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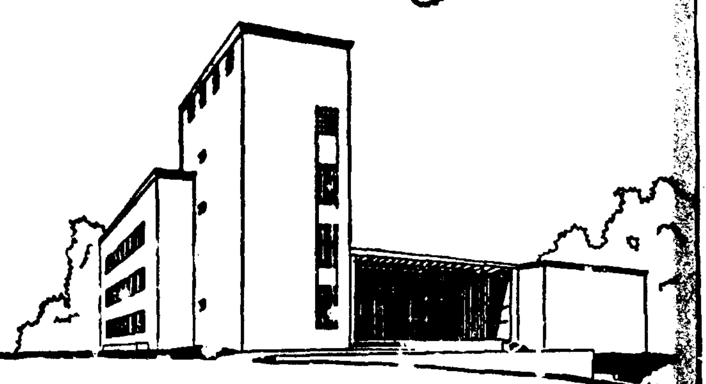

GRADUATE SCHOOL of INDUSTRIAL ADMINISTRATION

William Larimer Mellon, Founder

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OPERATIONS RESEARCH IN THE DESIGN OF MANAGEMENT INFORMATION SYSTEMS*

by

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MANAGEMENT INFORMATION SYSTEMS PROJECT
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1. Introduction

A useful starting reference for discussion of a topic which exhibits some ambiguity is a clear definition of terminology. To this end, a management information system can be described as:

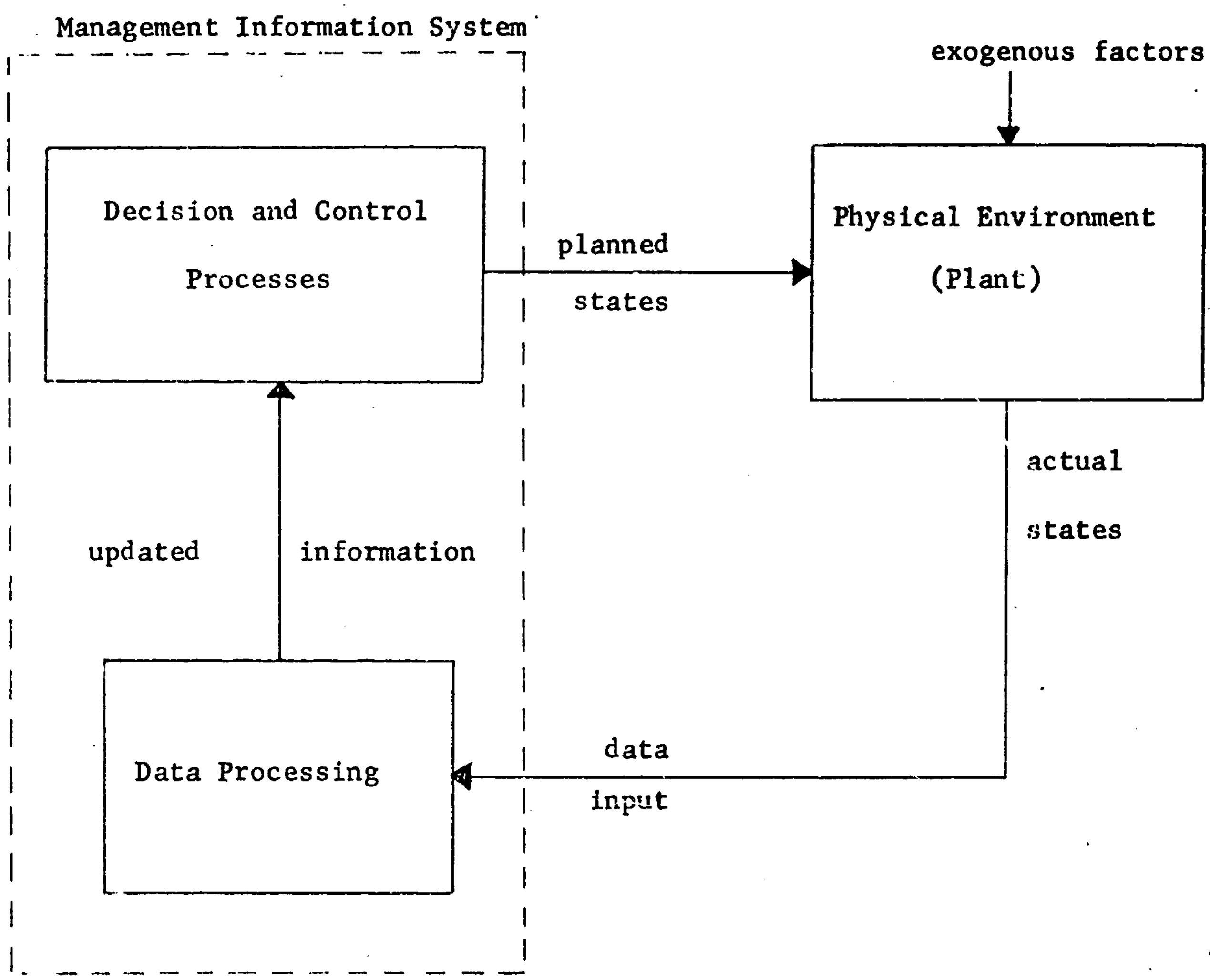
> The combination of human and (typically computer-based) capital resources which results in the collection, storage, retrieval, communication, and use of data for the purpose of efficient management of operations in an organization.

In this context it is essential to distinguish between usage of the terms "data" and "information." Data are facts or inputs to the system--the reports or images of the activities of an organization--which are collected and stored. Information is the intelligence or system output which results from the conversion of data into a "product" which enables management to take action appropriate within a particular frame of reference. For example, an item of data, such as an employee's social security number, may become information when provided in response to a particular inquiry which facilitates the execution of a decision. Management information systems, therefore, include consideration not only of data processing activities but of decision-making and control processes, as well.

The basic operating cycle in management information processing is outlined in Figure 1. As indicated in the diagram, the output of the decision and control process functions within a management information system are "planned states" of the world. The "actual states" which result in the physical environment of the organization are the consequence of these planned inputs and exogenous factors which are not directly controlled by management. Observations recorded on these actual states provide "data input" to the data processing function of the system, which in turn provides

Figure I

BASIC OPERATING CYCLE IN MANAGEMENT INFORMATION PROCESSING



"updated information" for decision-making and control; and so on.

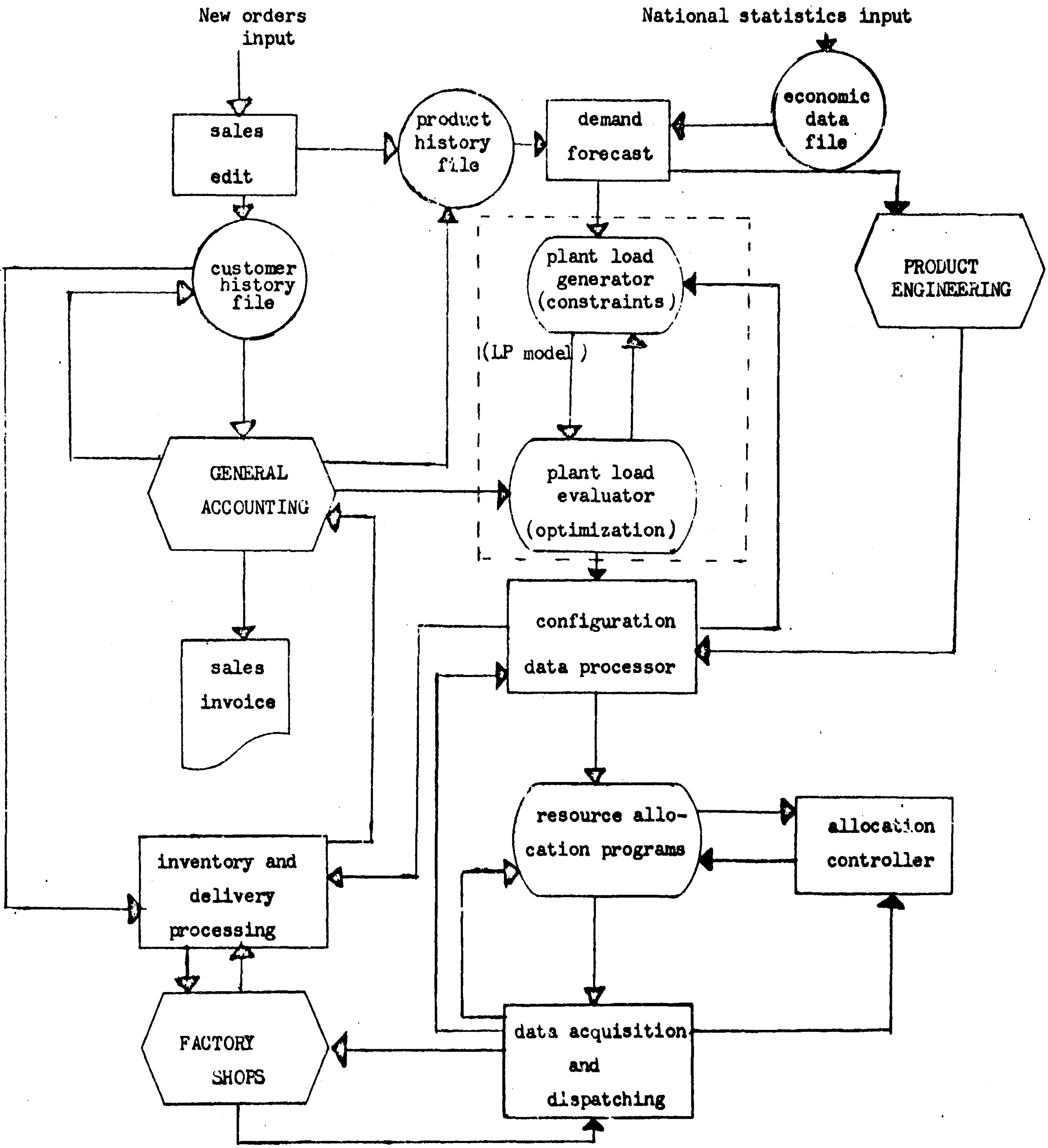
The design of management information systems is concerned with the identification and detailed specification of the information and data processing resources required by an organization for decision-making and control. These considerations can be made more explicit by reference to a specific example, such as the system illustrated in Figure 2.

Figure 2 illustrates an example of a management information system that might be employed in a manufacturing firm for servicing order processing, production and inventory control functions. The physical environment of the organization is represented in the diagram by the three hexagonal blocks labeled: "General Accounting," "Factory Shops", and "Product Engineering." Exogenous data inputs to the system are given as new sales orders and aggregate economic statistics. After data editing, incoming orders are posted to both customer and product history files. Verification of customer credit on new sales orders is performed by General Accounting for postings in the customer history file. This file then provides inputs on outstanding sales orders to the inventory and delivery processing functions which, upon shipment of an order, notify accounting for customer billing and posting of payment when received.

The product history and economic data files provide inputs to the demand forecasting function which, in turn, provides sales forecast inputs to an aggregate planning decision model and the product development engineering function. In the example system, we have assumed that the former decisions are accomplished through a linear program (labeled "LP Model") which serves as the operating decision system. (In another context this aggregate decision system might correspond to a management planning committee,

Figure 2

MANAGEMENT INFORMATION SYSTEM EXAMPLE FOR A MANUFACTURING FIRM



which establishes target levels of operation, such as quarterly or monthly production volumes.) Output decisions from the linear programming sub-system--say, monthly production, inventory, and work force levels--are subsequently extended by the "configuration data processor" into parts inventories (bill-of-material explosions) and daily shift manning requirements. Physical resources are then allocated on an individual basis to meet these requirements and dispatched to the factory shops. Actual states which obtain in the plant environment are monitored (either continuously or periodically) as a basis for schedule and inventory control, and detailed plans are modified accordingly.

A few comments are worth noting regarding the oversimplified management information system example of Figure 2. To begin with, the principal decision-making functions (or sub-programs) in the system include the blocks labeled "LP model" and "resource allocation programs." Similarly, control functions are represented primarily by feedback flow-lines, and key data processing activities are otherwise apparent. However, in each case the blocks indicated require further detailing to completely specify the system design; for example, the individual constraints of the linear program, the organization of the respective data files, the elements in the system monitoring factory operations, and so on.* To complete this detailed specification of the design the components of decision making, data processing, and control would again appear in each of the sub-systems--but on a more microscopic level. Thus, the design of management information

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* For example, cf. Hess and Kirkland [29b] for an illustrative system design of an integrated management information and process control system in a [illegible]ll.

systems involves the identification and specification of decision, data processing, and control functions at all levels in the hierarchical structure of the system.

A second observation regarding the information system example is the fact that nothing has been said concerning electronic computers, either within the diagram or otherwise. Clearly, as indicated above, before the system design is determined completely the physical equipment "hardware" and "software" must be specified for executing data processing functions and the like, however, the computer is incidental only as a capital resource alternative. That is, the computer is a toolwhich may contribute to the effectiveness of a management information system design, but it is not an essential consideration for all designs. This leads to a related consideration which is often overlooked in practice: data processing systems vis-a-vis management information systems. Data processing is an essential element in the design of management information systems but it is only one of several considerations involved. While an efficient data processing system is a necessary requirement for effective management information, the latter does not automatically follow from the former.

A final observation regarding the management information system example concerns approaches within the design process for determining the necessary detailed specifications. In this regard, we come to the basic objective of this discussion which is to illustrate how the techniques of operations research have been and can be employed to advantage in systems design. For example, referring to Figure 2, recall we incorporated operations research directly in the design of one of the major sub-systems for decision making, viz., the "LP model". In a similar fashion we might have included the specification of OR within the control process functions, such as implementing PERT (program evaluation and review technique) within the block labeled "allocation controller." Comparable opportunities for the application of operations research to the specification of each of the remaining blocks in the diagram could be identified as well. Rather than outline these opportunities within the specific (and limited) context of this system example, however, I would like to broaden the discussion framework and review some of the available literature employing formal models for the study and design of management information systems. All of the references cited in this review are listed alphabetically in the bibliography appending the discussion. Although this bibliography is not an exhaustive listing, it should serve as a representative introduction to the field.*

In the next section we survey formal analyses of problems in the design of data processing operations. These studies are primarily concerned with the preparation, classification and coding of input data; organization and planning of computer processing operations; data selection and retrieval;

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* In the course of this literature search it became necessary to omit certain fields from consideration. One important field that was intentionally excluded is psychology, including the areas of artificial intelligence [59], small group research [57], and applications of information theory in behavioral research [1, 4, 40]. Although the present status of this research appears of only indirect relevance to management information systems design, it is clear this situation will change in the future.

and the evaluation of data processing systems. In the section following, models that have been proposed for the study and design of management information systems are discussed. For the most part, this research views the data processing function as one of several components in the total systems design. Although simulation has been the principal approach in this research, it is argued that more mathematical analysis of operating systems can and should be included in the development of these models.

2. Mathematical Models of Data Processing Problems

Perhaps the most apparent initial focus of consideration in the design of management information systems is the data processing activity itself. For present purposes, research on data processing design can be partitioned into activities which are independent of or dependent upon the existence of an electronic computer at the heart of the system. In the former case, library scientists and others have been concerned with the basic issues of indexing, coding, and classifying documents for their efficient retrieval, cf. [14, 20, 35, 53, 72]. It has been suggested by some [25], that a statistical analysis of the descriptors or key-words used to classify documents could provide parameters which in turn would specify the organization of the file system used to store the records, for example, as outlined in Figure 3. Mathematical analysis of the hierarchical structure in data files to determine its organization has been proposed in other contexts as well, [15, 31, 73]. For instance, the precedence relations that exist between detail parts and sub-assemblies in production and inventory operations have been recognized as factors whose data elements can be described in terms of simple matrix relations [10, 43, 47]. Liberman

Figure 3

SAMPLE MODEL FOR FILE ORGANIZATION

Source: R. M. Hayes, "Mathematical Models for Information Retrieval", p. 268-298, in P. L. Garvin (ed), Natural Language and the Computer (McGraw-Hill, 1963)

Problem:

Measure of the degree of association, relevancy, and the closeness of terms or documents.

Definitions:

Let elements a_{ij} of an (nxm) "association" matrix assume values either 1 or zero depending on whether the row description (or point-term) i has been assigned to the column document j. Let A_j represent the j-th column of the matrix $[a_{ij}]$, and $N(A_j)$ represent the number of ones in column A_j

Association Model:

$R(A_j \cdot A_k)$ as a measure of the correlation between columns (documents) is computed from the sum of the products of the differences of each element from average values for its columns, that is,

$$R(A_j \cdot A_k) = \Sigma_{i=1}^{n} (a_{ji} - \bar{A}_j)(a_{ki} - \bar{A}_k).$$

and Homer [46, 32] have expanded these simple matrix models to include the identification of data relationships between functional decision-making groups within organizations and have developed an "integrated data system model" for the firm. Comparable models have also been proposed to describe business data processing operations within the computer hardware, [65, 74].

Lombardi [48, 50] has argued that the introduction of automatic data processing capability into business information systems has altered the character of considerations for file organization and design, and he has proposed a computer programming language intended to overcome "traditional" shortcomings, [52]. Clearly, once the computer is specified as an integral component in the data processing function, problems peculiar to its operation must be acknowledged within the design. Among computer data processing problems of importance are file processing procedures [41, 42, 51], programmed file operations [11, 56], sorting and addressing for internal and bulk storage [78, 27, 60], and systems equipment design [69]. This latter consideration includes specification of peripheral and input-output characteristics of the equipment [9, 18, 21], internal storage requirements [12], and the basic design configuration [2, 13, 71]. The recent development of time-sharing modes of operation has expanded the variety of system design alternatives [34, 58, 64] and also the basic associations among users of the system [63, 64]. Two examples of models proposed for computer data processing design are summarized in Figures 4 and 5.

The evaluation of specific equipment alternatives becomes substantially simplified if data processing requirements have been made precise

Figure 4

SAMPLE MODEL FOR FILE DATA PROCESSING

Source: R. H. Day, "On Optimal Extracting From a Multiple File Data Storage System: An Application of Integer Programming," Operations Research (May-June 1965), p. 482-493.

Definitions:

Suppose there exist m-files (F_1, ..., F_j, ..., F_m) from which data may be extracted, and k-requests (R_1, ..., R_i, ..., R_k) for data from the system.

Let a_{ij} = 1 if request R_i can be satisfied by searching file F_j
= 0 otherwise.

Let t_j be the length of file F_j, for j=1, 2, ..., m.

Let the decision variable x_j be equal to either 1 or 0, depending on whether file F_j is or is not searched.

Model:

Minimize $\lambda = \Sigma_{j=1}^{m} t_j x_j$ (total tape search time)

Subject to:

$\Sigma_{j=1}^{n} a_{ij} x_j \geq 1$ (each request must be satisfied)

for i=1, 2, ..., k

x_j be a non-negative integer, for j=1, 2, ..., m

Figure 5

SAMPLE MODEL FOR COMPUTER STORAGE BUFFER DESIGN

Source: I. Delgalris and G. Davison, "Storage Requirements for a Data Exchange," IBM Systems Journal (3, 1; 1964), p. 2-13.

Problem:

To determine the input/output buffer storage requirements of the data exchange used to connect the communication network and central processor in a real-time system.

Definitions:

Let $f(X)$ denote the probability of a message of length X arriving; and $h(Y)$ denote the probability of using Y blocks of storage when the line utilization is p, for example, if the block size is equal to 1 and storage is reserved for the message until transmission has been completed and the message removed from the buffer, then

$$h(Y) = \begin{cases} 1 - p & \text{for } Y = 0 \\ p\, Yf(Y) / \Sigma_X Xf(X) & \text{for } Y > 0. \end{cases}$$

Model:

If Y_{iI} is the number of storage units used by transmission Line i, the number of units used by all N_I lines is Z_{NI}, where $Z_{NI} = Y_{1I} + Y_{2I} + \cdots + Y_{NI}$. Then $E[Z_{NI}] = N_I p_I \,(E[X^2]/E[X])$ and

$$\sigma^2_{Z_{NI}} = N_I p_I \,(E[X^3]/E[X]) - E[Z_{NI}]^2 / N_I.$$

The amount of buffer storage required is Z^*_{NI}, for

$$Z^*_{NI} = E[Z_{NI}] + h \cdot \sigma_{Z_{NI}} ,$$

where h is chosen to permit overflow the specified percent of the total time.

at the outset, either through systems analysis [22b] or a meaningful statement of system objectives by the organization management [16]. Mathematical models [24, 66] and computer programs [29] have been developed to evaluate various equipment alternatives, given specifications of the system requirements. For example, in [66] requirements and design configurations are specified as the element details of vectors. Measures are then defined on the vector spaces which provide indices for the evaluation of data processing system alternatives. However, as Hitch [16a] argues, in most instances management is unable to state objectives for an information system in the degree of detail required by the systems designer. Thus to provide effective total systems design, the analyst must possess the capability for evaluating management's information requirements as well as alternative approaches for data processing. Too many case histories can be cited where a good data processing system was supporting a poor management information system. With this fact in mind, we turn our attention to proposed models of total systems.

3. Mathematical Analysis for Total Systems Design

Boyd and Krasnow [6] effectively argue against "clerical" cost displacement as the sole criterion for evaluating the data processing activity in management information systems. For example, the "timeliness" of management information is often a critical economic consideration; data processing delays result in information delays for decision-making [38] and control [33] with corresponding deterioration in management's performance. The precise translation into economic terms of the consequences of "intangible" factors in a system configuration is the most difficult problem facing the designer of total information systems for management. Marschak [54, 55], Radner [61, 62] and others [37, 70] have attempted to deal with this issue by developing a formal theory on "information economics" for business system design, and other authors [17, 19, 67, 68] have shown comparable concern for non-business environments, such as military intelligence organizations.

Another problem of similar magnitude facing the designer of total information systems is his analytical facility to be able to deal with the extremely complex structure of large systems [26, 44, 45]. That is, even if one assumes that all of the information-economic relationships are well defined, the issue still remains of whether or not the many faceted components within the systems design can be analyzed as an entity. One approach to the complexity problem has been to develop the design sequentially over time [69]. For example, following the Homer-Liberman [32, 46] description of organization data flows in terms of matrix models, one might extend the model to include constraints on information requirements, and finally a criterion function based on operating costs. Henderson [28], presents one such formulation of the total systems design problem as an integer linear programming model. The difficulty in this analysis is the eventual size of the model, and in Henderson's case, the absence today of computationally efficient integer programming computer codes to provide a general solution.

This does not mean that attempts to optimize the design of total information systems are necessarily doomed to failure. For example, in [39] an empirical study is reported in which optimal information systems are obtained for an idealization of an aggregate production planning system.

Operations research provides the methodology for a quadratic programming formulation of operating cost criteria and obtaining a system of production decision rules. Information data processing alternatives are then evaluated relative to their effect on the control-decision rule system performance. Although the study represents only a first approximation to the general design problem, it does serve to illustrate that optimal or near - optimal solutions are feasible in certain organizational contexts.

The principal analytical alternative to total optimization models is simulation. While the preceding discussions show that normative mathematical analysis can considerably assist in the specification of various aspects in the systems design, the present state of the art suggests that simulation becomes the only modeling alternative when all of the complexities of the system are considered simultaneously. For example, the complication that organizations consist of humans who effect and are affected by information systems and design alternatives appears capable of analysis only through simulation, [5]. (Excerpts from Bonini's simulation model are presented in Figures 6 and 7). The shortcoming of much of the simulation literature, however, is that researchers often solicit the simulation model too early in their analysis. That is, the mathematics of operations research can provide the detailed specifications necessary at each stage in the process of designing management information systems. It is principally at the final stages of design, when all the system components must be evaluated collectively, that simulation often provides a true comparative advantage for analysis.

Figure 6

EXCERPT FROM SIMULATION MODEL OF TOTAL SYSTEM: PART 1

"Flow Chart of Decisions Made at Various Levels in the Firm Model"*

Executive Committee

1. Formulate sales expectations and cost.
2. Determine the projected profit level.
3. Set price.
4. Set administrative budgets.
5. Exercise control over the manufacturing vice-president and the general sales manager.

Manufacturing Vice-President

1. Determine preliminary cost and budget estimates.
2. Set the "target" level of operations.
3. Influence manufacturing administrative expense.
4. Exercise control over the plant supervisor and the industrial engineering department.

Industrial Engineering Department

1. Revise production cost standards.

Plant Supervisor

1. Set the immediate level of operations for the plant.
2. Request revisions in production cost standards.
3. Exercise control over the foremen.

Foremen

1. Influence variable manufacturing costs.
2. Request revisions in production standards.

General Sales Manager

1. Determine preliminary sales and budget estimates.
2. Set sales quotas for sales districts.
3. Influence sales administrative expense.
4. Exercise control over the district sales managers.

District Sales Managers

1. Determine district sales forecasts.
2. Set quotas for salesmen.
3. Influence sales administrative expense.
4. Exercise control over the salesmen.

Salesmen

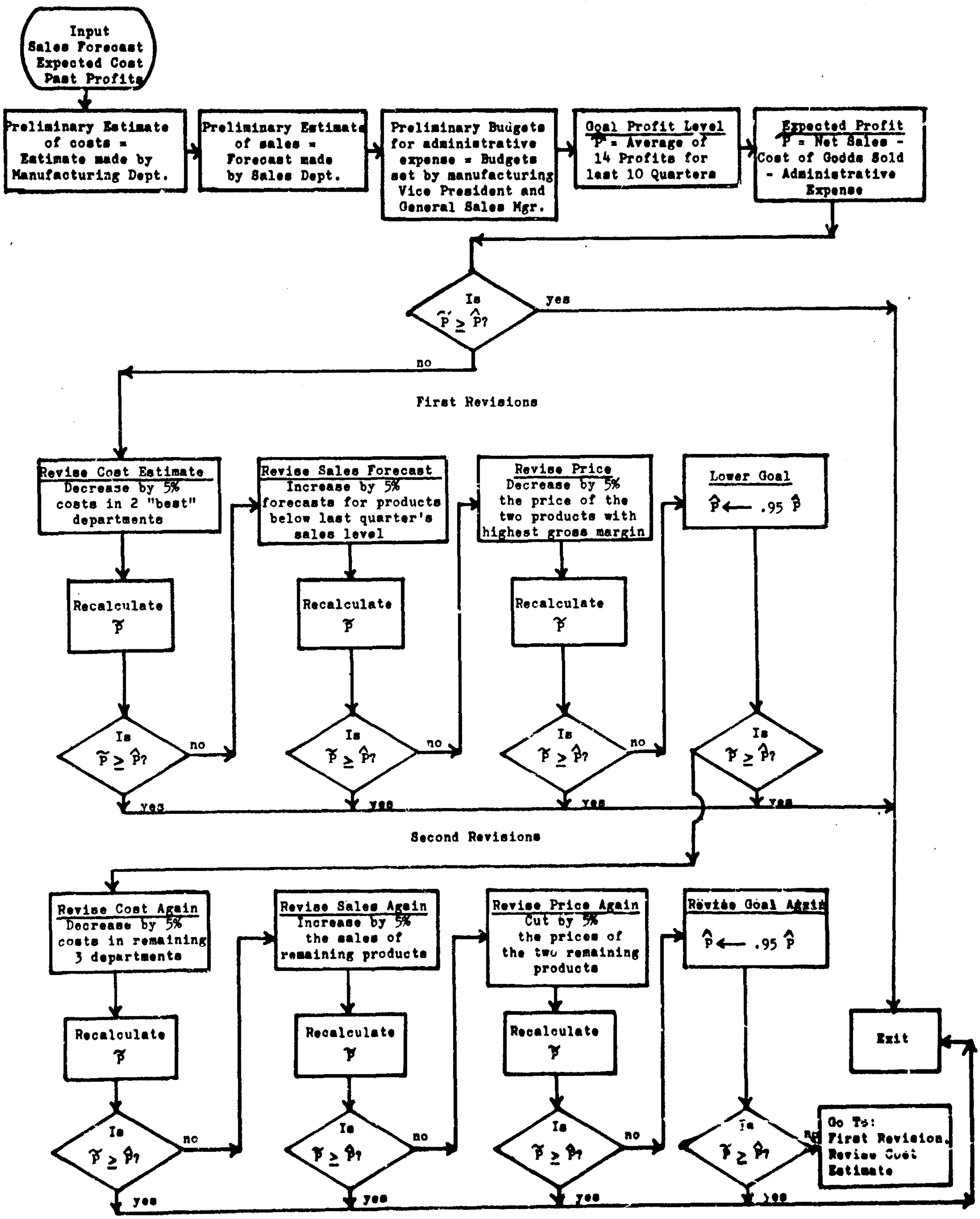
1. Make a territory sales forecast.
2. Expand sales effort.
3. Bargain with the district sales manager about sales quota.

*Source: C. P. Bonini, Simulation of Information and Decision Systems in the Firm, (Prentice-Hall, 1963), p. 31.

Figure 7

EXCERPT FROM SIMULATION MODEL OF TOTAL SYSTEM: PART 2

"Flow Chart-Determination of the Over-all Company Plan"*



* Source; C. P. Bonini, ibid, p. 43.

4. Conclusions

This review was based on an updating of an earlier literature survey reported in [36]. In the course of the discussion we found that many of the techniques of operations research have been employed to advantage at various stages in the process of designing management information systems. More specifically, the existence of comprehensive data banks within organizations provides a major opportunity for the application of operations research models to the normative analysis of decision, data processing, and control functions and a corresponding opportunity to improve operating performance.

An organization can realize the full economic potential of advanced data processing techniques and comprehensive data files only through the careful exploitation of these resources in the design of their management information systems. Operations research provides a natural framework for the analysis and specification of management decision-making and control processes in information system design. The close coordination of operations research and data systems activities within modern business firms is, therefore, a practical necessity today.

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13. ABSTRACT

The design of management information systems is concerned with the identification and detailed specification of the information and data processing resources required by an organization for decision-making and control. This paper surveys a representative selection of the literature on management information systems in which mathematical models are employed as the basis for analysis and systems design.

Operations research provides a natural framework for the specification of management decision-making and control processes in information system designs. To realize the full economic potential of advanced data processing techniques in management information systems today, the close coordination of operations research and data systems activities has become a practical necessity for the modern business firm.

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