FTD-HC-23-1507-71

FOREIGN TECHNOLOGY DIVISION

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THE THEORETICAL PRINCIPLES OF THE ORGANIZATION OF INFORMATION SYSTEMS

by

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18

UNCLASSIFIED
Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Foreign Technology Division Air Force Systems Command U. S. Air Force	2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED 2b. GROUP

3. REPORT TITLE

THE THEORETICAL PRINCIPLES OF THE ORGANIZATION OF INFORMATION SYSTEMS

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Translation

5. AUTHOR(S) (First name, middle initial, last name)

Kulikowski, J. L.

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
1970	14	11

8a. CONTRACT OR GRANT NO.	9a. ORIGINATOR'S REPORT NUMBER(S)
b. PROJECT NO.	FTD-HC-23-1507-71
c. DIA Task Nos. T71-05-09 and T71-05-13 d.	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report) AP1024331

10. DISTRIBUTION STATEMENT

Approved for public release; distribution unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	Foreign Technology Division Wright-Patterson AFB, Ohio

13. ABSTRACT

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DD FORM 1 NOV 65 1473

UNCLASSIFIED
Security Classification

UNCLASSIFIED

Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Information Storage and Retrieval						
Data Processing						
Information Processing						

UNCLASSIFIED

Security Classification

FTD-HC-23-1507-71

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by Joint Publications Research Services

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English pages: 14

Source: Archiwum Automatyki i Telemechaniki (Records of Automation and Telemechanics) 1970, Vol. 15, No. 4, pp. 441-453

Approved for public release; distribution unlimited.

PO/0031-70-015-004

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FTD-HC-23-1507-71 Date 30 Nov 1971

THE THEORETICAL PRINCIPLES OF THE ORGANIZATION OF INFORMATION SYSTEMS

[Article by Dr Juliusz Lech Kulikowski, Engineer, Institute of Automation of the Polish Academy of Sciences; Archiwum Automatyki i Telemechaniki, Polish, Vol 15, No 4, 1970, pp 441-453]

(This article is the text of a paper given at the Dzien Informatyki [Information Science Day], 8 May 1970, organized as part of the symposium entitled "The theory of large systems and their applications" in Jablonna, 4-9 May 1970. The editors of this journal believe that the paper, being a survey, will bring to a broad group of readers an understanding of this important problem area.)

Summary

This article presents a survey of the theoretical problems connected with the organization and design of systems for processing and transmitting information. It gives a definition of information systems (IS) and classifies them from various points of view. It discusses briefly the most important aspects of the organization of IS, such as physical structure, functional structure, software, and operating principles. It presents certain problems connected with estimating the value of information supplied to its users by an IS. In a supplement it gives an example of the solution of the problem of optimum distribution of information in mass memory units of an IS, based on methods of integer programming.

1. DEFINITION AND CLASSIFICATION OF INFORMATION SYSTEMS

We shall use the term information system (IS) for a system (i.e., a certain organized complex of technical equipment together with the people operating it) whose basic task is collecting, storing, processing, disseminating, and/or publishing information in accordance with the requirements imposed by the users of the IS. Since each of the tasks mentioned here is connected with a change in the utility value of the information, an IS can be defined more succinctly as a system whose main task is to change the utility value of information. In using the term "change" we usually mean an increase in the utility value of information; but IS are possible whose task is to devalue information, such as scrambling systems, or systems for intentional disinformation.

An IS consists basically of functionally isolated component parts of a certain higher "large system"; this latter system defines for the IS the scope of its tasks and the criteria for evaluating their performance. In many cases the higher system is for the IS also an external center from which information proceeds to the IS and to which that information is returned; but systems are also possible in which the sources and recipients of information are outside the range of the higher system (e.g., the national network of ZETO centers).

The growing interest in the theory of IS which can be noted in recent years is the result of progress in the techniques in communications media and automatic information processing. The most important stages in this progress were the general application of electronics in telecommunications, the appearance of electronic computers with changeable programs, the development of algorithmic programming languages, the formation of multi-access and multi-programmed computing systems, miniaturization and increased reliability of electronic equipment resulting from the use of integrated circuits, etc. These achievements make it possible to achieve efficiency indexes in information processing which were impossible with traditional systems. The realization of an IS meeting the demands of modern technology is simultaneously a great organizational enterprise requiring considerable investment expense, and is thus associated with a certain economic risk. This implies the need for working out the scientific foundations of designing IS; and that is one of the main tasks of IS theory. The theory of IS must be based on the achievements of such scientific disciplines as information theory, the theory of computers and algorithms, the theory of control, and the theory of organization; but it is not identical with any of these. The tasks of IS follow from the specifics of modern IS, whose essential feature is the interaction of information transmission systems, computing systems, and specialized information systems, autonomous mass memory units and stores of information carriers, and heterogeneous intermediate and peripheral equipment permitting either the exchange of information among technical units of an IS or exchange of information between technical equipment and the service personnel. The need for developing research in such a broadly defined area was propagated by the Institute of Automation of the Polish Academy of Sciences at symposia and scientific conferences in 1967 [4], 1968 [5], and 1969 [6], and in various articles [1, 2, 3]. The aroused interest in information science which has recently been observed in Poland fully confirms the current importance of this field of research.

IS can be classified from a number of different points of view, of which these are some examples:

1. From the point of view of the application of the IS: into intermediary systems in the processing or transmission of information (e.g., a communications system, the service network for ZETO centers, etc), advisory-service systems (e.g., a system for collecting and disseminating scientific and technical information, records systems, multi-access systems for automatic

design , etc), supervisory systems (e.g., an air-traffic control system, a system controlling the course of a technological process, an automatic alarm system, etc), and control systems, which are in a certain sense a development of supervisory systems, since they also involve the process of making decisions and transmitting these decisions to the executive elements of the control system.

2. From the point of view of the organization of work in the IS: into systems organized conventionally, including continuous systems (e.g., an observation system which operates continuously), cyclic systems (e.g., a system of cyclic control of the condition of technical installations), and acyclic systems (e.g., an automatic flight-planning system executing a constant cycle of operations only at the randomly selected moments when new "customers" report in), systems which operate by grouping information tasks into "blocks" (e.g., computing systems which operate on the so-called batch method), and multiprocessing systems which permit the parallel performance of information tasks defined by independent algorithms and programs (e.g., multi-access computing systems based on time sharing).

3. From the point of view of the synchronization of work between the IS and the environment: into systems working on their "own" time and only slightly connected with the pace of changes occurring in the external environment (e.g., most systems for automatic planning and administration for economic purposes), and systems working in "real time", in which the rate of information processing is precisely determined by the pace of changes occurring in the external environment (e.g., systems for controlling technological processes distinguished by a high rate of change through time and requiring rapid intervention by the control system).

4. From the point of view of the type of connection between component parts of the IS: into systems of low-level integration, in which no actual physical connections among the units of information equipment are needed and the flow of signals at certain phases is replaced by transport of material information carriers ("off-line" connections using punched cards, punched tape, etc), and systems with a higher degree of integration in which the information equipment is physically connected, and the only form in which information is transmitted is through the flow of signals ("on-line" connections).

5. From the point of view of the degree of standardization of the component parts of the IS: into systems which are standardized and not standardized on various levels, such as the physical parameters of the signals (principally external signals transmitting information among the parts of the IS), codes, word formats, external languages, etc.

6. From the point of view of the class of algorithms executed by the IS: into universal systems, in which the class of algorithms is not determined, (e.g., a service computing system which can execute any computing program for scientific or technical purposes), and specialized systems, in which the class of algorithms and programs is determined from the outset (e.g., an automatic records and diagnosis system for the health services performing information operations in a strictly defined form).

7. From the point of view of the autonomy of control in the IS: into fully autonomous systems with their own means of transmitting and processing information (e.g., a system for the automatic control of rocket flight, comprising a highly integrated complex of technical equipment designated exclusively for this purpose), and systems with limited autonomy which use information from other systems at various phases of information processing, (e.g., an automatic airline reservation system using leased teletype lines, or a system for administering an enterprise using the services of ZETO to process its data).

8. From the point of view of the structural permanence of the IS: into stationary systems, in which changes in structure do not play an essential role, quasi-stationary systems (e.g., a meteorological system considered from the point of view of its gradual evolution as the number of observation points grows), and non-stationary systems with a rapidly changing structure (e.g., a military communications system considered from the point of view of the possibility of sudden damage which might eliminate certain links, thus requiring operational control of the stream of information flowing through the system).

9. From the point of view of the technique of information processing used in the IS: into digital or alphanumeric, analog, and hybrid (mixed) systems.

10. From the point of view of the degree of automation of the basic information operations in the IS: into traditional systems based mainly on human work, semi-automatic systems in which only a part of the information operation is automated (e.g., an information and documentation system in which documents are described and summarized manually, while the operations associated with entering them into permanent storage, retrieving them, and distributing them on the requests of clients are automated), and automatic systems (e.g., the emergency signaling system of a power grid).

This classification is obviously not complete; in particular it does not take into account the fact that we are usually dealing with systems with mixed features (e.g., a system which is automatic only on the lowest levels of the hierarchy, and semi-automatic on higher levels). Nevertheless this gives an idea of the great variety of problems which can be encountered in designing an IS: and the problems may be quite specific for each type of IS. This is in turn responsible for the great variety in design problems associated with IS. The problem in designing an IS for information and documentation may be, e.g., the optimal location of information storage centers, the allocation of information storage among them, and the selection of the best means of transmitting information; whereas in an automatic materials records system in a machine-building factory the problem may be the best means of breaking the system down such that each level of the hierarchy will receive only the information most useful from the point of view of the decisions to be made on that level. The tasks of optimization will thus be different, although sometimes they can be solved using similar mathematical techniques. These techniques are principally the various aspects of operations research theory: linear programming, integer programming, dynamic programming, queueing theory, etc. IS theory also has a number of general aspects. These concern particularly the theory of the value of information, which is the basis for evaluating the efficiency of operation of an IS and also evaluating its organization. It should be stressed that the object of IS theory is more the organization of IS than the design or principles of operation of their component parts, which belong rather to other scientific and technical disciplines such as communications theory, the theory of computers and automata, etc.

2. THE ORGANIZATION OF INFORMATION SYSTEMS

The term organization of IS means here a description, as formal as possible, of the following features of IS:

A. The physical structure of IS;

B. The functional structure of IS, including

   a. Technical structure, and

   b. Information structure;

C. IS software;

D. Operating rules of the IS.

The physical structure of an IS means a description of the location of the points of exchange of information with the external environment (i.e., input and output), points where information is collected, processed, and moved about; it also includes the paths by which information is transmitted among these points. The physical structure of an IS can thus be described using a certain geometric grid in two- or three-dimensional space.

The technical structure of an IS can be described using a certain dimultigraph whose nodes represent the names and types of technical equipment making up the IS, and the directed branches represent the information connections symbolizing the paths of signal flow or of the transport of information carriers among units of equipment.

The information structure of an IS means the set of complex information procedures executable within the given technical structure. There can be more than one such procedure within a given IS: in a multi-access system each user may, for example, initiate a procedure independently of the other users, as the following graph crudely illustrates:

Human operator	Local processor No $\underline{k}$	Data transmission channel	Central processor	Central mass memory

A complete information structure should, however, reflect a number of other details, such as the sequential phases of coding and translation of data and its storage in memory buffer systems, and should also indicate which blocks of mass memory are accessible in a given information procedure. Each information procedure must be included in the technical structure of the given IS: this is a basic condition of its executability. For example, among the information procedures executable in a given IS may be a system for automatic control of a technological process, which provides different procedures for bringing the installation on stream, for normal operation, and for emergency conditions. These procedures, and thus the types of information connections associated with them, may be essentially different, even though they are executable in the same IS technical structure. From the formal point of view a complex information procedure can be defined as a consistent system of information procedures connecting certain sets of information [5]; the theory of these procedures can thus be treated as a specialized part of algebra.

An example of partial optimization of one organizational component of an IS, based on integer programming, is included in the supplement. Other examples can be found in articles [9, 10]. A survey of the mathematical methods used in this case is presented in the article by S. Walukiewicz [11]; the article by M. Libura [7] contains a brief survey of applications of queueing theory to the analysis of certain individual functional structures and operating rules used in modern IS.

3. THE VALUE OF INFORMATION

The statistical measure of the quantity of information which C. E. Shannon introduced has been repeatedly criticized. The criticism stems from the fact that this value does not reflect the semantic, logical, or utility value of information, and is also based on a relatively narrow, probabilistic model of information procedures which in a number of cases turns out to be useless. These strictures are undoubtedly correct, but it is also obvious that one cannot diminish the significance which Shannon's concept has had in the development of science and technology, nor the practical significance of the statistical theory of communication in certain fields of science.

The problem of estimating the value of information, as we have noted, takes on particular importance in developing the theory of IS: the efficiency of an IS can be measured in terms of the change in the value of information making up the main body of the IS. But we must make clear what we mean by the term "value of information", since in everyday language this concept is quite ambiguous.

In the general case the "value" of something, and thus of information, can be expressed in terms of the elements of a linear space (i.e., of a space in which the operations of summing elements and multiplying them by real numbers are defined), in which a given principle of semi-ordering of elements is defined [4]. We shall call such a space K space (using the term proposed by the Soviet mathematician L. V. Kantorovich). This principle permits comparing some pairs of elements $a, b \in K$ with one another, which is to say stating at least one of the following relations for them:

$a \leqq b$ (meaning "a does not follow b"),

where

1. For each $a \in K$
   $a \leqq a$;
2. For any $a, b \in K$
   if $a \leqq$ and $b \leqq a$, then $a = b$;
3. For any $a, b, c \in \Lambda$
   if $a \leqq b$ and $b \leqq c$, then $a \leqq c$.

If for $a, b \in K$ it is not true that $a \leqq b$ or that $b \leqq a$, then we shall call a pair of elements a, b a non-relative pair in the sense of the given relation of semi-ordering.

In any linear space X the principle of semi-ordering can be introduced. For this purpose it is sufficient to define in it a certain convex cone S, or set $S \subseteq X$ such that

1) if $a, b \in S$, then $a+b \in S$; also;
2) if $a \in S$ and k is a positive real number, then $k \cdot a \in S$.

Let us consider any two elements $a, b \in X$. We introduce the principle of semi-ordering into X assuming that

1) $a \geqq b$ if and only if gdy $(a-b) \in S$;
2) $a \leqq b$ if and only if gdy $(b-a) \in S$;
3) w in the remaining cases a, b comprise a non-relative pair.

On similar principles the relation of semi-ordering can be introduced into a space of real numbers, complex numbers, vectors with real or complex terms, matrixes with real or complex terms, or real or complex functions, and, with certain assumptions, of random variables and functions as well. Each of these quantities may then be used to express value. This is of essential significance in the analysis of large systems with certain criteria of quality. Since such a system evaluates the efficiency of operation of an IS from the point of view of its criteria, an increase in value in the higher system is the most suitable measure of the value processed by the IS. In order to estimate that value the following reasoning must be performed: a certain message w must be supplied to the higher system by the given IS, whereupon the gain in the higher system will equal $x'_w (x'_w \in K)$, or it will not be supplied at all and then the gain for the higher system will be $x''_w (x''_w \in K)$. It should obviously be defined how the higher system will behave if the IS does not supply the message. The equation

$$x_w = x'_w - x''_w \tag{1}$$

can be considered the value of the information contained in message w and supplied by the IS, as evaluated from the point of view of the higher system. This value, however, must not be confused with the value of information evaluated from the point of view of the IS itself. This latter obtains a certain reward y'_w when it has performed its information tasks, and a certain reward y''_w, which can be negative, when the message w is not supplied by the IS. We assume that $y'_w, y''_w \in K_1$, where K_1 is a Kantorovich space not necessarily identical with space K (e.g., its sub-space). The equation

$$y_w = y'_w - y''_w \tag{2}$$

can be considered the gross value of the information contained in the message w supplied by the IS to the external environment as evaluated from its own point of view. But there are production costs associated with the processing of message w in the given IS, and these we shall denote by z_w. In reality, then, the IS obtains a net profit equaling $y'_w - z'_w$ when the message w is produced in the IS, and equaling $y''_w - z''_w$ when it is not produced. From the point of view of the IS the real value of the information contained in message w equals

$$v_w = (y'_w - z'_w) - (y''_w - z''_w). \tag{3}$$

Similarly, when it receives message w from the IS the higher system bears cost y'_w, while when it does not receive the message (i.e., when a different procedure is executed) it bears cost z''' (which need not be directly connected with cost z''_w). As a result the higher system estimates the real value of message w as

$$u_w = (x'_w - y'_w) - (x''_w - z'''). \tag{4}$$

Clearly, the IS is interested in performing the information task (i.e., in supplying information w to the higher system) only when

$$v_w \in S_1, \tag{5}$$

where S_1 is the above-mentioned cone of positive elements in space K_1.

The difference

$$r_w = u_w - v_w \tag{6}$$

is the added value created by the IS and supplied to the higher system. It is clear that from the point of view of the higher system maintenance of the IS is profitable only when

$$r_w \in S, \tag{7}$$

where S is a cone of positive elements in space K.

The above considerations relate to an isolated message w; clearly, though, they could easily be generalized for the case of a stream of messages considered over a long period of operation of the IS. This generalization does not encounter any difficulties of a formal nature, since the value of the information as an element in linear space can be multiplied by real numbers (e.g., by probabilities) and summed. But when a number of information tasks are performed in an IS, the real value of the information contained in the messages supplied to the higher system cannot always be considered independently. The value x'_w, for instance, is in many instances a monotonically diminishing function of the delay occurring between the moment when message w is supplied to the higher system and the moment when a need for that message is expressed. This delay may in turn be a monotonically increasing function of the number of information tasks which are performed simultaneously by the IS. The operating rules must therefore provide a higher priority for information tasks which are distinguished by a high rate of devaluation of the information they contain. The queueing models considered in the literature rarely take this factor properly into consideration.

Let us now emphasize the relative independence of the quantity of information contained in a given message from its value. The dependence of the value on the quantity of information very often takes the form of a uni-model curve; the value increases as a function of the quantity of information up to a certain maximum, whereupon it may show a tendency to fall. This is the result of the fact that the higher system has limited opportunities for effectively utilizing (e.g., in the process of administration or production control) an excessive quantity of information supplied per unit time; for this reason the task of the IS may sometimes be to increase the value of information by limiting its quantity (by selection).

In concluding our considerations of the value of information it is worth directing attention toward the need for developing research on the utility value of formalized languages (the pragmatic theory of language). Two measures of the practicality of a language as a means of communicating information in an IS are its ability to express certain messages and the cost associated with this. This cost may have a number of elements, such as the costs of translation from a given language to other languages used in the IS, the costs of transmitting information expressed in the given language (e.g., the costs associated with the length of expressions conveying a given content), the costs of information loss associated with the language's vulnerability to distortion, the semantic ambiguity of expression in the particular language, etc. The value of a language can be estimated only from the point of view of a definite IS, through analysis and comparison of two models: a model of the IS in which the language is used for certain defined information procedures, and an analogous model, in which the language is not used (i.e., in which another formalized language is used to execute the same information procedures). Research of this type comprises a difficult but extremely interesting branch of the theory of information systems, but one in which work is just beginning to be done.

SUPPLEMENT

OPTIMIZATION OF THE DISTRIBUTION OF STORED INFORMATION

Let us assume that a certain set A of information is given, which can be divided into semantically separate subsets $A_k, k \in \langle 1, K \rangle$. Let a given spatial structure of the IS be given; we shall denote the points at which information is stored in this structure by Q_i, and $\in \langle 1, I \rangle$. Let us assume that we are considering an information-service type IS. Customers register at points Q_i asking for access to certain groups of information from sets A_k. The customer pays for access to the information at a rate which depends on the value of the information received. We shall assume that this value depends on the subset of A_k from which the information is taken, and on the time which passes between the moment the request for the information is registered and the moment when it is obtained. The operating costs of an IS include the costs of inputting information into the mass memory systems located at nodes Q_i, the costs of storing it, the costs of transmitting information between nodes Q_i, and the handling costs associated with retrieving the needed information and preparing it for transmission to the customer. The task consists of locating subsets A_k at the individual nodes Q_i in the most economical way, keeping in view the foreseeable needs of customers at individual nodes for certain types of information. The possibility must also be included of reproducing certain subsets A_k and simultaneously storing them at various nodes Q_i.

Let us introduce the following notation:

$e_i, i \in \langle 1, I \rangle$ is the cost of inputting a unit of information into the mass memory at node Q_i;

$g_i, i \in \langle 1, I \rangle$ is the cost of storing a unit of information per unit time in the mass memory at node Q_i;

$V_i, i \in \langle 1, I \rangle$ is the permissible quantity of information which can be stored in the mass memory at node Q_i;

$r_{ij}, i, j \in \langle 1, I \rangle$ is the distance between nodes Q_i and Q_j;

$n_k, k \in \langle 1, K \rangle$ is the quantity of information contained in a message from subset A_k;

$N_k, k \in \langle 1, K \rangle$ is the quantity of information contained in subset A_k;

$u_{jk}, j \in \langle 1, I \rangle, k \in \langle 1, K \rangle$ is the established payment for supplying information from subset A_k to a customer at node Q_j assuming that the delay in filling the request equals zero;

$z_{jk}, j \in \langle 1, I \rangle, k \in \langle 1, K \rangle$ is the number of requests for information from set A_k received per unit time at node Q_j; and

$h_i, i \in \langle 1, I \rangle$ is the maintenance cost (cost of operation and collection) of node Q_i per unit time.

In addition, let us introduce into our considerations the following state variable:

$$x_{ijk} = \begin{cases} 1 \text{ if the subset of information } A_k \text{ is located at node } Q_i \\ \text{and is accessible to a customer from node } Q_j\text{; and} \\ 0 \text{ in the opposite case.} \end{cases}$$

Let us define the profit of the IS per unit time as a function of the state variables. At any unit time node Q_j receives z_{jk} requests for which, if they are filled instantly, the customers pay $z_{jk}u_{jk}$ currency units per unit time. Since information from subset A_k located at node Q_i is supplied to the customers at node Q_j with a delay of t_{ijk}, the customers actually pay a sum equal to $x_{ijk}z_{jk}u_{jk} \cdot \exp(-H_{jk} \cdot t_{ijk})$ where $H_{jk}, j \in \langle 1, I \rangle, k \in \langle 1, K \rangle$ is a positive coefficient of devaluation of the information from set A_k from the point of view of the customer at node Q_j. The delay t_{ijk} is made up of three components: of the time t'_{ij} necessary for the information request from node Q_j to be received at node Q_i, the time t''_i necessary to retrieve the desired information from the mass memory at node Q_i, and the time t'''_{ijk} necessary for preparing the information from subset A_k to be transmitted from node Q_i to node Q_j:

$$t_{ijk} = t'_{ij} + t''_i + t'''_{ijk}.$$

The delay t'_{ij} is associated only with the distance between the nodes:

$$t'_{ij} = a' \cdot r_{ij},$$

where a' is a non-negative coefficient of proportionality.

The time necessary to retrieve the information t''_i is associated mainly with the quantity of information stored at node Q_i. This quantity can be evaluated as follows:

$$W_i = \sum_k^K x_{iik} \cdot N_k,$$

and as a result we assume that

$$t''_i = a'' \cdot \ln\left(b \sum_k^K x_{iik} N_k\right),$$

where a'' and b are non-negative numerical coefficients.

The time t'''_{ijk} is dependent both on the distance between the nodes and on the volume of information transmitted. As an approximation we can assume that

$$t'''_{ijk} = d' r_{ji} + d'' n_k,$$

where d' and d'' are non-negative coefficients of proportionality.

Customers making requests to node Q_j thus pay for the fulfillment of their requests, per unit time.

$$R_j = \sum_i^I \sum_k^K x_{ijk} z_{jk} u_{jk} \cdot \exp \cdot \left\{-H_{jk}\left[a' r_{ji} + a'' \ln\left(b \sum_{k'}^K x_{iik'} N_{k'}\right) + d' r_{ji} + d'' n_k\right]\right\} =$$

$$= \sum_i^I \sum_k^K x_{ijk} z_{jk} u_{jk} \cdot \left(b \sum_{k'}^K x_{iik'} N_{k'}\right)^{-a'' H_{jk}} \cdot \exp[-H_{jk}(a' r_{ji} + d' r_{ji} + d'' n_k)].$$

Thus the gross profit earned at all the nodes of the IS equals

$$R = \sum_j^I R_j.$$

The operating costs of a system per unit time are made up of the following components: The costs of operation and collection at individual nodes, the costs of inputting information into the permanent memory, the costs of storing information, the costs of fulfilling information requests (handling costs), the costs of submitting requests, and the costs of transmitting the desired information to the destination node. Let us evaluate the individual cost components for an individual node Q_i. The permanent cost of operating node Q_i per unit time can initially be denoted by h_i. The cost associated with inputting information into the permanent memory equals

$$h'_i = \frac{1}{T} \sum_k^K x_{iik} c_i N_k,$$

Since this is a one-time cost, it refers to the period T during which the IS is collecting information. The cost of storing information at node Q_i per unit time equals

$$h''_i = \sum_k^K x_{iik} g_i N_k.$$

The handling costs associated with retrieving information and preparing it for transmission are

$$h_i''' = \sum_{j}^{I} \sum_{k}^{K} x_{ijk} z_{jk} l_{ik},$$

where l_{ik} is the handling cost for processing an individual message from set Λ_k at node Q_i.

The costs of submitting requests to node Q_i per unit time are

$$h_i^{IV} = f \cdot \sum_{j}^{I} \sum_{k}^{K} x_{jik} \cdot z_{ik} \cdot r_{ij}.$$

And the costs of transmitting information to the requesting points per unit time are

$$h_i^{V} = \sum_{j}^{I} \sum_{k}^{K} x_{ijk} z_{jk} (f' r_{ij} + f'' n_k),$$

where f' and f'' are coefficients of porportionality.

Therefore the full operating cost of an IS per unit time is

$$h = \sum_{i}^{I} (h_i + h_i' + h_i'' + h_i''' + h_i^{IV} + h_i^{V});$$

which is, as can easily be noted, a linear function of the state variables x_{ijk}.

The net profit for the IS per unit time equals

$$R' = R - h.$$

The profit R' should be maximized by the proper selection of state variables. These variables should meet the following limitations:

$$x_{ijk} \geqslant 0 \quad \text{for} \quad i, j \in \langle 1, I \rangle,\ k \in \langle 1, K \rangle,$$

$$x_{ijk} \leqslant 1 \quad \text{for} \quad i, j \in \langle 1, I \rangle,\ k \in \langle 1, K \rangle;$$

A further system of linear limitations is associated with the requirement that the type of information defined for each node be supplied from not more than one node (if the given type of information is stored in a certain node, then that node must be primarily accessible to customers applying directly to that node):

$$\sum_{i}^{I} x_{ijk} \leqslant 1 \ \text{dla} \ j \in \langle 1, I \rangle,\ k \in \langle 1, K \rangle.$$

The last system of inequalities expresses the requirement that each type of information be stored in at least one node of the IS:

$$\sum_{i}^{I} \sum_{j}^{I} x_{ijk} > 0 \quad \text{dla} \quad k \in \langle 1, K \rangle.$$

The fact that the profit R is a nonlinear function of the state variables x_{ijk} encounters a basic difficulty. This difficulty can be avoided by replacing the actual value t'' of the retrieval time at node Q_i with its maximum value:

$$\overline{t_i}'' = a'' \cdot \ln(bV_i) \geq t_i'',$$

which is independent of the state variables. A similar linearization of the function of profit R is possible providing that we add one more system of linear limitations:

$$\sum_{k}^{K} x_{ijk} \leq 1 \quad \text{dla} \quad i \in \langle 1, I \rangle.$$

The problem of optimum distribution of information stored in the IS has been reduced to a typical problem in linear programming in binary numbers. A survey of the method of solving such problems is given in the article by S. Walukiewicz [11].

Manuscript submitted 26 May 1970.

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