PROCESS/PRODUCTION CONTROL: A SYSTEMS DYNAMICS STUDY

Roger Neil Millen
Suffolk University, School of Management

ABSTRACT

Using data from a large primary steel products company, two Industrial Dynamics simulation models were constructed to study the effects of process control computer-generated information on management control systems. The first model represented the existing system, the other a proposed process control/business control interfaced system.

The research provides an initial step in the solution of the problem of integrating process control and management control systems by investigating the relationship between process information and control decisions at the operating level of management.

The proposed system model indicated much less fluctuation in inventory levels following changes in demand, lower backlog ratios, higher inventory ratios, lower delivery delay ratios, and higher levels of customer satisfaction. The proposed system was also fairly insensitive to changes in the time between transmissions from the process control system to the management control systems once the interface was effected.

INTRODUCTION

The most important recent trend in automatic control in industry has been the attempt to bring under unified control whole plant complexes utilizing a hierarchy of computers. The underlying concept was discussed as early as 1962 by Roth [17], who proposed using a number of self-contained control units which are interconnected to form a hierarchy system. Hodge [10] and Friedl [7] felt that besides processing applications such as payroll and inventory accounting, the central computer system of tomorrow would allow information gathering, communicating, and decision making, and also monitor and control the manufacturing processes of a company.

Spaulding [18] discussed the implication of the hierarchy concept of control on management decision making and Mouly [15], in a survey of integrated process control applications and projections of its integration with business functions, noted the following.

> It is believed that the trend towards process control will not stop at the process level, but that the production control and the management control functions will progressively be included in the design of fully-integrated, on-line, real-time control systems.

Such developments have forced a whole new level of consideration of the problems of multilevel, multi-input control systems, and of the effects of such systems on management control. Yet, while there has been much speculation concerning the effects of the hierarchy concept on the management processes that exist today, little investigation has been made of the effects of process control on managerial control functions.

Stevenson and Jakubik [19] discussed the indirect benefits of process control to managerial control; they concluded as follows.

> The unpredictable benefits, the intangibles are those which come incidentally from the handling of large volumes of information required to produce the tangible benefits of optimization and better process regulation.

Hammerton [8] approached the problem of integrating process and business control by attempting to formulate a generalized description of the business environment within which process control technology is applied and a description of the information needs of the business. He then explored the interaction of these information needs with the information generated by process control systems.

Whitman [20] observed that the field of management has developed principles and techniques for improving the performance of subordinates in routine control situations and in their generation of better information for decision making. He further observed that the application of process control computers has exactly the same objectives, except through the use of computers.

The argument is presented that a good process control/business control interface is achieved by designing the process control system in accordance with managerial control principles (e.g., "span of control," "exception principle"). There is, however, one obvious pitfall in this approach; any deficiencies in the existing managerial control function are automatically established in the process control system. As an example, consider the exception principle. While the manager is relieved of reviewing data indicating satisfactory operating conditions, he must at all times be aware that the absence of reports does not preclude the existence of unsatisfactory conditions. The interface must, therefore, come from a unique systems design concept, not merely the cross application of process and managerial control concepts.

Hammerton [8] observed that while the control information needs of the physical processes and those of the business system have been identified and the nature, extent, and justification of the interaction of these needs have been explored, little progress has been made toward integration of the two sets of control needs. One of the major problems, he observed, is the lack of understanding of the benefits of closer integration, a condition which seems to stem mainly from the lack of appropriately competent personnel and, hence, from a lack of investigation.

Meadows is quoted [13, p. 40] as follows.

> There are too few competent people working in both process control and business information systems...those that are available have too much to do to worry about the integration of the two types of systems.

The studies of the process control/business control interface related above attack the problem with a variety of approaches. However, with the exception of the article by Hodge [10], which addressed the interaction of process and business control directly, and the text by Hodge and Hodgson [11], the literature is impressive for the extent and depth of its coverage of the technical aspects of process control, but demonstrates an apparent lack of concern for related business aspects.

Thus, process computer control systems analysts continue to research the possibilities of hierarchies of process control computer systems. Likewise, information systems analysts are designing management information systems (MIS), Decision Support Systems (DSS), Intelligent Systems (IS), and management information and control systems (MICS). The control portion of MICS, however, is financial control. Little has been done in examining the effect of these systems on one another to provide a first step toward the design of a total integrated management information and control system (TIMICS) such as that described by Crowley [2].

SCOPE OF THE RESEARCH

The research described herein provides an initial step in the solution of this problem by investigating the relationship between the automatic control computer, which controls the manufacturing process, and control decisions at the operating level of management. The specific objectives of the research were to examine the effects of process control computer-generated information on management control functions as they exist, to design an interfaced system which would improve control and performance measures, and to identify changes in the control structure required by the new system.

Two System Dynamics models, one of the existing system and one of a proposed process control/business control interfaced system, were used to study the effects of process control generated information on management control functions.

The system studied and modeled was the flat products line of a large primary steel products manufacturer. Control was the responsibility of the Planning and Scheduling Group, Central Production Planning, Production Control Department. The material processing part of the system is actually a number of separate, semi-independent, semi-autonomous steel producing and processing mills, each run by a mill superintendent. These mills have evolved over a period of many years from being totally autonomous and under the sole direction and control of the mill superintendent to the present state where many of the mills are under some degree of control of a central production planning and control department. Much of the autonomy and independence enjoyed by these mills during their early growth has continued because of the unwillingness of some mill superintendents to give up control over any part of their mill's operation; this despite the efforts of management to centralize control and avoid the suboptimization of previous years.

The information processing part of the system resides in the production planning, scheduling, and control function of the company. The scope and complexity of this function have been increasing over the years as top management seeks to centralize its control over the sprawling, physically separate, and remote group of mills that comprise the company. This particular product line was chosen for analysis because it is here that the impact of the process control computer is being felt. Of the six mills involved in producing the flat products line, one was under complete computer control; three had computers on-site gathering and regressing data to establish models for process control; two of the mills were being augmented by computer-controlled facilities; and the last mill was being considered for computer control, but did not have any computer hardware on-site. All of the mills are tied in to the central data processing facility which handles production recording and all the business control functions of the company.

The process control installation which is "on-line" created some problems for the central production planning, scheduling, and control groups. Information requirements and timing changed, the new system was more sensitive to schedule changes, information availability was affected and the group members required computer-related knowledge not previously needed. The need for a process control/business control interface became apparent when the problems associated with one on-line installation were projected ahead to the time when all the mills went on-line. An intradepartmental communication of the Systems Planning Department read in part as follows.

> In the Long-Range Plan some discussion was presented about the time that would elapse before we need to consider the interfacing of data processing and process control equipment. We now have five process control computers on-site and three others under consideration....The interfacing of these computers is imminent.

The research analyzed some effects of the proposed interfacing on management control at the operating level.

The Study - Part 1

Three very important characteristics of the process control/business control interface have been acknowledged in the literature. These characteristics are the importance of the high-volume information flow, the existence of information feedback, and the shortening of time delays on information requirements and availabilities associated with computerized process control systems. Therefore, any attempt to study the effects of the process control/business control interface must, of necessity, be capable of including these characteristics. Because of the preceding considerations and the size and complexity of the system chosen as the research vehicle, analytical methods of solution were ruled out and simulation was chosen as that method of analysis which offered the most fruitful results.

A Macroscopic View of the System

An initial study was made of the physical plant, its production processes, and management structure. This was followed by detailed analysis of the material, information, and decision components which tied the structure together. Fig. 1 illustrates the sequence of operations in that portion of the flat products line under study and the information processing systems, both for process and business control, which tie the processes together. The boundaries chosen for that portion of the system to be modeled correspond to the limits of responsibility for the central production planning group and are indicated by dashed lines. While Fig. 1 depicts two information flow networks, data processing and process control,[1] the model treats all flows of information in the same manner.

[1] Justification for this approach can be found in Forrester [6], Bonney [1, p. 119], and Porter [16, p. 59].

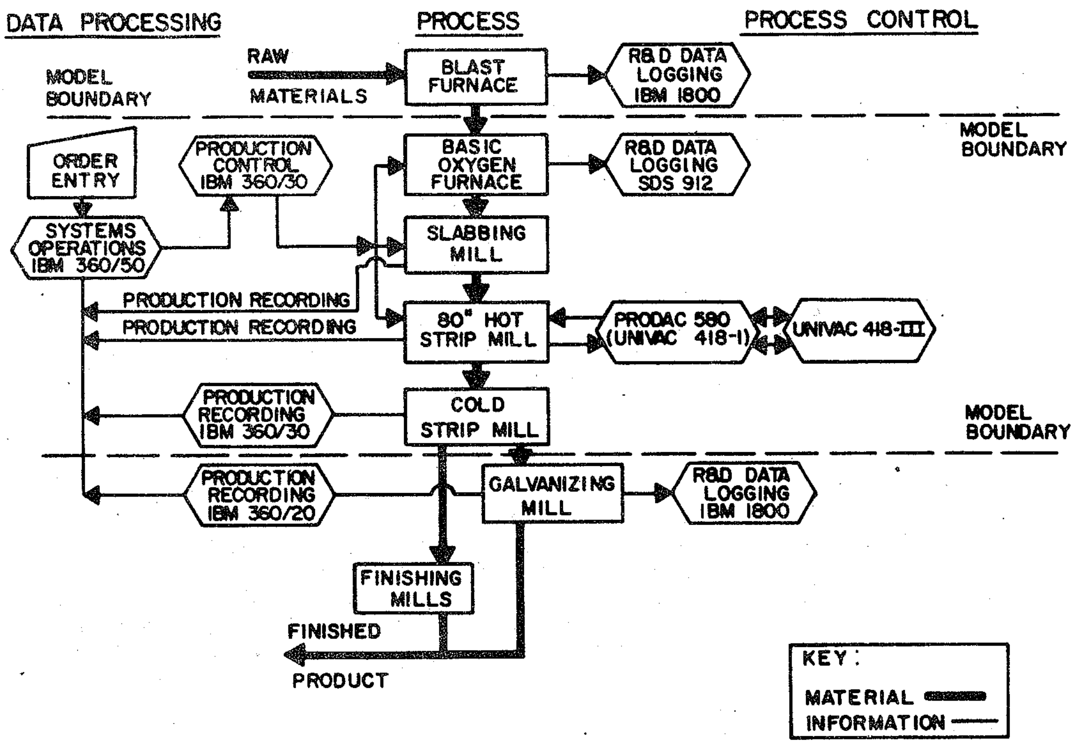

Figure 1 Present system material and information flow.

The next phase of the research effort was spent collecting data and constructing preliminary models of the production and information processing sectors and determining the relationships among these sectors, and determining the relationships among these sectors, the market, automatic controls research and development efforts, and automatic computer process control installations. Models construction, data collection, debugging, and finalization culminated with the present system model verification by the appropriate plant managers. Various operating level and staff managers verified the behavior of the various sectors of the model under typical demand patterns.

Fig. 2 provides a macroscopic flow diagram of the present system model which idenfifies the various sectors of the model and the relationship among them. It is the production control function, in particular Central Production Planning-Planning and Scheduling, which processes all information passing from the Market to the Production Sectors and between the Production sectors themselves. Because of this, any changes in information flow or any information overload will affect production control more than any other management function.

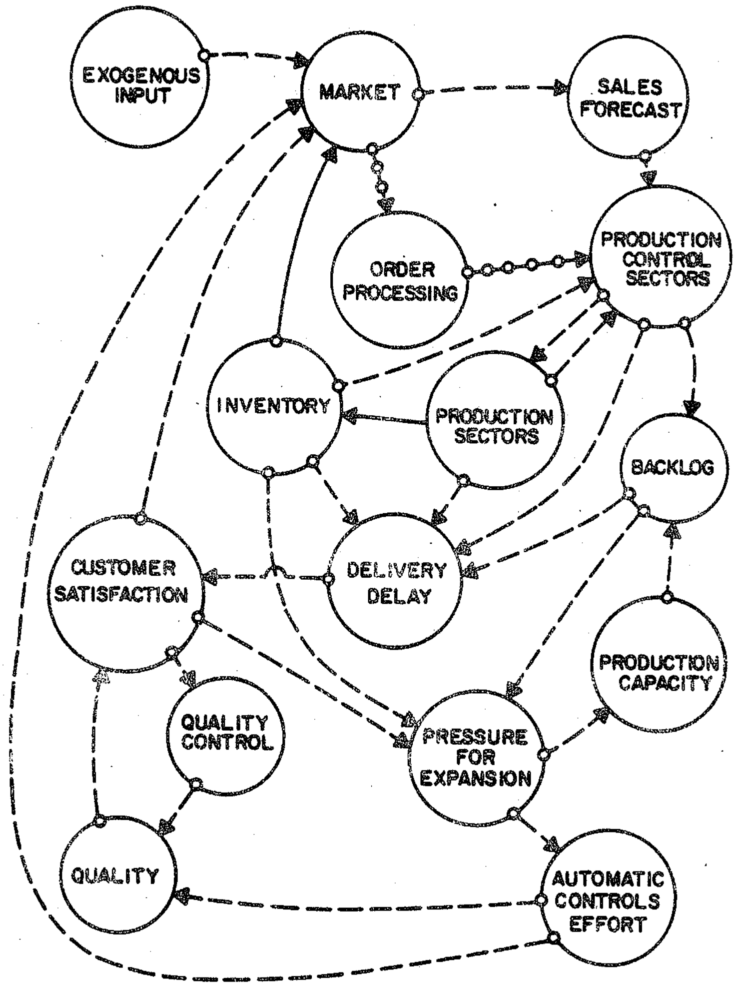

Figure 2 Sectors of the models.

Ideally, the only changes to the present system model necessary to describe the proposed system would be the representation of the proposed information flow generated by the process control computers. However, during the course of the study changes were both planned and made to the physical facilities of the flat products line. These changes appear in Fig. 3, which shows the planned material flow and the proposed process control/business control information interface. The macroscopic flow diagram shown in Fig. 2 serves equally well for the proposed system model as the changes made involved recoding within the individual sectors only and not the addition, removal, or the changing of relationships between sectors.

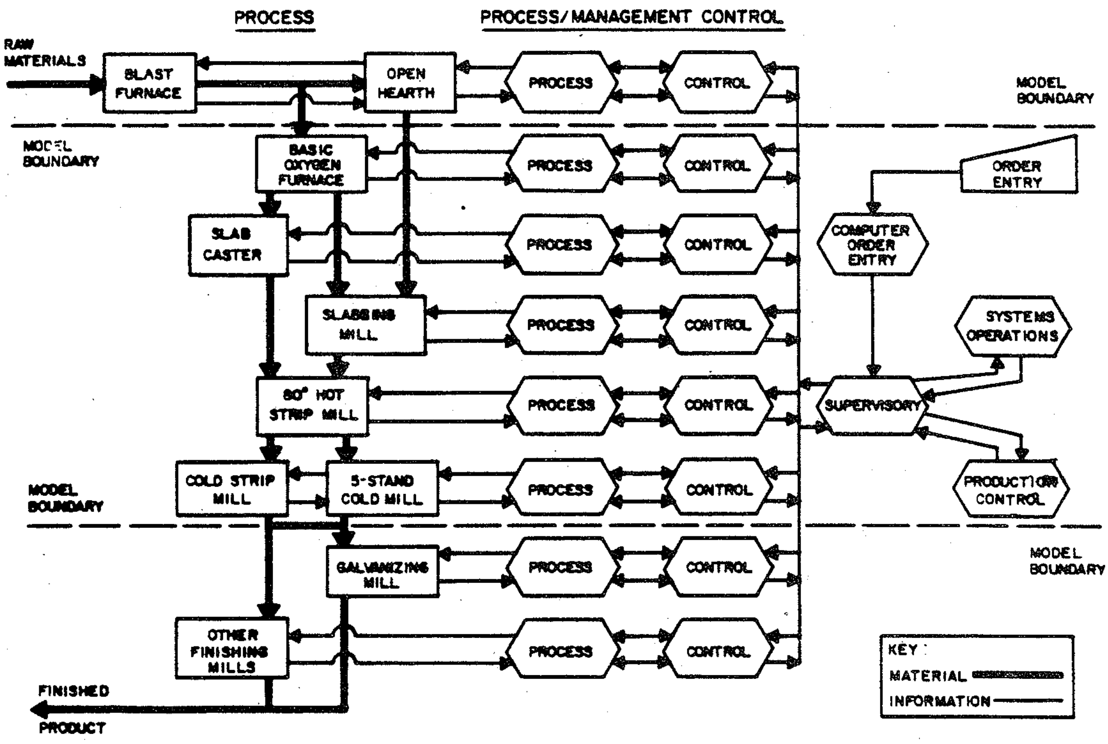

Figure 3 Proposed system material and information flow.

The models were stabilized, and verified initially under constant demand and then subjected to three endogenous and three exogenous demand inputs to study and compare their dynamic response. The models were run for 6 years of simulated time with delta time equal to 0.05 week, or approximately 1 8-hr shift.

Results

A comparison of the results of the runs of the two system models showed the differences attained by control decisions based on timely, accurate, and most important, complete information in the proposed system. As opposed to the present system, where information is delayed and man-made decisions are split up sequentially among the various control decision centers, the proposed system, utilizing a supervisory computer which receives all information in real time, is able to make control decisions based on all the available information. The indicators of better, or "tighter," control which resulted were the follwing. 1) Inventories are maintained with much less fluctuation and faster recovery periods following changes in level of demand. 2) In-process inventories are held at better levels (as a function of demand) with less fluctuation,. 3) Production rates for the various processes have less variability and adjust to changes in demand more smoothly and in less time.

4) Backlog ratios are lower under various demand patterns. 5) Slab inventory ratio was higher under the demand conditions tested. 6) Customer satisfaction levels were consistently higher. 7) Delivery delay ratios were lower throughout the seven runs. 8) Pressure exerted back onto the system was consistently lower and, as a result, automatic controls efforts received less pressure and the indicated production capacity figures were lower for all the simulation runs. Figs. 4 and 5 are examples of the dynamic response of selected variables in the present and proposed system models, respectively, to a step increase in the demand.

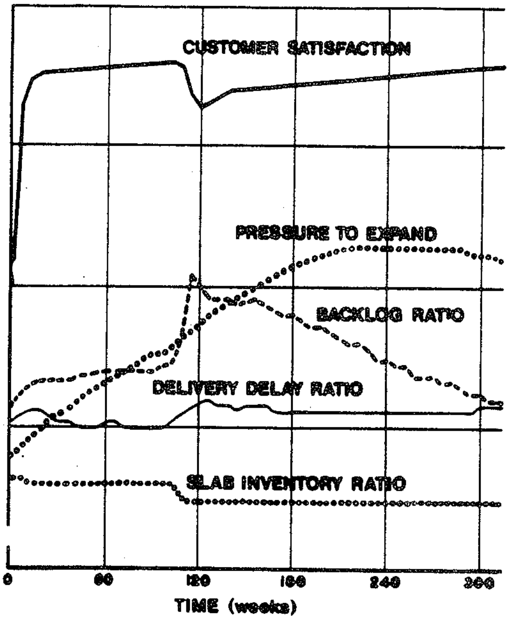

Figure 4 Present system response of selected variables to a step input in demand at week 104.

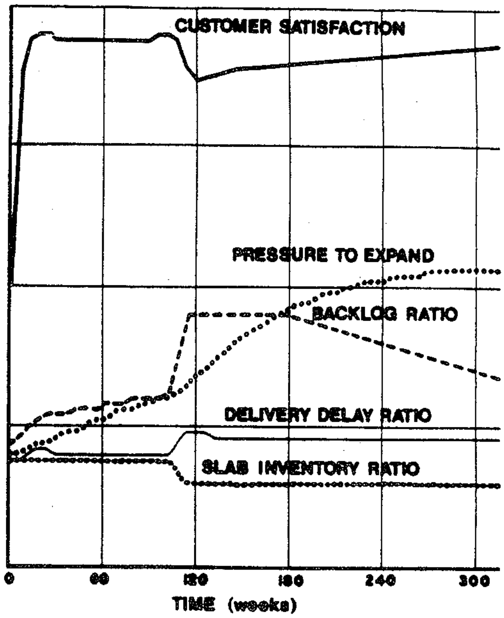

Figure 5 Proposed system response of selected variables to a step input in demand at week 104.

While the economic justification of the proposed system was beyond the scope of this study, it is understood that the dollar value of the improvements discussed above would have to be compared with the cost of implementing such a system before a given organization could justify such an undertaking. However, at a time when steel manufacturers are being pressured by customers to stock more products for "off-the-shelf" delivery, a system which gives the illusion of off-the-shelf delivery, to the customer by providing real-time flexible process/production control offers many hard-to-price benefits to the firm which not only wants to remain competitive, but wishes to become a leader in the marketplace.

Hammerton [8] points out that when the process control and business control systems are interfaced in accordance with the hierarchy concept of control discussed earlier, this configuration has two important effects on costs attributed to the collection of data for management and business control. Firstly, the communication links are justified and established primarily to carry operating data on the process to the supervisory computer at fixed intervals. The additional volume of data needed for the control of business functions is insignificant. Hence, the added communication costs are quite small. Secondly, compared to operator intervention, the costs of origination of business information that can be derived from operating data used for control of the process are minor or nonexistent.

Experience has shown that the economic justification of computer-based information systems of any kind has always been a much more serious problem than their design and implementation. Much work remains to be done in developing methods for both evaluating improved performance on an economic basis and economically justifying the information systems required to effect the improvement. (See Demski [3], [4] and Feltham [5].)

The Study - Part II

Once the advantages of the process control/business control interface were determined, it was deemed desirable to examine the effects of information transmission delays on the degree of control attained in the proposed system model. Again, simulation was chosen as that method of analysis which offered the most fruitful results.

Several sectors of the model which were not needed for this phase of the investigation were removed and the coding for information transmission between the Production Control Sectors and the Production Sectors was expanded considerably.

The model was subjected to three exogenous input functions: ramp, step, and sine and information transmission time delays of 0, 2, 4, and 6 hr. The model was run for 1 year of simulated time with delta time equal to 0.00625 week, or 1 hr.

The runs using a zero information transmission delay simulated the effects of an on-line real-time process control/business interface; these runs were used as the base to which the other runs were compared. The information transmission delays of 2, 4, and 6 hr simulated the effects of batching the process control computer generated information for these periods of time before transmitting it to production control to be used for updating schedules.

Results

The performance of the proposed system model, once the interface was effected, was remarkably insensitive to the effects of batching as compared to on-line information processing.

Table 1 summarizes the total throughput of the system in KT during the 52 weeks when the demand input function of 35 KT/Wk is subjected to the following exogenous input functions:

1) a ramp of slope equals 0.4 starting at week 16
2) a step function of 10 KT/Wk at week 16
3) a sine function of amplitude 10 KT/Wk and period equals 52 weeks starting at week 0.

INPUT FUNCTION \ INFORMATION DELAY	NONE	2 hr	4 hr	6 hr
CONSTANT	1901.5	1901.6	1901.6	1901.7
RAMP	2066.5	2066.3	2066.0	2065.8
STEP	2201.0	2200.8	2200.7	2200.5
SINE	1920.8	1921.1	1921.3	1921.2

Table 1 System throughput after 52 weeks of operation under tested input and information delay conditions (kilotons)

CONCLUSIONS

The results of the study of management control based on process control computer generated information suggest the following.

1) The present one man per production unit method of planning, scheduling, and controlling operations is suboptimal (see Kramp [12]) when compared with control attained by a process control/business control interface.

2) The delays and resultant distortions in the present information transmission system greatly reduce the effectiveness of managerial control.

3) Improvements were noted in all areas of information and operations control when the management control/process control information interface was simulated.

4) Once the process control/business interface was effected, batching (as opposed to on-line real-time information transmission) did not seriously affect the degree of control attained.

5) The structure of management control functions will be affected in both size and skill requirements when process control/business control information interfaces are effected.

6) The separate development of MIS, MICS,DSS, IS and a hierarchy system of process control computers is undesirable. Because a large part of the information needed for management control can be incorporated into the process computer system at little additional cost, the parallel and coordinated development of the two systems is imperative.

Although the models used in this research effort were based on a particular industrial situation, the results are, to a degree, generalizable to other types of industries. The methods of planning, scheduling, and control employed by many organizations are based on information reception, processing, and transmission systems similar to those of the firm studied.

REFERENCES

[1] M. C. Bonney, "Some considerations of the cost and value of information," Comput, J., vol. 12, pp. 118 - 123, May 1969.

[2] W. J. Crowley, "Can we integrate systems without integrating management?" in The Computer Sampler: Management Perspectives on the Computer, W. F. Boore and J. R. Murphy, Eds. New York: McGraw-Hill, 1968, pp. 269 - 281.

[3] J. S. Demski, "Decision-Performance control," Accounting Rev., vol. XLIV, pp. 669 - 679, Oct. 1969.

[4] --, "The decision implementation interface: Effects of alternative performance measurement models," Accounting Rev., vol. XLV, pp. 76 - 87, Jan. 1970.

[5] G. Feltham, "The value of information," Accounting Rev., vol. XLIII, pp. 684 - 696, Oct. 1968.

[6] J. W. Forrester, Industrial Dynamics. Cambridge, Mass.: M.I.T. Press, 1961.

[7] P. J. Friedl, "Analog, digital, and hybrid computers in process control," IBM Sci. Ctr., Palo Alto, Calif., Tech. Rep. 320-3208, Mar. 30, 1966.

[8] J. C. Hammerton, "Integrating process and business control," Business Automation; pt. I, vol. 14, pp. 32 - 39, Apr. 1967; pt. IL vol. 14, pp. 38 - 42, May 1967.

[9] J. B. Heyne, "Planning for research in management control systems," Systems Development Corp., Santa Monica, Calif., Tech. Man. 546, 1961.

[10] B. Hodge, "Company control via computer," Chem. Eng., vol. 72, pp. 177 - 180, June 7, 1965.

[11] B. Hodge and R. Hodgson, Management and the Computer in Information and Control Systems. New York: McGraw-Hill, 1969.

[12] J. J. Kramp, "An industrial dynamics study of the effects of total system suboptimization caused by assembly line balancing optimizing criteria," master's thesis, Purdue Univ., Lafayette, Ind., June 1968.

[13] L. Meadows, Jr., from "Integrating process and business control," by J. C. Hammerton, Business Automation, pt. II, vol. 14, p. 40, May 1967.

[14] R. N. Millen, "Industrial administration of computer-controlled complexes: Some effects of computer process control on management information and control," Purdue Lab. Appl. Ind Contr., Sch. Eng., Purdue Univ., Lafayette, Ind., Rep. 31, Aug. 1970.

[15] R. J. Mouly, "Systems engineering in the glass industry," presented at the Int. Cong. Glass, London, England, June 1968.

[16] E. H. Porter, "The parable of the spindle," Harvard Bus. Rev., vol. 40, pp. 58 - 66, May - June 1962.

[17] J. F. Roth, "The application of the hierarchy system to on-line process control," presented at the Symp. Recent Developments in Industrial Electronics, London, England, Apr. 2 - 4, 1962.

[18] A. T. Spaulding, "Is the total system concept practical?" in Management systems, P. P. Schoderbek, Ed. New York: Wiley, 1967, pp. 149 - 153.

[19] W. R. Stevenson and R. F. Jakubik, "The intangibles of computer process control," Oil and Gas J., vol. 64, pp. 94 - 97, Sept. 12, 1966.

[20] K. A. Whitman, "The role of management principles in process computer control," Chem. Eng., vol. 75, pp. 67 - 72, July 1, 1968.