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COST MANAGEMENT IN OPEN INFORMATION SYSTEM DEVELOPMENT FOR AN INDUSTRIAL ENTERPRISE *

The problem of synergetic openness management at an industrial enterprise information system (IS) at design and development stages is examined. Analytical solution to the problem was proposed allowing IT companies manage the costs of creating an enterprise IS with specific characteristics of synergetic openness. It is shown that optimal cost distribution over time results in timely development of IS with required performance characteristics.

Keywords: *open information system; design and development stage; cost management.*

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УПРАВЛІННЯ ВИТРАТАМИ ПРИ РОЗРОБЦІ ВІДКРИТОЇ ІНФОРМАЦІЙНОЇ СИСТЕМИ ПРОМИСЛОВОГО ПІДПРИЄМСТВА

У статті розглянуто задачу управління синергетичною відкритістю інформаційної системи (ІС) промислового підприємства на етапах її проектування та розробки. Отримано аналітичне рішення поставленої задачі, що надає можливість ІТ-компанії керувати витратами при створенні ІС підприємства із заданими характеристиками синергетичної відкритості. Продемонстровано, що оптимальний розподіл витрат у часі дозволяє вкластися в задані строки розробки та отримати на виході ІС з необхідними експлуатаційними характеристиками.

Ключові слова: *відкрита інформаційна система; стадія проектування та розробки; управління витратами.*

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УПРАВЛЕНИЕ ЗАТРАТАМИ ПРИ РАЗРАБОТКЕ ОТКРЫТОЙ ИНФОРМАЦИОННОЙ СИСТЕМЫ ПРОМЫШЛЕННОГО ПРЕДПРИЯТИЯ

В статье рассмотрена задача управления синергетической открытостью информационной системы (ИС) промышленного предприятия на этапах ее проектирования и разработки. Получено аналитическое решение поставленной задачи, предоставляющее возможность ИТ-компании управлять затратами при создании ИС предприятия с заданными характеристиками синергетической открытости. Показано, что оптимальное распределение затрат по времени позволяет уложиться в заданные сроки разработки и получить на выходе ИС с требуемыми эксплуатационными характеристиками.

Ключевые слова: *открытая информационная система; стадия проектирования и разработки; управление затратами.*

Introduction. Production management information systems (IS) of a contemporary industrial enterprise (ERP systems) must have the necessary set of performance properties, including properties of integrability and adaptability (O'Leary, 2004: 272). A.N. Danilov and V.Y. Stolbov (2015) propose a composite indicator of instrumental

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openness (availability of environment interaction tools) and introduces the concept of IS synergetic openness degree as the system's ability to respond quickly to requests from external users and other information systems (α for this parameter). Using a non-linear convolution to comprehensively evaluate the quality of information system, the degree of IS synergic openness may be defined as (Danilov and Fedoseev, 2015):

$$\alpha = \lambda_1 \lambda_2 \lambda_3 (\mu_1 + \mu_2 + \mu_3 + \mu_4)/4. \tag{1}$$

Here we use the following designations: λ_1 is the degree of integrability at the data level. This parameter can be defined on the expert basis in the range [0,1]; in this case, $\lambda_1 = 0$ if IS does not enable integration with any systems at the data-level, and $\lambda_1 = 1$ if IS enables integration with any systems at the data level. This parameter can be defined through the l_1/L_1 ratio, where l_1 is the number of systems IS can be integrated with at the data level; L_1 is the number of systems used at this enterprise the IS must be integrated with at the data level; λ_2 is the degree of integrability at the level of services that can be defined similarly to λ_1; λ_3 is the degree of integrability at the process level; μ_1 is the degree of modifiability. This parameter can be defined on the expert basis in the range [0,1]; in this case, $\mu_1 = 0$ if IS does not enable modifications, and $\mu_1 = 1$ if IS enables modifications of any of its components. Note that IS must be modified using the system's built-in adjustment (adaptation) means rather than by changing its source code; μ_2 is the degree of mediated implementation. This parameter can be defined on the expert basis in the range [0,1]; in this case, $\mu_2 = 0$ if IS can only be implemented by its developer, and $\mu_2 = 1$ if IS can be implemented by any similar service provider (external or in-house one); μ_3 is the degree of scalability. This parameter can be defined on the expert basis; in this case, μ_3 if IS is not scalable, and $\mu_3 = 1$ if IS is unlimitedly scalable; μ_4 is the degree of cross-platform suitability. This parameter can also be defined on the expert basis; in this case, $\mu_4 = 0$ if IS can be run on a single hardware and software platform only, and $\mu_4 = 1$ if IS can be run on any platform.

Obviously, the degree of instrumental openness of an information system $\alpha_1 = 0$, if at least one of the parameters of the integrability is 0. Otherwise, this order parameter will vary from 0 to 1.

If all the parameters of the information system are equal to 1, the composite indicator will also be 1, indicating the full synergistic openness of the system for a particular industrial enterprise. However, it is obvious that the higher is the degree of instrumental openness, the higher would be its development cost. Therefore, each enterprise now faces a difficult task of choosing the most efficient automated management information system, and IT company encounters the task of creating a software product with predetermined properties at the lowest cost.

Relevance of the study. Papers by various authors dedicate much attention to the issues of open information systems. However, they mainly consider the following issues: management of an open source community depending on complexity, uncertainty and interdependence of tasks to be solved (AlMarzouq et al., 2015; Hadka et al., 2015); management of various open data sources for the development of different subject areas (Mokrane and Parsons, 2014; Wang et al., 2014; Martinez-Garcia et al., 2013); handling issues related to safety of systems, including those consisting of several interacting components (Martinelli and Matteucci, 2012; Shim, 2014; Alekseev, 2015); building high-performance heterogeneous systems, and methods to improve their efficiency (Andrianova et al., 2014; Zhevnerchuk and Nikolaev, 2012). Unfortunately, proper attention is not paid to the issues of cost management at the stages of design and development of open information systems with predetermined performance properties, which emphasizes the relevance of studies in this area.

Problem statement. The process of creation (design and development) of an information system with predetermined properties is considered as the object of management. Within this process, it is important for an IT company (IS developer) to get a software product with necessary characteristics to promote it at markets.

We assume that the process under consideration is divided of time into stages, each of them ends with the description of the condition of the IS to be created by some set of system parameters – the order parameters y_i, $i=\overline{1,m}$. In this case, each order parameter y_i is an aggregating value that determines the desirable condition of the system or its new system property, which is seen as a planned deliverable. One of such order parameters for IS can be the system's synergistic openness (SO), which means the system's ability to respond quickly to external actions, including the requests of the society, customer requirements etc. As noted above, it is important for the IS of an industrial enterprise to have the necessary degree of adaptability (y_1) to particular features of manufacturing process management and to the processes it should maintain. In addition, IS must interact with other information systems of an enterprise. To do so, it must have the necessary degree of integrability (y_2). In this case, according to the proposed evaluation (1), the IS SO is defined as the product of y_1 and y_2, i.e. $\alpha = y_1 \times y_2$.

Obviously, for different IS the parameters y_1 and y_2 may vary and be different between each other by several times. However, the higher is the IS SO, the higher is its ability to respond to external requests and, therefore, the higher is the competitiveness at the IT product market. So, it is important for IT companies not only to be able to assess IS SO, but also to manage the creation of IS with predetermined system properties, optimally allocating their resources at all the stages of design and development.

Let us consider the determination of necessary costs for the development of an IT product with predetermined properties of SO within a predetermined period.

Mathematical statement of the problem. We consider the creation of with predetermined properties of adaptability y^*_1, integrability y^*_2 and synergistic openness α^*. IS is thought to be developed within some period of time, and to provide the properties y_1 we invest funds

$$z_1(t) = k_1 t, \quad t \in [0, T_1], \tag{2}$$

and properties y_2:

$$z_2(t) = k_2 t, \quad t \in [0, T_2], \tag{3}$$

where k_1, k_2 are the coefficients describing the rate of investment; T_1 and T_2 are the moments of these investments.

In this case, investment of money z_1 and z_2 is thought to be made simultaneously or with a delay for some time τ. In the latter case, money is first invested in the development of a part of the elements of the system adaptability, and then in the development of all the remaining elements of IS (Figure 1).

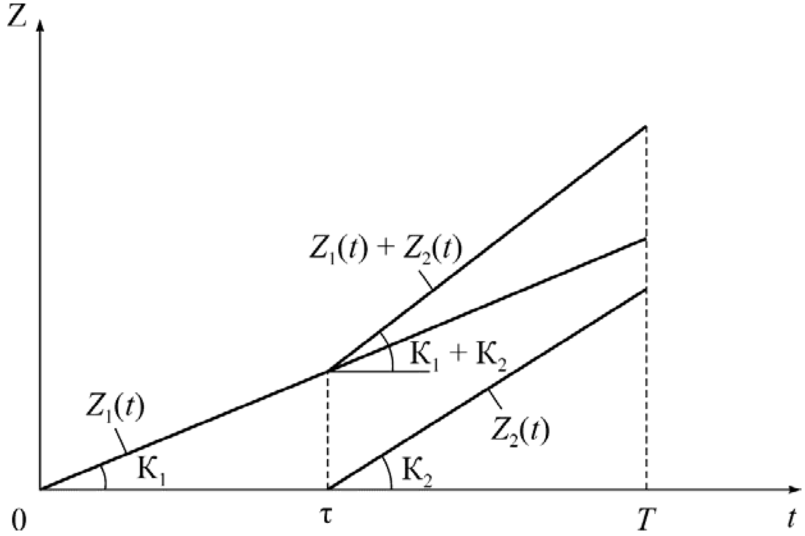

Figure 1. **Growth of costs for IS creation,** *developed by the authors*

The function of time consumption is as follows:

$$z(t)=\begin{cases} k_1 t, & 0 \le t \le \tau \\ (k_1+k_2)t, & \tau \le t \le T \end{cases}. \quad (3)$$

Obviously, the costs at time T are:

$$z(T)=k_1 T + k_2(T-\tau). \quad (4)$$

We want such minimum time T and necessary costs $z(T)$ to have the predetermined system properties, i.e.:

$$y_1(T) \ge y_1^*;\ y_2(T) \ge y_2^*;\ \alpha(T) \ge \alpha^*. \quad (5)$$

Solution of the problem. In solving this problem, we assume that the growth of IS's system property $y_1(t)$ is described by the following model:

$$\begin{cases} \dfrac{dy_1}{dt} = k_3 \dfrac{dz_1}{dt} - k_4 y_1, & t \ge 0 \\ y_1(0) = y_{10},\ k_3, & k_4 > 0, \end{cases} \quad (6)$$

where k_3 is the coefficient describing how efficiently the work of an IT company is organized; k_4 is the coefficient describing the "obsolescence" rate of adaptation elements in IS to be created.

Upon integrating (2), we obtain

$$y_1(t) = \frac{k_1 k_3}{k_4} + \left(y_{10} - \frac{k_1 k_3}{k_4} \right) e^{-k_4 t},\ \ t \ge 0. \quad (7)$$

Assuming $y_{10} = 0$ (IS is created "from the scratch"), we get

$$y_1(t) = \frac{k_1 k_3}{k_4}(1 - e^{-k_4 t}), t \geq 0. \tag{8}$$

Defining the minimum time T_1 at which the condition is met $y_1(T_1) = y^*_1$. Using the solution (3), we get:

$$y_1(T_1) = \frac{k_1 k_3}{k_4}\left(1 - e^{-k_4 T_1}\right) = y_1^*. \tag{9}$$

Therefore:

$$T_1 = \frac{1}{k_4}\ln\left(1 / \left(1 - \frac{k_4}{k_1 k_3} y_1^*\right)\right). \tag{10}$$

The solutions obtained suggest that the growth of the system property y_1 to the predetermined value y^*_1 is described by an exponential function, the form of which is shown in Figure 2. Knowing the required development time T_1, it is easy to determine the necessary costs to achieve the predetermined parameter y^*_1:

$$z_1(T_1) = k_1 T_1. \tag{11}$$

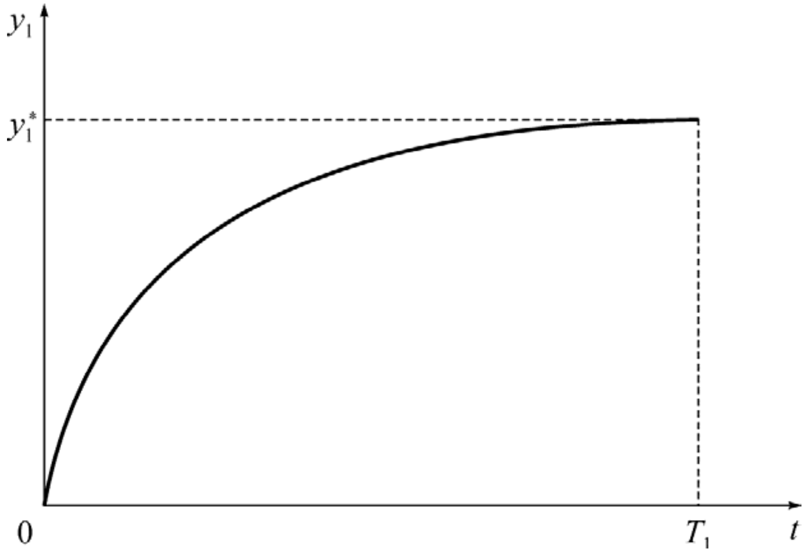

Figure 2. **The y_1 vs. development time dependence,** *developed by the authors*

We now turn to the system parameter $y_2(t)$, the growth of which will be described by the following model:

$$\begin{cases} \dfrac{dy_2}{dt} = \dfrac{dz_2}{dt} y_2(1 - y_2), & t \geq 0 \\ y_2(0) = y_{20}, & z_2(t) = k_2(t) \end{cases}. \tag{12}$$

It should be noted that, unlike the growth model of y_1, this makes allowance for the accumulation effect, which is typical for the integrated IS. The closer is the value of y_2 to the maximum value (in this case – 1), the slower is the process of developing necessary integration elements.

Upon integrating (6), we obtain

$$y_2(t) = y_{20} / \left(y_{20} + (1 - y_{20})e^{-k_2 t}\right), \quad t \geq 0. \tag{13}$$

The function (7) is given by the logistic curve (Figure 3), which has typically an initial plateau of the accumulation of information components of the system integration, after which there is a sharp increase in the growth rate of y_2.

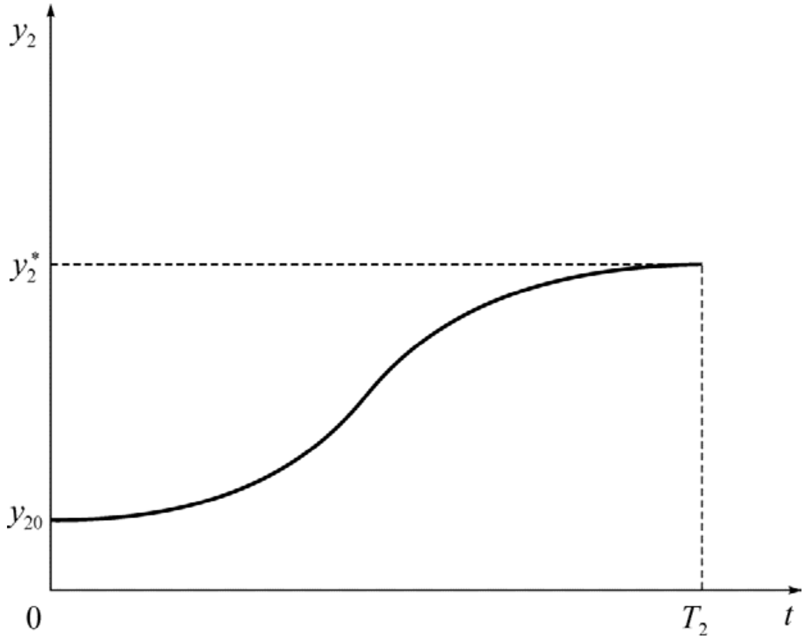

Figure 3. **The y_2 vs. development time dependence,** *developed by the authors*

Let us determine the minimum time T_2 with which the system property y_2 reaches the predetermined value y^*_2*. Using (7), we obtain:

$$y_2(T_2) = y_{20} / \left(y_{20} + (1 - y_{20})e^{-k_2 T_2}\right) = y_2^*. \tag{14}$$

Therefore:

$$T_2 = \frac{1}{k_2} \ln \frac{(1 - y_{20}) y_2^*}{y_{20}(1 - y_2^*)}. \tag{15}$$

It should be noted that in (8) $y_{20} \neq 0,$ as following the development of IS at the previous stage $[0,\tau]$, the system acquired some set of information components required for integration with other ISs. However, the value y_{20} is usually small and does not exceed 0.1.

Using the obtained dependencies, the creation of IS with the predetermined properties y^*_1, y^*_2 and α^* can be represented as shown in Figure 4. Apparently, the minimum time for creating IS with the predetermined properties is defined as:

$$T = \max(T_1, \tau + T_2). \quad (16)$$

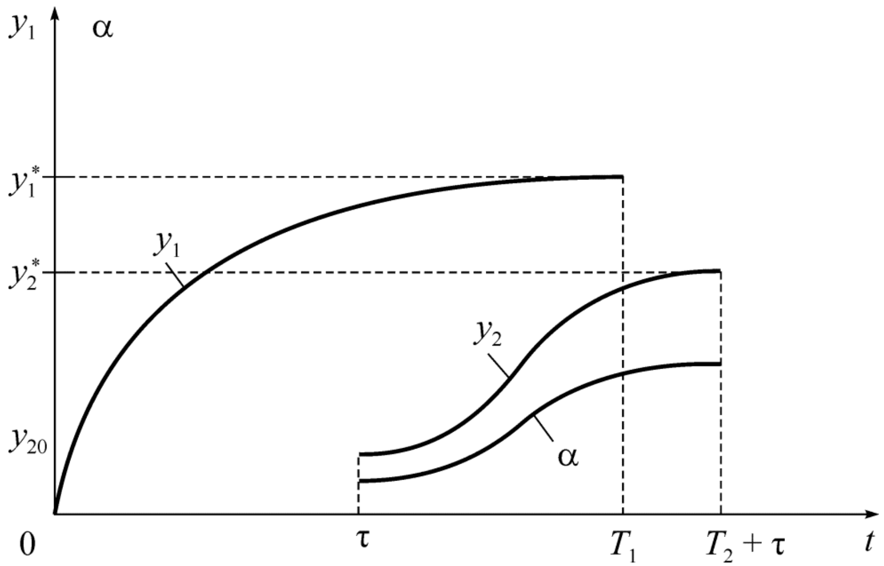

Figure 4. y_1, y_2 **and** α **vs. development time dependencies,**
developed by the authors

In this case, the total cost of creating IS will be:

$$z(T) = k_1 T_1 + k_2 T_2. \quad (17)$$

Hence, if the times T_1 and $T_2 + \tau$ are different significantly, it leads to an increase in the development time T. Therefore, IT companies usually seek to reduce T by controlling parameters k_1, k_2 and τ.

As a working example, let us consider the creation of ERP system by an IT company. In the development of IS, we used the following initial data corresponding to the capabilities of the company: $k_1 = k_2 = 1$ mln conventional units/month; $k_3 = 0.2$ mln conventional units/month; $k_4 = 0.1$ mln conventional units/month.

The properties of the ERP system being created were affected by the following conditions:

$$y_1^* \geq 0.8; \quad y_{10} = 0; \quad y_2^* \geq 0.6; \quad y_{20} = 0.1. \quad (18)$$

Let us define the development time and necessary costs for creating the IS.

According to (4), we determine the time required to create the necessary components to adapt the IS:

$$T_1 = \frac{1}{k_4} \ln\left(1/\left(1 - \frac{k_4}{k_1 k_3} y_1^*\right)\right) = \frac{1}{0.1} \ln\left(1/1 - \frac{0.1}{1 \times 0.2} \times 0.8\right) \approx 7 \text{ months.} \quad (19)$$

Using (8), we can determine the necessary time for creating the components of the 2nd system property of IS:

$$T_2 = \frac{1}{k_2} \ln \frac{(1 - y_{20}) y_2^*}{y_{20}(1 - y_2^*)} = \frac{1}{1} \ln \frac{(1 - 0.1) \times 0.6}{0.1 \times (1 - 0.6)} \approx 2.5 \text{ months.} \quad (20)$$

In this case, the delay time (τ) can be taken equal to 4.5 months. Then, the total time for creating IS with predetermined properties will be $T = 7$ months and the total costs will be:

$$z(T) = k_1T_1 + k_2T_2 = 1\times7 + 1\times2.5 = 9.5 \text{ mln conventional units.} \quad (21)$$

In this case, time distribution of costs takes the form as shown in Figure 5.

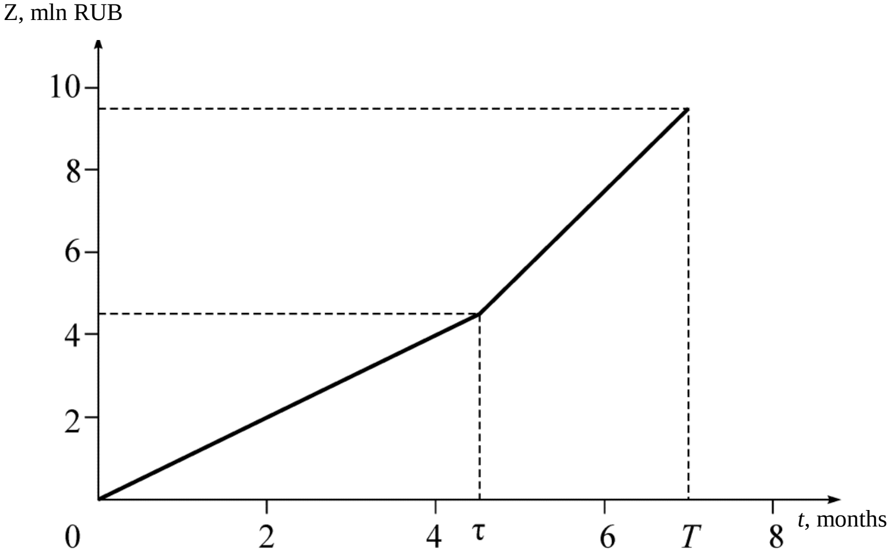

Figure 5. **Growth of costs for developing IS,** *developed by the authors*

It should be noted that, in practice, it is often necessary to complete the project related to IS development within some predetermined period of time. This requires the optimization problem for resource allocation to be formulated and solved for the project to meet a deadline.

Let it be required to create an ERP system for some industrial enterprise with predetermined properties of synergetic openness y^*_1, y^*_2 and α^* within a determined period of T.

In the above denotations, this management problem can be formulated as follows: to find such optimum parameters k^*_1, k^*_2 and τ^*, at which $T = T_2 + \tau^* = T$ and the restrictions on performance properties of IS are met: $y_1(T) = y^*_1 = 0.8$; $y_2(T) = y^*_2 = 0.6$.

In this case, the remaining parameters of IS and the IT company involved in development of the ERP system remain the same:

$$y_{10} = 0;\ y_{20} = y_{20}(\tau^*) = 0.1;\ k_3 = 0.2;\ k_4 = 0.1. \quad (22)$$

The total time for creating the IS is predetermined and is equal to $T = 6$ months, and the period of delay τ^* cannot be less than 2 months, i.e., $\tau^* \geq 2$.

Using (4) obtained above and the new restriction $T_1 = T$, we can get:

$$T_1 = \frac{1}{k_4}\ln\left(\frac{1}{\left(1-\frac{k_4}{k_1^* k_3}y_1^*\right)}\right) = T. \quad (23)$$

This allows finding the optimal parameter k^*_1, which describes the rate of investment at which the condition $y_1(T) = y^*_1$ is met within the required time T.

$$k_1^* = \frac{k_4}{k_3}y_1^* / \left(1-e^{-k_4T}\right) \quad (24)$$

Similarly, using the solution (8) and the condition for the time of development $T_2 + \tau^* = T$, we can obtain:

$$k_2^* = \frac{1}{T-\tau^*}\ln\frac{(1-y_{20})y_2^*}{y_{20}(1-y_2^*)}. \quad (25)$$

Based on the conditions of the problem, we assume $\tau^* = 2$ months.

Substituting other initial data in to (12) and (13), we obtain:

$$k_1^* = \frac{0.1}{0.2}\times 0{,}8 / \left(1-e^{-0.1\times 6}\right) \approx 1.2 \text{ mln conventional units/month}; \quad (26)$$

$$k_2^* = \frac{1}{6-2}\ln\frac{0.9\times 0.6}{0.1\times 0{,}4} \approx 0.6 \text{ mln conventional units/month}. \quad (27)$$

As expected, if compared with the solution of the previous problem, the rate of investment into achievement of the first system property in the IS to be created has increased by 0.2 mln conventional units per month since the development time was reduced by 1 month, and the rate of investment into achievement of the 2nd system property was reduced almost by 2 times since the time allocated was increased from 2.5 to 4 months. In this case, the total time for completing the project will be equal to 6 months.

The obtained solution is shown in Figures 6–7.

The presented results suggest that an ERP system with predetermined synergistic properties can be developed within the required period, investing in project under development being performed almost uniformly, which is usually favorable for company-developer.

It should be noted that further reduction of project implementation time will require not only a sharp increase in money investments, but also different organization of the IT company's work, which is described by the process model parameters k_3, k_4, and y_{20}.

The proposed model for managing the development of ERP systems for a number of industrial enterprises was introduced in the IT company "Gelikon Pro", and it enabled improving the efficiency of work planning during the creation of ERP systems with required synergistic properties and reducing the total costs for projects implementation.

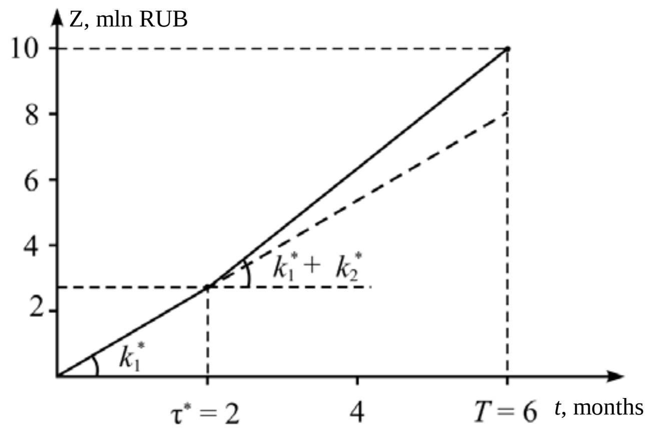

Figure 6. **Distribution of costs for creating IS,** *developed by the authors*

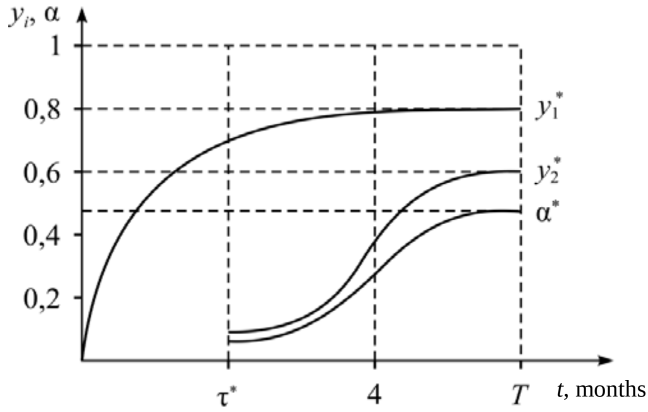

Figure 7. **IS synergic openness parameters vs. development time dependence,** *developed by the authors*

Conclusion. We introduced the concept of information system (IS) synergetic openness as its ability to respond quickly to the needs of external and internal consumers. It is noted that the instrumental component of the IS synergic openness is implemented at the IS design and development stage.

The paper offers a composite indicator of the efficiency of production management information systems (ERP systems), the synergetic degree of system's openness being used as this composite indicator. This indicator makes allowance for the degree of integrability and adaptability of the system taking into account the requirements of industrial companies.

The paper sets a problem of managing the IS synergic openness during the design and development of IS with predetermined properties. We obtained an analytical solution to this problem, thus enabling the IT company manage its costs while creating the IS with predetermined characteristics of synergic openness.

Optimum time distribution of costs allows meeting the predetermined deadlines for the development of IS with required performance characteristics.

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