The problem of the optimal timing of equipment change taking into account the life cycle of information resources

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Abstract. The paper solves the problem of the optimal timing of equipment change in the process of capacity management, taking into account the life cycle of information resources. A simple method for determining the optimal timing for replacing equipment intended for storing and processing information resources is proposed. The purpose of this task is to compare the residual value of equipment in operation and the cost of using it. Since the cost of equipment falls over time, and the cost of operating it increases, there is a moment in time when the costs begin to exceed the residual value of the equipment, and this moment is considered optimal for the transition to new, more productive equipment. This problem is considered in relation to data storage systems, which are currently implemented mainly in the form of disk systems, but the method used is universal. The method is illustrated by a numerical example for one of the IT organizations. Recommendations for servicing disk storage systems are given. Further prospects for the development of this problem with the improvement of the methodology are outlined.

1. Introduction
Nowadays information technology (IT) has become an integral part of any activity. In some cases, it plays a supporting role, in others it is the basis of the business. An independent direction of management has been formed - information technology service management (ITSM).

One of the processes implemented in IT management is the so-called Capacity Management [1]. The goal of the capacity management process is to provide the necessary processing and storage capacity at the right time and in a cost-effective manner, ensuring an appropriate balance of capacity in the IT organization. In the process of capacity management, the management of information resources plays an important role, which serve as the basis for the creation of information products and the provision of information services. The value of the information contained in a particular information resource may be different. Information resource is born, lives and dies, like everything else. So, we can talk about the life cycle of an information resource, including an electronic one. This, of course, also applies to the equipment of IT organizations.

A major contribution to the development of information theory and information management belongs to C. Shannon, J. Pierce, R. Fisher, N. Wiener, L. Brillouin, A. Kolmogorov. In the works of G.A. Dorrer, G.M. Rudakova, E.M. Gritsenko [2,3,4] considered the life cycle of educational EIR. The authors solve the problems associated with increasing the efficiency of search, transmission and analysis of information. The problem of the IR structure optimizing allowed us to reduce the current costs associated with servicing information resources.
Earlier, a mathematical model of the life cycle of information resources based on the Markov chain formalism was proposed [5,6]. The mathematical methods of Markov chains allow one to evaluate many characteristics of information processes in systems, such as the probable time of completion of certain stages of work, mean time between failures, average productivity, and others.

In [7], using the program "Life Cycle of Information Resources", an analysis of the utilization of disk equipment is provided, based on the data obtained, it is possible to select the equipment that is optimal in terms of price, volume and speed of access.

The considered works do not solve the problem of the optimal timing of equipment change in the process of capacity management, taking into account the life cycle of information resources.

Based on the results of [5,6,7], it is possible to formulate the problem of efficient use and replacement of capacities for processing and storing data. The purpose of this task is to compare the residual value of equipment in operation and the cost of using it. Since the cost of equipment falls over time, and the cost of operating it increases, there is a moment in time when the costs begin to exceed the residual value of the equipment, and this moment is considered optimal for the transition to new, more productive equipment. This problem is considered in relation to data storage systems, which are currently implemented mainly in the form of disk systems, but the method used is universal.

2. Methods
In this paper, the following assumptions are made.

1. Information resources are classified in accordance with the Dublin Core Metadata Element Set (DCMI) [8].
2. In accordance with the classification of business processes developed by the American Productivity & Quality Center, the following business processes for the management of IR are identified [9], which we consider as stages of the IR life cycle during its existence:
   - creation,
   - storage,
   - processing (ordering, searching, changing and updating),
   - archiving,
   - destruction.

3. During the life cycle, the relevance of the information contained in the information resource changes. From this point of view, information can be classified as critical, important and unimportant [9].

   As a rule, the relevance of information decreases over time, therefore, the specified classes of relevance occur sequentially.

   Let there be a set of information resources $R = \{ R_i \}$, where $i = 1,...,n$ – the type of IR according to the DCMI classification, $j = 1,2,3$ – the degree of relevance of the resource; at the same time $j = 1$ corresponds to resources of critical importance, $j = 2$ to important resources, and $j = 3$ to unimportant resources.

   Each resource enters the information system and goes through its entire life cycle.

   Consider a newly created information system. Then the total volume of stored $U_j(t)$ resources at the initial moment $t_0 = 0$ will be $U_{j0} = 0$ Mbytes respectively, $j = 1,2,3$. Consider the forecast of these values for the period from $t_0$ to $t_F$, where $t_F$ is the forecasting horizon, months. As you know, the volume of resources received and stored in IT organizations is growing very quickly. According to various sources, this growth is exponential with a positive indicator. The cost of storing and processing resources also increases in proportion to their volume, or even faster, taking into account inflation and the complication of these processes. Thus, the cost of storing and processing IRs of the $j$ type, depending on time, can be represented as
\[ C_j(t) = c_j(t)U_j(t) = k_j(\exp(\mu_j t) - 1). \]  

Here
\( C_j(t) \) - cost of storing and processing all resources, RUB,
\( c_j(t) \) - cost of storing and processing a resource unit, RUB/MB,
\( U_j(t) \) - amount of stored resources, MB,
\( k_j \) - the cost of services, RUB,
\( \mu_j \) - the rate of resources entering the system is 1/month.

Let’s now consider the dynamics of changes in the cost of equipment. As already noted, with the current level of information technology, these are usually disk arrays and equipment serving them. The cost of equipment decreases as it is used due to physical and moral deterioration.

The dependence describing the loss of the cost of equipment serving resources of the \( x \) type can be described by the expression
\[ \phi_j(t) = A_{0j} - A_{0j}\exp(-\lambda_j t) = A_{0j}(1 - \exp(-\lambda_j t)), \]  

where \( A_{0j} \) - initial cost of equipment. RUB,
\( A_{0j}\exp(-\lambda_j t) \) - the residual cost of the equipment,
\( \lambda_j \) - the rate of decrease of the equipment cost, 1/month.

Thus, at time \( t \), the total cost of equipment for resources of the \( w \) type becomes equal to
\[ G_j(t) = C_j(t) + \phi_j(t) = k_j(\exp(\mu_j t) - 1) + A_{0j}(1 - \exp(-\lambda_j t)). \]  

In accordance with the classical theory of equipment replacement [10], the most adequate indicator is the average monthly cost calculated for the period from the beginning of the system operation to the current moment. Thus, we arrive at the indicator
\[ \gamma_j(t) = \frac{G_j(t)}{t} = \frac{C_j(t) + \phi_j(t)}{t} = \frac{k_j(\exp(\mu_j t) - 1) + A_{0j}(1 - \exp(-\lambda_j t))}{t}, \]  

where \( \gamma_j(t) \) - the average cost of the system, calculated for the period \( t \) RUB/month.

When deciding on the moment of equipment replacement, it is natural to choose the moment \( t^* \), when the indicator \( \gamma_j(t^*) \) will reach a minimum.

The moment \( t^* \) can be determined numerically by solving the one-criterion optimization problem \( t^* = \arg \min \gamma_j(t) \), or, in the simplest case, by calculating the values of the function \( \gamma_j(t) \) with a certain time step and choosing the minimum point.

However, a more general approach is also possible. Equating to zero the derivative of the function \( \gamma_j(t) \), we obtain the expression
\[ \frac{d\gamma_j}{dt} = \left(\frac{k_j(\mu_j(\exp(\mu_j t))) \lambda_j(\exp(-\lambda_j t)))}{t^2} - \left[\frac{k_j(\exp(\mu_j t) - 1) + A_{0j}(1 - \exp(-\lambda_j t))]}{t^2}\right] = 0 \]  

This expression vanishes when the numerator is zero. After some transformations, condition (5) can be written as
\[
\frac{1 - \exp(-\lambda_j t)(1 + \lambda_j t)}{1 - \exp(\mu_j t)(1 - \mu_j t)} = \frac{k_j}{A_{0j}}.
\]  

Relation (4.6) depends on two parameters: \( \frac{k_j}{A_{0j}} \) and \( \frac{\lambda_j}{\mu_j} \), and for them, you can build a nomogram, which determines the value \( t^* \).

When accounting for inflation, calculations become more complicated, but the general idea remains the same.

3. Results
Earlier studies of the dynamics of information resources, which were carried out according to the data of the IT department of one of the municipal institutions of the city of Krasnoyarsk using the program "Life cycle of information resources", showed that the main load falls on the hard drives of archival storage [11]. Equipment with a high access speed is used regularly, but the amount of information processed on this equipment is not so large. Equipment with an average access speed is used least of all. In addition, the analysis of the dynamics of resources over a number of years in combination with expert estimates made it possible to estimate the parameters of the model for all relevance classes. Based on this, we will calculate the optimal time for changing equipment with high, medium, and low access speeds. The following metrics are calculated for each relevance class.

\( C = k(\exp^{\lambda t} - 1) \) – cost of storing and processing IR on a certain type of equipment, RUB, \( \phi = A_{0j}(1 - \exp^{-\mu t}) \) – the residual cost of the equipment; RUB, \( G = C + \phi \) – total cost of equipment, RUB, \( \gamma = \frac{C + \phi}{t} \) – the average cost of the system, calculated for the period \( t \) of RUB/month.

All calculations were performed for the time interval \( t = 1, \ldots, 60 \) with a step of 1 month. Qualitatively, the graphs for all types of resources are identical.

For high-speed equipment and processing, respectively, resources of high relevance \( (j = 1) \) the following indicators are accepted.

The initial cost of equipment \( A_{0j} = 95000 \) rubles, the service price \( k_j = 2700 \) rubles, the intensity of resources entering the system \( \mu_j = 0.065 \) 1/month, the rate of cost reduction \( \lambda_j = 0.03 \) 1/month.

![Figure 1. Function graphs \( C_1(t), \phi_1(t) \) and \( G_1(t) \).](image-url)
The calculated graph of the values $C_1(t), \varphi_1(t)$ and $G_1(t)$ is shown in figure 1, and the graph of the average cost $\gamma_1(t)$ is shown in figure 2.

For medium-speed equipment and processing of important resources ($j = 2$), the following indicators are accepted: $A_{02} = 60,000$ rubles, $k_2 = 2000$ rubles, $\mu_2 = 0.055$ 1/month, $\lambda_2 = 0.03$ 1/month.
The calculated graphs of the values \( C_{2,3}(t), \varphi_{2,3}(t) \) and \( G_{2,3}(t) \) are shown in figures 3 and 5, and the graphs of the average cost price \( \gamma_{2,3}(t) \) are shown in figures 4 and 6.

For low-speed equipment and processing of unimportant resources, the following indicators are taken: \( A_{03} = 45000 \) rubles, \( k_{3} = 1500 \) rubles, \( \mu_{3} = 0.08 \) l/month, \( \lambda_{3} = 0.03 \) l/month.

Analyzing the minimum values on the graphs shown in figures 2, 4, 6, it can be seen that the optimal terms for replacing equipment \( t_{j}^* = \arg \min \gamma_{j}(t), j = 1,2,3 \) are, respectively, \( t_{1}^* = 30 \) months, \( t_{2}^* = 35 \) months, \( t_{3}^* = 25 \) months.

4. Discussion
For \( j = 1 \), a disk array based on level 10 RAID technology is optimal. RAID 10 is a mirrored and striped disk array. It is a RAID 0 array of multiple RAID 1 arrays. RAID 10 has the highest performance and reliability, with 50% disk space utilization required to handle high resource availability.
Due to the fact that hardware with an average access speed of $j = 2$ is used the least, the RAID 5 disk array is suitable, which is widely used in real business tasks. A typical scenario is to use servers in the area of data storage for user applications and transaction execution. It is recommended to use it in data storage systems primarily for unimportant information with a small load on disks, for example, in video surveillance systems.

Since the main load falls on the archival storage disks $j = 3$, maximum information reliability is required, therefore it is optimal to use RAID 1, because it has high reliability and works as long as at least one disk in the array is functioning. The most common scenario is mirroring the two system drives of servers.

5. Conclusion
A simple method is proposed for determining the optimal timing for replacing equipment intended for storing and processing information resources. The technique is illustrated with a numerical example for one of the IT organizations.

According to experts, the obtained values are consistent with the actual policy of the IT organization. In fact, with the intense work of information systems, modernization or replacement of disk arrays is carried out in 2 - 3 years. In this case, the longest period of operation without replacement (about 3 years) is obtained for equipment with an average access speed. The proposed calculation method allows us to clarify these terms. The further development of this work is associated, firstly, with the improvement of the methodology for assessing the parameters of the model, and secondly, taking into account the discount rate of funds.

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