together with a related implementation delay; and second, the magnitude of information transmission delays.

The model contains a series of decision rule algorithms beginning with the generation of a sales forecast and continuing on through the detailed scheduling and assignment of materials and manpower. These algorithms are applied periodically and new plans and schedules are generated based on the sensing of new demand information as well as "accomplishment-to-date" in the physical system. These algorithms closely parallel typical planning and scheduling sequences in a real manufacturing enterprise.

Thus, increasing the frequency of the planning cycle specifically implies the availability of information systems of increased capacity and sophistication.

Table 3 lists the characteristics of the three planning cycles used in the feasibility runs. The slow cycle corresponds to once-a-month, medium to every-two-weeks, and fast to once-a-week planning and scheduling. The implementation delay (output transmission delay) represents the time lag between the availability of the basic new planning information and actually putting the plan into effect.

The second aspect of the information processing system chosen for manipulation was that of information time lags (input transmission delays). The information processing system senses various aspects of the environment and physical system through more or less distorted images. A principal distorting influence is that of information delays. For example, it may be necessary to write today's purchase orders based on last week's inventory figures.

Two sets of such delays were used in the feasibility runs as indicated in Table 4. In the slow set, incoming orders and shipping and receiving status are sensed through a one-week time lag and in-plant movements are assigned a two- or three-day delay as shown. In the fast set, the first category delays were reduced

**Table 3 Planning cycles**

| *Characteristic* | *Slow* | *Medium* | *Fast* |
|---|---|---|---|
| Length of period | 1 month | 2 weeks | 1 week |
| Implementation delay | 7 days | 4 days | 2 days |

**Table 4 Information delays**

| *Information category* | *Slow* | *Fast* |
|---|---|---|
| Incoming orders for products<br>Open purchase orders for raw material<br>Product shipments<br>Raw material receipts | 1 week | 1 day |
| Part movements, finished parts to assembly | 3 days | 0 |
| Raw material movements into process<br>Finished part movements into inventory | 2 days | 0 |

**Figure 6 Demand pattern**

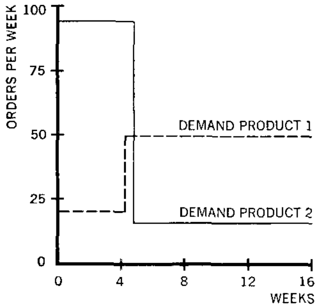



**Table 5 Parameter combinations for simulation runs**

| | | Planning cycle | | |
|---|---|---|---|---|
| | | *Slow* | *Medium* | *Fast* |
| Information | Slow | (1) | (2) | |
| delays | Fast | | (3) | |

to one day and the inplant delays to zero. (The latter change implies some type of on-line production monitoring system.)

Three values of the planning cycle and two sets of information lags yield six combinations which were the basis for the feasibility runs. Three of these runs (as designated in Table 5) will be described in some detail.

**role of demand pattern**

The activity which initiates the internal functioning of the simulation model is the stream of incoming orders for products. This demand pattern is also the most direct means for loading and testing the management control capabilities of the model. A prime function of the management is, in a broad sense, to respond in an effective way to the demand pattern. As noted above, the purpose of the feasibility runs was to determine whether significant differences in performance would result from changes in selected aspects of the information processing system. In order to amplify any such differences, a severe response requirement was placed on the model through the demand pattern. This was accomplished by imposing an abrupt change in the product demand mix.

Figure 6 is a graphical representation of the demand pattern used for all six of the feasibility runs. The initial level of demand for Product 1 is at the rate of 20 orders per week, and for Product 2, 95 orders per week. At the end of the first four weeks of simulated operation, Product 1 orders rise suddenly to 50 per week, while Product 2 orders drop suddenly to 15 per week. Demand remains at these levels for the balance of the 16-week period simulated.

Prior to starting each run, the model was initialized by providing a stock of raw materials and finished parts in the proportions required to supply the processing and assembly functions at the initial demand mix. The amount of the initial raw material stock was adjusted between runs so as to be compatible with the planning cycle used.

In addition, the forecasting algorithm was given "historical" demand levels which also reflected the initial demand mix.

The effect of these initializing values was to put the modelled enterprise approximately in the condition of having operated for an extended period at the initial demand mix and of having no expectation that this would change.

The nature of the management response problem presented can be anticipated by an examination of the demand pattern.

At each reporting cycle the pertinent physical rates and levels are sensed and extended by the appropriate actual and standard cost values to produce a set of conventional financial statements including a manufacturing expense statement, an income statement, a statement of cash flow, and an abbreviated balance sheet tabulating current assets. Table 7 illustrates the form of these statements.

**Table 7 Form of weekly financial statement**

| | | |
|---|---|---|
| *Manufacturing expense statement* | | |
| Raw material purchases | $ xxxx | |
| Direct labor expense | xxxx | |
| Indirect expense | xxxx | |
| Depreciation | xxxx | |
| Total expense | | $xxxxx |
| Deduct inventory incr./decr. | | |
| Change in raw material inventory | $ xxxx | |
| Change in in-process inventory | xxxx | |
| Change in finished parts inventory | xxxx | |
| Change in assembly inventory | xxxx | |
| Net change in inventories | | xxxxx |
| Cost of goods sold | | $xxxxx |
| *Income statement* | | |
| Sales | | $xxxxx |
| Deduct: | | |
| Standard cost of goods sold | $xxxxx | |
| Manufacturing cost variance | xxx | |
| Cost of goods sold | | xxxxx |
| Gross profit on sales | | xxxx |
| Less selling and admin. expense | | xxxx |
| Net profit/loss on operations | | $xxxx |
| *Cash flow* | | $xxxx |
| *Balance sheet* | | |
| Cash | | $xxxxx |
| Inventories | $ xxxx | |
| In-process | xxxx | |
| Finished parts | xxxx | |
| Assembly | xxxx | |
| Total inventories | | xxxxx |
| Total current assets | | $xxxxx |

## Results of simulation runs

**slow planning, slow information**

Perhaps the most direct indication of the response of the physical system to product demand is given by a comparison of the actual shipments of finished products with the demand pattern. Figure 7 gives this comparison.

In all the graphs of Figure 7, there is an initial rise from zero shipments which reflects the initializing phase of the run during which the assembly operation is loaded from the finished parts inventory. This process only affects shipments for the first 2 weeks.

In the case of Run 1 it will be noted that shipment of Product 1 responded rapidly to the demand step with shipment actually exceeding the new level by the 7th week.

This rapid initial response reflects the fact that assembly is "to-order." During the 11th and 12th weeks, however, Product 1 shipments dropped sharply. Shipment did not again match the demand rate until the 16th week.

The pattern of Product 2 shipments reflects the easier response problem posed by the downward step in demand.

Figure 8 displays two aspects of performance which summarize the relationships between the demand and shipping patterns, the backlog of unfilled orders and delivery time.

**Figure 7 Comparison of demand and shipment**

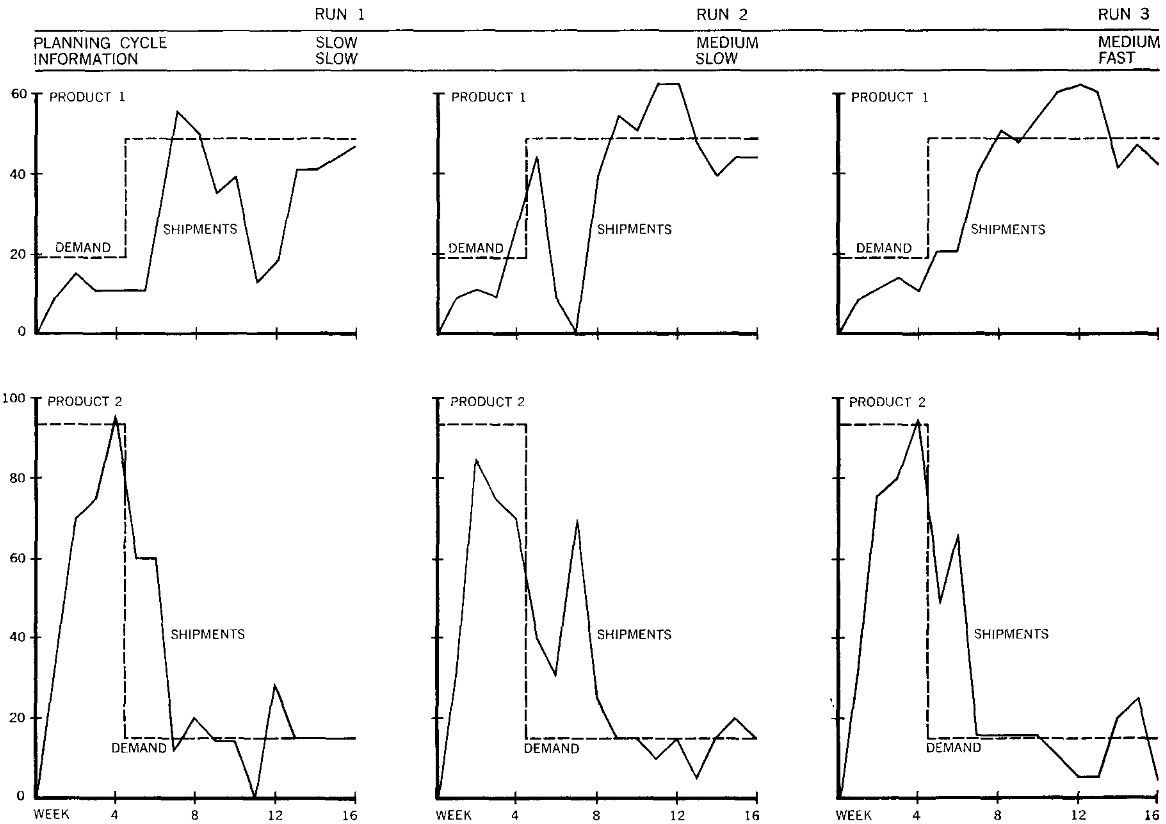
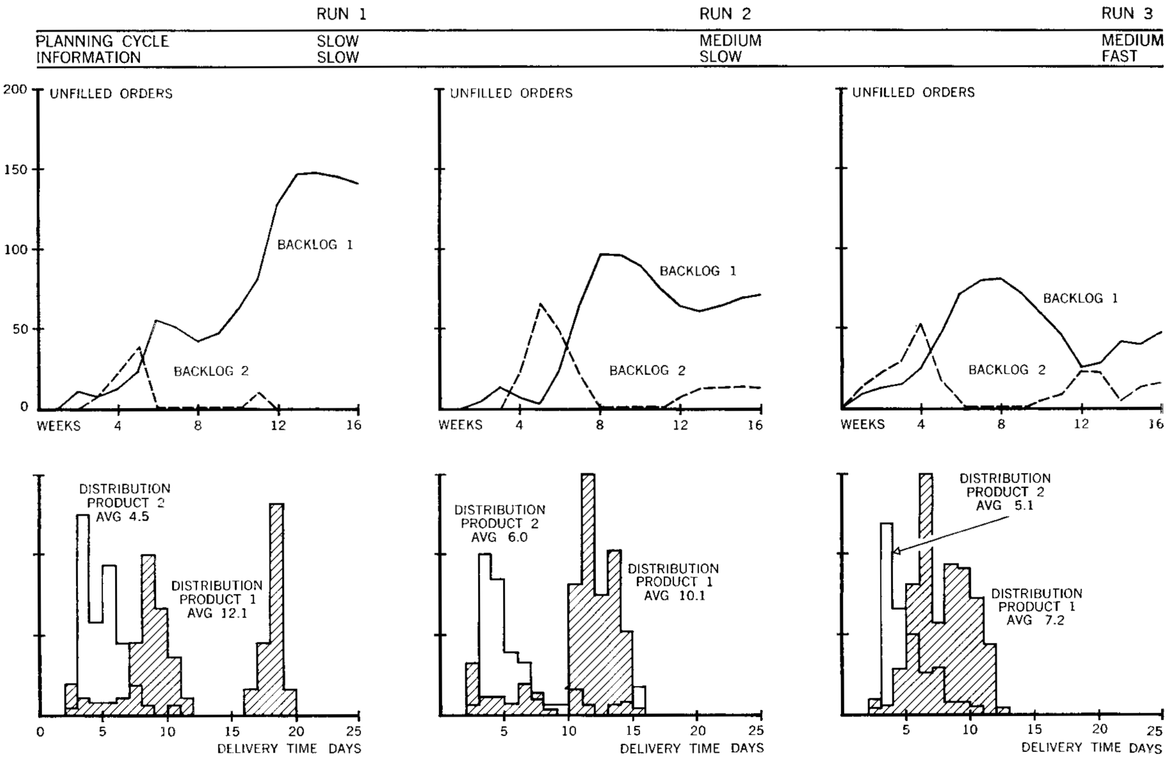


**Figure 8 Order backlog and delivery time**

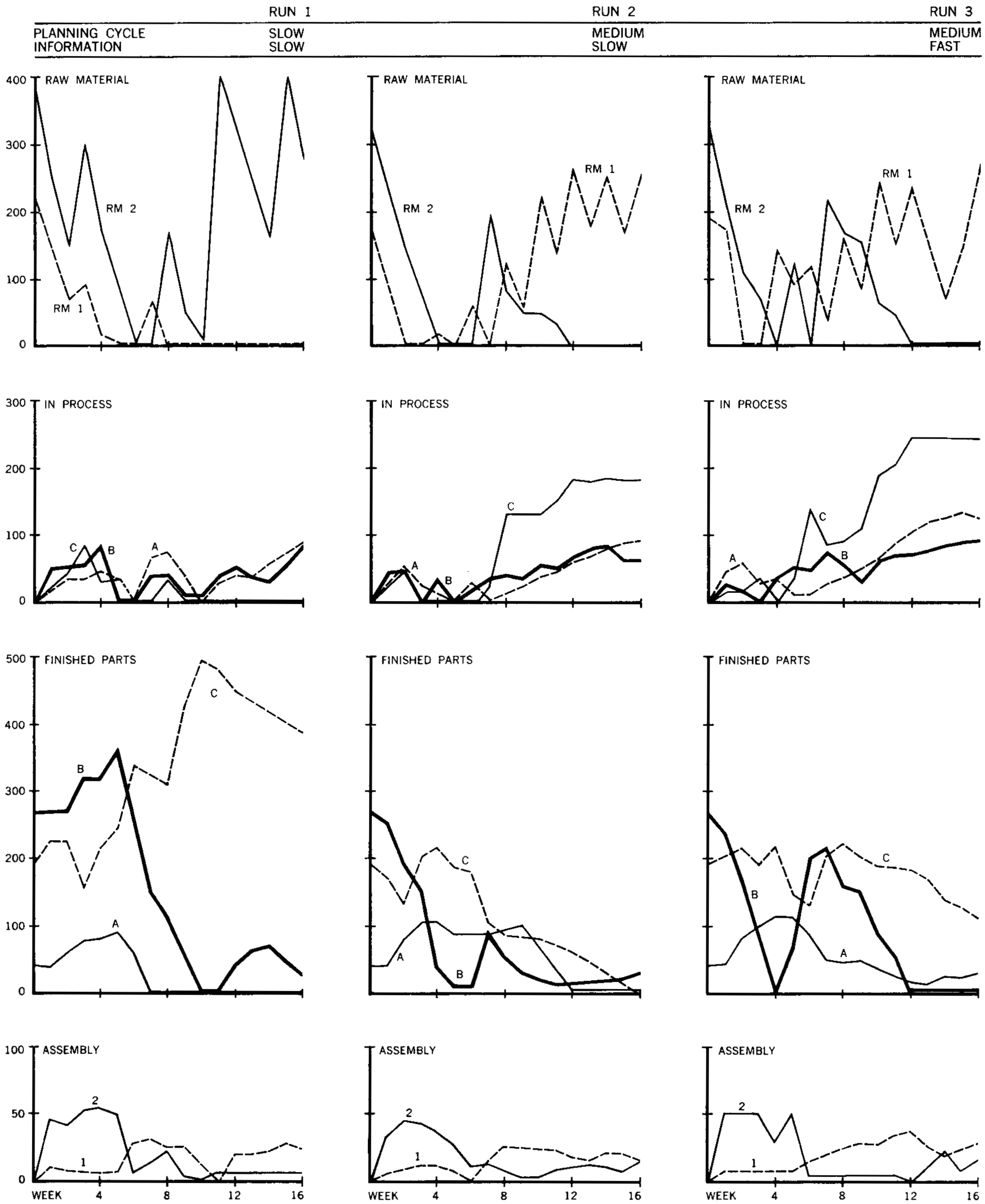



The unfilled orders graph for Run 1 reflects the initial Product 1 shipping response to the demand step, with the backlog rising to about 50 units and being held approximately at that level through the 10th week. The abrupt rise in unfilled orders for Product 1 which begins at about the 11th week resulted from the shipping lag noted above. The Product 2 backlog pattern shows only small accumulations with complete elimination of unfilled orders in the final weeks.

For a firm of the type represented, perhaps the best single overall measurement of physical performance is that of delivery time, i.e., time from receipt of an order to shipment of the order. The lower portion of Figure 8 is in the form of histograms showing the distribution of delivery times for the entire 16-week simulated period. In Run 1, average delivery time for Product 1 was 12.1 days. The distribution, however, is a bimodal one. The left portion of the histogram is representative of delivery performance before the 11th-week shipping lag. The right portion, with an average of about 18 days, represents performance for the latter part of the simulated period. As might be expected, delivery time for Product 2 was relatively much better, with an average of 4.5 days.

We can find the explanation for the 11th-week decline in Product 1 shipments by observing inventory behavior. Figure 9 is a week-by-week plot of inventory levels.

**Figure 9 Inventories**




A part of the initial draw-down of raw material shown in Figure 9 for all runs reflects the initial phase in which the processing function is loaded during the first week of operation.

In Run 1, it will be noted that raw material outages developed during the 5th, 6th and 7th weeks with corresponding dips in the in-process stock. Finished part stocks, however, were generally sufficient to support assembly and shipping.

A shipment of Raw Material 1 was received during the 7th week, but the quantity was not adequate to support the new demand level for parts A and B. During the 10th week the stock of Part B, the part common to both assemblies, was exhausted with the result that assembly was largely shut down during the 10th and 11th weeks. This was reflected in the poor shipping performance shown in Figure 7 for those weeks.

The material outages noted above were accompanied by substantial idleness of the work force during the corresponding intervals. As a result, manpower utilization for the run as a whole was only 77%.

In Run 1 it was not until the 11th week that adequate supplies of Raw Material 1 began to be received. Excessive quantities of Raw Material 2 continued to be received through the 9th week. One result may be seen in the soaring inventory of Part C.

Both of these phenomena are symptoms of delayed recognition of the magnitude of the change in the demand pattern and slow corrective action in raw material ordering. The secondary effects, as shown, were poor shipping performance and low average manpower utilization.

The run results discussed thus far represent only selected output values out of the total available from the program, but serve to illustrate the very comprehensive picture of physical behavior which is available from the model. In addition to the weekly values, two measures of physical performance were also illustrated: manpower utilization and delivery time. None of these data, however, provide a direct economic evaluation, which is our present objective. It remains for the financial accounting framework to provide this vital link.

Figure 10 summarizes financial results as tabulated in the weekly financial statements illustrated in Table 7. Weekly levels of income and expense are plotted and show the resulting profit or loss. The current assets graph pictures the weekly fluctuations in cash and inventories.

Cumulative financial performance in Run 1 for the 16-week period resulted in recording a net loss of $23,600. Current assets showed a net decrease of $7,600.

**medium planning, slow information**

It will be recalled from Table 5 that the only key parameter change between Runs 1 and 2 was in the planning cycle with a medium (two-week) cycle being substituted for the slow (one-month) cycle. The forecasting technique remained the same as did all the other decision rules. The demand pattern was identical for all runs.

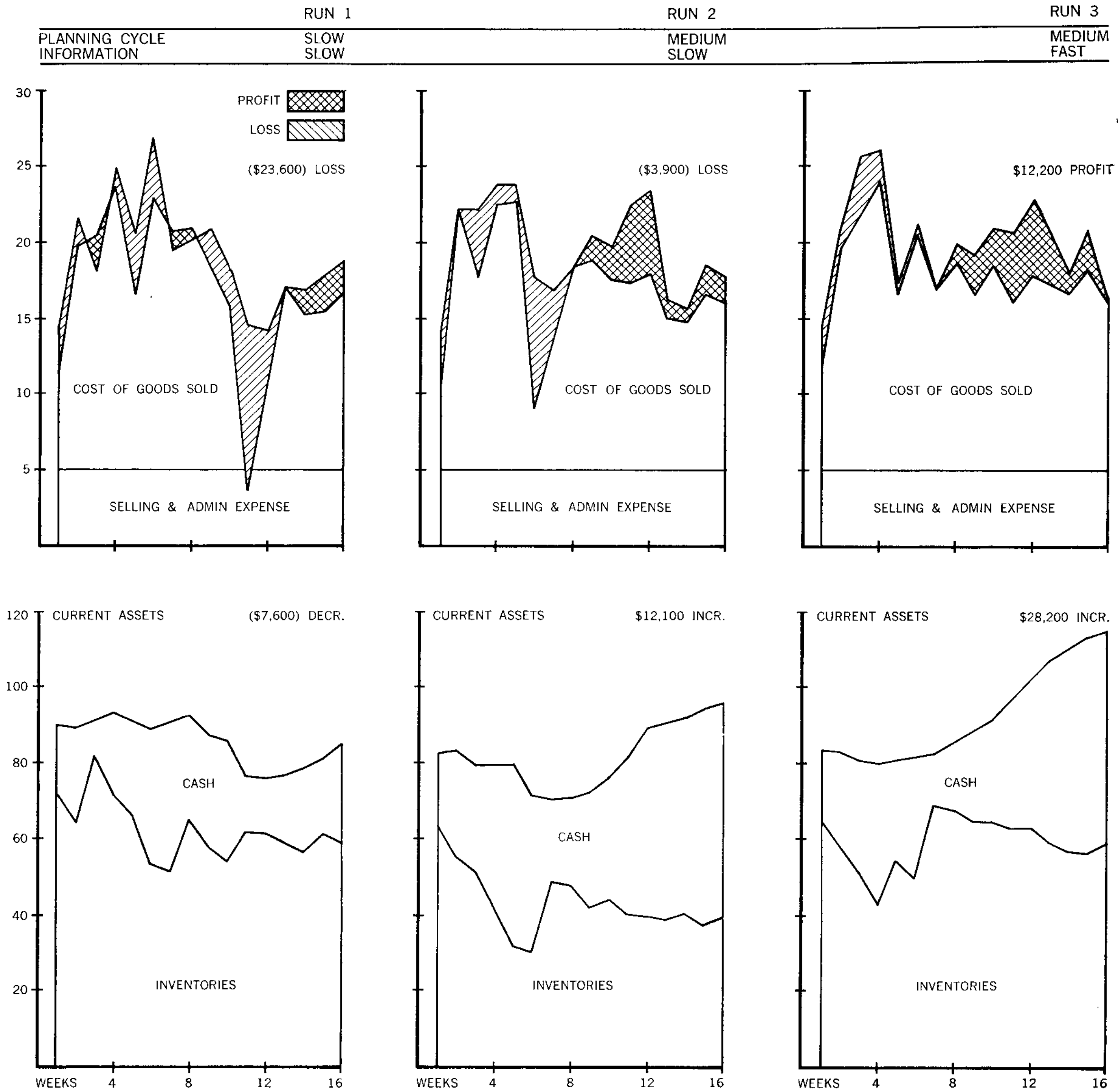
Figure 7 permits a comparison of shipping performance with Run 1. An early dip in Product 1 shipments occurred in the 7th week but was accompanied by a high shipping rate for Product 2.

The backlog graph of Figure 8 indicates a general improvement over Run 1. Run 2 delivery time for Product 1 was reduced to 10.1 days.

In Figure 9 inventory behavior may be compared. The two-week raw material ordering pattern which accompanies the medium planning cycle in Run 2 is reflected in more frequent and smaller "saw teeth" in the raw material inventory graph. In the case of finished parts inventory, the over-shooting of Part C stock, which was noted in Run 1, is much less severe in Run 2.

In general, the improved responses of Run 2 shortened the period of readjustment and resulted in improved manpower utilization (82%), and better delivery performance.

**Figure 10 Financial results**



These improvements in the physical performance of Run 2 are summarized and cast in an economic framework by the financial accounting output which appears in Figure 10. Run 2 performance for the 16-week period resulted in a net loss of only \$3,900 and an increase in current assets of \$12,100.

In comparing the financial outcomes between Runs 1 and 2, it is interesting to examine results in the 11th week. Run 1 recorded a net loss of \$10,500 for the week whereas Run 2, having accomplished its rebalancing and material "turn-around," recorded a net profit of \$4,800 with sustained earnings thereafter. It is revealing to note that during the same 11th week, Run 2 actually had a lower investment in inventories (\$41,200) than Run 1 (\$62,200).

At the 11th week, Run 1 inventories consisted largely of the unneeded inventory of Part C and unfinished materials, whereas, Run 2 had attained a reasonable balance of the right inventories throughout the physical system. It seems clear that Run 2 benefitted from better inventory management which in turn resulted in improved utilization of facilities and manpower.

The demand pattern was identical for both runs and thus presented the same hazards and opportunities. Run 2 management was no more "intelligent" (the decision rules were unchanged), but was simply made more effective through the improved response capability permitted by the shorter planning cycle. The value of this change from a one-month to a two-week planning cycle is of the order of \$19,000 (reduction in loss from Run 1 to Run 2), in the model context for the period shown.

**medium planning, fast information**

In Run 3, the planning was kept at the medium (two-week) frequency as in Run 2, and the reduced information lags of the fast set were substituted for the slow lags.

A comparison of earnings between Runs 2 and 3 places a value of about \$16,000 on this reduction in information delays.

The financial results for the runs described above, together with results for the other three runs, are summarized in Table 8. It will be seen that, within this very limited exploration, a continuous improvement in performance resulted from either an increase in planning frequency or a reduction in information delays.

Since there is stochastic "noise" in the model, statistical significance was tested by introducing a different random number

**Table 8 Summary of profit or loss**

| | | *Planning cycle* | | |
|---|---|---|---|---|
| | | *Slow* | *Medium* | *Fast* |
| Information delays | Slow | (\$23,600) Loss | (\$3,900) Loss | \$11,500 Profit |
| | Fast | (\$1,100) Loss | \$12,200 Profit | \$24,000 Profit |

sequence in repeat runs. The differences in economic performance, described above, were shown to be highly significant in the statistical sense.

## Summary and concluding observations

This paper has defined a method for evaluation of some major "intangible" aspects of an information processing system in terms of its contribution to the dynamic control of a firm as measured by the overall economic performance of the firm.

Application of the method has been demonstrated by a series of simulations carried out using a specific model of a hypothetical firm.

The feasibility of the method has been tested to the extent that selected parameter changes which are representative of "improved" information processing have been reflected in significant improvements in over-all economic performance of the modeled firm.

The extension of this method to useful economic evaluation of proposed systems in real firms will depend on how successfully the critical dynamics of the real enterprise can be described in model form. In addition, there is a need for fuller understanding of the effects of selective aggregation and/or scaling down of the multiple characteristics of the real firm, since some degree of abstraction will always be required to obtain models of manageable size.

Results such as those described in this paper, together with the current rapid rate of development in modeling and simulation techniques, serve to strengthen the authors' belief that the method described shows significant promise for eventual extension to useful evaluation of real information processing systems.

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CITED REFERENCES AND FOOTNOTES

1. Forrester, Jay W., *Industrial Dynamics,* The MIT Press, 1961.
2. The model described in this paper is entirely discrete in nature. If one wished to describe continuous events within the physical system of a model (e.g., flow processes), sensors would report the *rate* of occurrence of such events.
3. Programming was accomplished with the use of the simulator described in a paper by G. Gordon, "A General Purpose Systems Simulator," *IBM Systems Journal,* Vol. 1, September, 1962.