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STORAGE POLICIES FOR INFORMATION SYSTEMS

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ABSTRACT

The cost of an item of information in a storage system is defined as the sum of an initial cost, a time dependent cost, and a usage cost. Item usage is assumed to follow a simple exponential obsolescence pattern. A decision rule for the economic holding time of an item in storage is derived from the model and based on a policy of minimizing the average cost of usage. Some properties and implications of the rule and policy are discussed. This model is developed in the context of large research libraries but should be applicable to other kinds of information systems.

Introduction

It has been pointed out by C. W. Churchman [1968] that the more important issue in current efforts to develop automated information systems is not how to merely computerize existing clerical practices, but how to use this new technology to enlarge our concept of information systems so as to include the user as a more integral and active component. If libraries, accounting systems, or other kinds of information systems are to be made more responsive to the needs of the persons using them, then the appropriate level of planning and control must be broad enough to include the user as an effective participant. Churchman goes on to point out that even a well-designed user-library system would be a subsystem in a larger environment and would run the risk of suboptimizing its policies relative to the larger system.

N. R. Baker [1967] has suggested one way to formalize the notion of system expansion by defining a service system as composed of three active components: the service agency proper, its users, and its funders. The funder component is the final arbiter of system performance. This model permits a closed-loop analysis of the interactions among the three groups, which Baker used to show that the "servicers" can expect to become increasingly more constrained in their decision-making unless they can make satisfactory decisions before users exercise their influence and before funders exercise their powers of control to force the decisions. The service agency must convince the others that learning, not influence and control, is the dominant factor and the most productive approach; and they must demonstrate the fact that they are exploiting fully the political, economic, and technical resources which are available to them.

Libraries are among the world's largest information systems. They provide a rich history of operational experience for the student of general information systems and a large working environment in which to test new design concepts. Although conventional libraries are essentially manual systems for the handling of mechanically-stored information in book form, many of their operating characteristics are readily transferable to more sophisticated systems using computers and microform storage devices. This is most apparent in the library operations research studies of recent years, and the seminal work in this field is reported in the recent monograph by P. M. Morse [1968]. Library operations research studies have concentrated on the problems of storing and using library materials, while library and information scientists have focused on problems of organizing and retrieving these materials according to their intellectual content. The latter problems seem to constitute a more difficult long-run research field, since the introduction of the newer methods of information storage preclude direct user access and require newer methods of obtaining remote intellectual access to the file.

Much of the operational analysis of libraries is related directly to the problem of library size, and the use of such options as depositories, interlibrary loans, blanket orders, duplication, and compact storage, as means of optimizing library size relative to the observed usage of the library. Usually, the library under study is thought of as a member of a larger information network which permits local suboptimization without precluding the possibility of the user going elsewhere for information. A good prototype example of this kind of approach is the model proposed by P. F. Cole [1962], and refined by M. K. Buckland and I. Woodburn [1968], by which it is shown that a 2,000 volume petroleum library can expect to satisfy the greatest number of user requests by subscribing to approximately 190 different journals or serials and holding them for about eleven years. Variations on this theme of "optimal library size" are seen in the study of depositories by Morse [1968] and W. C. Lister [1967] and the study of interlibrary loan by G. Williams [1968]. A more sophisticated approach is the fully stochastic model of H. M. Gurk and J. Minker [1968] which studies the effect of retention policies on the size of a data base for a computer utility.

The size of a library or data base seems to be the most important measure of its worth apart from its usage, since it suggests comprehensiveness or completeness of knowledge. This has long been the traditional measure of stature in library circles. The two important determining factors of size are the breadth of acquisition and the length of retention. These are also important factors in determining usage along with the ease of access. While some models have been developed which concentrate on library breadth, (see Leimkuhler [1967, 1968]), the problem of retention time has been given the greatest attention. The storage cost model and storage policy developed below is intended to reveal some of the essential economic characteristics of information storage systems in an elementary way by developing a decision rule for the holding time which is both practicable and near-optimal.

Cost of Storing a Single Item

Recent studies of the cost of operating library-type information systems, such as the work of Williams [1968], and R. Shisko [1968], suggest the following cost model for information storage systems:

$$K(t) = k_1 + k_2t + k_3u(t) \qquad (1)$$

Here $K(t)$ represents the total cost of holding one item for a period of t years; k_1 is the initial cost of acquiring the item; k_2t is the holding cost which is linearly related to the retention period; and $k_3u(t)$ is the usage cost which is proportional to the number of uses made of the item during the period t. This model is consistent with those used by Lister [1967] and Buckland [1968], although their models included more terms in order to recognize other control variables. Equation (1) could be discounted in order to obtain its equivalent present value as was done in the study by Williams. Equation (1) is not supposed to represent the ordinary way in which the costs of libraries or other types of information systems are reported for either budgetary or cost control purposes. Rather, it is intended to express storage cost as a function of time and usage in the simplest possible manner. There is no theoretical reason, for example, for not including user costs in the parameters along with the direct and indirect costs of the storage system proper.

In his study of book use models, A. K. Jain [1967] described several models which express book usage as a function of age. In all of these models the cumulative use, $u(t)$, increases monotonically with t, while $u'(t)$ decreases. The simplest of these models is the exponential case, that is:

$$u'(t) = re^{-bt} \qquad (2)$$

$$u(t) = (r/b)(1 - e^{-bt}) \tag{3}$$

where r is a scale parameter associated with the instantaneous initial usage level and b denotes the instantaneous obsolescence rate. The ratio (r/b) is the limit of $u(t)$ as t approaches infinity and therefore a measure of the lifetime usage of the item. Based on an extensive study of the M. I. T. Libraries, Morse [1968] proposed a usage model similar to that of equation (3) but including a constant or residual use term which is independent of age, that is, the usage rate drops exponentially to a residual level. He showed that this model results from a simple Markov process for the change in usage from year to year.

By substituting equation (3) into equation (1), the total, marginal, and average costs as a function of holding time are obtained respectively, as follows:

$$K(t) = k_1 + k_2 t + k_3(r/b)(1 - e^{-bt}) \tag{4}$$

$$K'(t) = k_2 + k_3' r e^{-bt} \tag{5}$$

$$\overline{K}(t) = (k_1/t) + k_2 + k_3(r/bt)(1 - e^{-bt}) \tag{6}$$

Both the marginal cost and average cost of retention time diminish to the level k_2 as the holding period increases, and the total cost becomes increasingly linear with time.

Cost of Providing Uses of an Item

A more interesting and useful cost relationship is obtained by expressing the total cost as a function of the cumulative usage during the retention period. By inverting equation (3), one obtains the time required to provide the first u uses of an item in storage, that is:

$$t(u) = \ln(1 - bu/r)^{-1/b} = (-1/b)\ln(1 - bu/r) \qquad (7)$$

By substituting equation (7) into equation (1), the total cost for providing the first u uses is defined as follows:

$$K(u) = k_1 - (k_2/b)\ln(1 - bu/r) + k_3u \qquad (8)$$

The marginal cost for providing the u^{th} service is approximately equal to

$$K'(u) = k_3 + k_2/b(1 - bu/r) \qquad (9)$$

where it is assumed that the derivative of K(u) approximates the finite difference, K(u) - K(u-1) . The average cost of providing the first u uses of an item is defined by the equation:

$$\overline{K}(u) = (k_1/u) - (k_2/bu)\ln(1 - bu/r) + k_3 \qquad (10)$$

While both the total cost and marginal cost of usage increase monotonically and quite rapidly with increased usage, the average cost decreases at first and then increases with usage.

The implications of equations (8), (9), and (10) can be more readily seen if they are expressed in terms of a relative measure of usage, x , which is the ratio of the cumulative usage over the lifetime usage, that is:

$$x = bu/r \tag{11}$$

It is convenient also to define the parameters K_2 and K_3 as follows:

$$K_2 = k_2/b \tag{12}$$

$$K_3 = rk_3/b \tag{13}$$

where K_3 can be interpreted as the total lifetime usage cost of an item, and K_2 as the holding cost for a relaxation interval, $1/b$. By using these definitions, the equations for the total, marginal, and average cost of usage become:

$$K(x) = k_1 - K_2 \ln(1 - x) + K_3 x \tag{14}$$

$$K'(x) = K_3 + K_2/(1 - x) \tag{15}$$

$$\bar{K}(x) = (k_1/x) - (K_2/x)\ln(1 - x) + K_3 \tag{16}$$

These relationships are plotted in Figure 1 to show their general shape and properties. The plotted values are based on the arbitrary assumption that k_1 , k_2 , and K_3 are of equal magnitude.

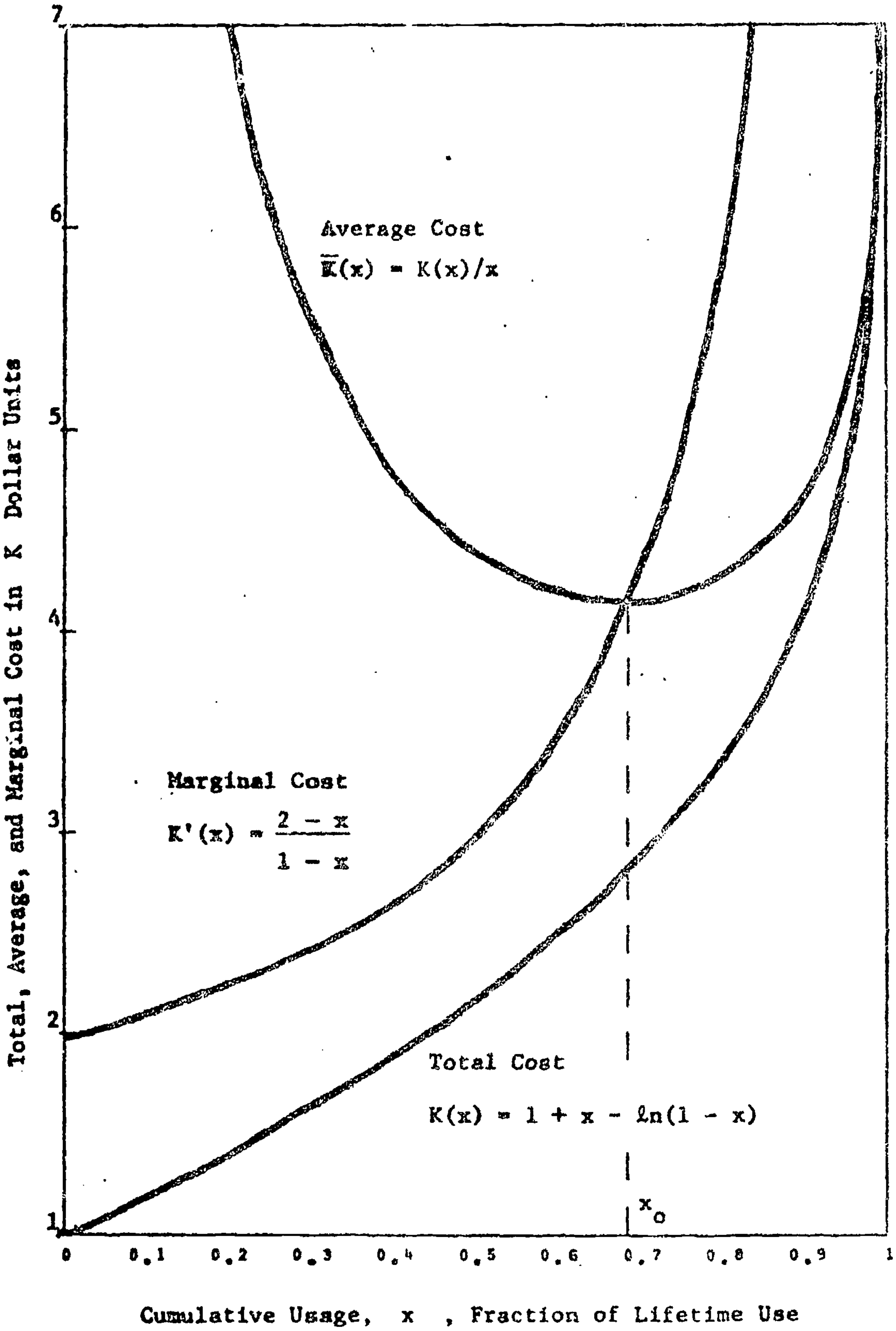

Figure 1--Information Storage Costs of One Item as a Function of its Usage, When Parameters k_1 , K_2 , and K_3 Are Equal to K .

Storage Policies for a Single Item

The total cost function, $K(x)$, consists of a linearly increasing component and a logarithmically increasing component which are weighted with the time-cost for storage. When the time-cost parameter, K_2, is relatively large, the total cost increases quite rapidly for higher values of x. This is reflected in the marginal cost which increases much faster than total cost. If it is permissible, it is reasonable to expect a library to discard an item before it has exhausted all of its potential usage in order to avoid the extremely high cost of continuing to hold the item indefinitely. In practice, it is more common for libraries to transfer infrequently used items to depositories unless assured of their availability in some other cooperating library. The experience with depositories has suggested that there is a significant cost associated with the selection and recording of such transfers. Much of this cost might properly be considered as an acquisition cost for the depository collection, although there would be some cost of changing records in the primary collection. The present model is not intended to account for all of the various options which are available to a library, although it could be expanded to include such options.

From the viewpoint of microeconomic analysis, a policy for limiting the retention time of an item and therefore limiting its usage should be based on a consideration of both the costs and the benefits incurred or avoided by the policy. An optimal economic policy should seek to expand service as long as the marginal benefits are of greater value than the marginal costs. If the resources are available, then all services should be expanded to the same point of zero marginal net benefit. If resources are limited, then the service should be expanded to the point where the marginal net benefit is the same for all costs, since, otherwise, the costs could be reallocated so as to increase the total net benefit. In order to apply these optimality principles directly one needs to evaluate the benefits derived from item usage in a manner which is directly comparable to the cost measurements. However, the direct measurement of the economic value of the benefits of information retrieval is an extremely difficult, if not impossible, task, and indirect methods are the only recourse.

An alternative approach to the establishment of storage policies is to choose that retention period which minimizes the average cost of usage. In addition to the practical advantage of being based on the direct measurement of costs only, this policy has economic attributes which recommend it as a near-optimal solution with regard to user benefits, also. There is good reason to suppose that the marginal and average benefits from item usage are relatively constant from the standpoint of anticipating such benefits for the purpose of establishing a policy. Furthermore, average benefits should be at least as great as the average cost in order that the entire venture is not unprofitable. By holding an item to the point where average cost is minimized, there it is an assurance that at least a break-even in the cost-benefit relationship has been achieved. This is a relatively conservative approach to the problem which is not at all unreasonable when there is almost complete ignorance about the relative worth of the benefits derived from item usage.

There is a well-established economic thesis which holds that the long-term tendency in competitive production is for the producers to be driven to the point of zero net profit, that is, where average cost equals average revenue. While the situation in information storage is not directly analogous, it seems to be quite similar in that there are usually alternative information sources available to the user, and these alternatives will be exercised as long as they can do so at less cost. The competitive interaction of users and suppliers should tend to match benefits with costs. Another argumant in favor of a minimum average cost policy is that it is a highly practical operational policy for a production or service subsystem to follow, since it motivates local efficiency and technical innovation. For example, it provides a viable guide to the management of a factory in meeting its production goals at minimum cost and for reporting to higher management the factory data they need to establish goals. Standard cost accounding procedures develop average cost figures which become a measure of factory performance.

Minimization of the Average Cost of Usage

A storage policy based on the minimization of the average cost of usage is relatively easy to implement on the basis of cost information alone. Since the average cost achieves a minimum value when it is equal to the marginal cost, a decision rule can be easily obtained by equating equations (15) and (16) and solving for x as follows:

$$\text{Min } \overline{K}(x) \Rightarrow k_1/K_2 = \ln(1 - x) + x/(1 - x) \quad (17)$$

This decision rule is evaluated in Table 1 where the relationship is shown between the parametric ratio (k_1/K_2) and the value of x which minimizes average cost. By referring to equation (3), it is possible to translate this decision rule into the holding times which minimize average cost as follows:

$$\text{Min } \overline{K}(x) \Rightarrow k_1/K_2 = e^{bt} - 1 - bt \quad (18)$$

where b is the obsolescence rate and bt expresses holding time in the number of relaxation intervals. By expressing holding time this way, it is possible to demonstrate the effect of the decision rule on holding time using equation (7). This is done in Table 1.

An approximate version of the decision rule can be obtained by expanding the exponential term in equation (18) and ignoring all but the first three terms in the expansion. This leads to the simpler rule:

$$\text{Min } \overline{K}(x) \Rightarrow t_h = \sqrt{2k_1/bk_2} \quad (19)$$

where t_h denotes a holding time which effects an approximate minimization of the average cost of usage. This version of the decision rule has some intuitive appeal because of its similarity to the economic lot-size formula of inventory theory. The control parameter t_h can be called the "economic holding time" for an information system. It can be seen in Table 1 how t_h tends to overestimate the time required to minimize average cost especially at unusually large values of the ratio (k_1/K_2). Equation (19) implies that the economic holding time will change as the square root of changes in the cost of acquisition and storage or changes in the obsolescence rate. As the cost of acquisition, k_1, decreases the holding time will decrease, and as the storage cost, k_2, decreases, the holding time is increased. An increase in the obsolescence rate will decrease the holding time and will decrease the total usage obtained from the item since, in equation (17), an increase in b decreases the parameter K_2, which decreases both the ratio (k_1/K_2) and the minimizing value of relative usage, x .

Table 1. Values of Relative Usage, Holding Times, and Costs which Minimize the Average Cost of Usage for an Item

Fraction of Total Life-time Usage x	Holding Time (relaxation intervals) bt	Ratio of Cost Parameters k_1/K_2	Economic Holding Time as Computed from Equation (19) $bt_h = \sqrt{2k_1/K_2}$
0.1	0.11	0.01	0.11
0.2	0.22	0.03	0.23
0.3	0.36	0.07	0.38
0.4	0.51	0.16	0.56
0.5	0.69	0.31	0.78
0.6	0.92	0.58	1.08
0.65	1.05	0.81	1.27
0.70	1.20	1.13	1.50
0.75	1.39	1.61	1.80
0.80	1.61	2.39	2.19
0.85	1.90	3.77	2.75
0.90	2.30	6.70	3.67
0.95	3.00	16.00	5.66
0.99	4.61	94.40	9.72

Concluding Remarks

It is interesting to note that the decision rule establishes the holding time independently of the usage parameter, k_3 . In fact, if only acquisition and time dependent costs are considered, the holding time would be the same. The interesting point is that it is reasonable to argue that almost all of the costs of operating a library can be allocated between these two cost categories, since most of the labor cost in libraries is expended for professional or semi-professional personnel who in many ways represent as much of a system investment as do the purchase price of the materials. Almost all categories of library cost correlate closely with the size of the collection and/or the acquisition rate of new materials. Even the acquisition costs are correlated closely with size, because of the steady exponential growth patterns which are characteristic of large libraries. Some, but certainly a small part, of direct library expense does vary directly with usage, as in the operation of reserve book rooms where items circulate with a very high frequency. If it is valid to consider storage system costs as being represented by the parameters k_1 and k_2 , only, then it would seem worthwhile to consider the cost parameter k_3 as being representative of the cost to the user in obtaining information from the system. Equations (8) or (14) would then represent the combined total cost to both the patron and the storage system for providing uses from an item, and the decision rule would determine the holding time which minimizes the combined average cost per use.

An alternative interpretation would be to consider the user cost, k_3 , as a monetary estimate of the benefit to the user for his effort in using the item, under the assumption that the user chooses among alternative sources in such a way as to eventually equate benefits with costs on the average. Under this interpretation, it would be appropriate to exclude k_3 from the equations and compare the marginal and average costs with the parameter k_3. The decision rule for holding time would be the same, but if it yielded a minimum average cost which is less than k_3, that is, if the benefit/cost ratio is greater than one, there would be an indication that the system is not operating at an optimal level of service and should be expanded beyond the point of minimum average cost. This interpretation seems to be in line with the arguments of R. L. Meier [1961], who found that university libraries were operating in a range where the average cost per unit of service was the same as the average cost to a student patron. However, he also found that the average cost to a faculty patron was much higher than the library cost figure, and that this situation was discouraging faculty patronage. He concluded that libraries should expand their services and absorb more of the faculty usage cost so as to obtain a net increase in total benefit to the university.

The model and policy advocated here and its accompanying speculation have not been fully tested by either analytic methods or by comparison with empirical data. They are offered as an alternative approach to the rational management of large library-type information storage systems. Constructive criticisms are invited. Although this model has been developed in the context of large research libraries, there is no evident reason why its line of argument would not be directly applicable to other types of information storage systems.

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