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New Realities of the Enterprise Management System Information Support: Economic and Mathematical Models and Cloud Technologies

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Abstract

The paper focuses on the urgency of the implementation of cloud technologies, which are a necessary condition for the development of enterprise management systems, give rise to a complex of insufficiently studied phenomena and processes and determine the need to find new tools in making and implementing reasonable management decisions. In the process of research, the sequence of construction and the overall structure of the enterprise management system, based on the use of cloud technologies, are determined, which allowed to build a mathematical model for calculating the probability of making an error-free decision, evaluating the efficiency of decision-making, a model of making a management decision for a certain time with the parallel method of operation of elements of the enterprise management system.

Keywords: Computer technologies, management information systems, management decisions, economic and mathematical modeling, cloud technologies.

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Introduction

The rapid development of scientific and technological progress, increasing the level of computerization, and intellectualization of economic processes are considered to be widely recognized trends in the development of solidarity information economy (Matviychuk, 2011; Mehta, 2008; Piskunova, 2010). Therefore, an important factor for an enterprise to achieve success in competition is its ability to organize activities using the latest information and communication technologies and related software (Andrikopoulos, 2013; Voynarenko, et al., 2016).

These circumstances determine the need to solve the problem of improving the economic efficiency of existing and developed information systems of subjects of economic activity, as well as the quality of their adaptation to the needs of the functioning of specific enterprises. It is important to take into account the circumstances that in the implementation of projects for the development and maintenance of systems, including software and computer and telecommunication equipment, it is possible to use different types of technologies and software to manage social-economic systems, changes in their development and prompt reasonable management decision making (Hryhorkiv, et al., 2017; Khajeh-Hosseini, 2011; Low). Modern approaches to the design and implementation of IT projects, as well as the tools of their team development and integrated approach in use, make possible the process of project implementation based on procedures for the distribution of works or business functions between a large number of highly specialized, highly qualified geographically distributed contractors, which allows using the most modern technological solutions for minimizing business costs (Mehta, et al., 2008; Sokolovskaya, et al., 2016; Ada). Cloud technologies, as a type of digital technology, particularly, enhance management. The idea that cloud-based software can be used by business, as mentioned in 1961 by scientist John McCarthy (Voynarenko, 2018; Epiphanes, 2008), at first the term "cloud technologies" was offered by President of Google Eric Schmidt in 2006, when the program Salesforce.com became the first "cloud" customer relationship management service (Kolyada, 2011).

In the initial stages of implementation, Saas services were not widely used, but during 2013–2016, a revolutionary "global migration" in cloud technology took place, that is, from virtualization, the world economy gradually transitioned into an "era of clouds" (Andrikopoulos, 2013). This requires every business entity (both large companies and small businesses) to adapt quickly to the requirements of the environment and rebuild their business management systems. The reasoning for the choice of the redevelopment of ways requires appropriate research, use of practical experience in combination with scientific methods and models to reduce risks in the introduction of new technologies and to successfully implement sustainable development strategies.

In economic theory, scientific approaches with the use of optimization methods of modeling of many economic processes have become widely used (Chub, et al, 2017). V.M. Andrienko, I. Yu. Ivchenko, Z.M. Sokolovskaya, and many other scientists consider problems of usage of economic-mathematical modeling in the study of complex economic systems and phenomena (Babenko, et al, 2018; Sokolovskaya, et al., 2016). Studies in the sphere of use of computer technologies in management systems mainly focus on evaluating their effectiveness based on the results of the activity of enterprises (Glushchevsky, 2016), or are carried out from the standpoint of assessing their impact on cost capitalization(Piskunova, 2010), or determining the effect of an IT project realization and calculation of its payback period (Voynarenko, et. al., 2016) etc. However, the problem of finding new ways of using different types of information and digital technologies in management practice, in particular, to make effective management decisions under the conditions of a complex interaction of different components and components of the automated control system, is extremely urgent now. We share the opinion, that economic and mathematical methods (one of which is the Markov process), can act as a constructive tool for the study of complex economic conditions and the sequence of management decision making in automated control systems in enterprises of different industries (Vitlinsky, 2012; Vovk, 2011). This will provide an objective assessment of the effectiveness of alternative solutions, optimize business cost management measures to reduce operating costs, and move to a new level of economic development.

Results and discussion

Social and economic transformations, digitalization, and cloud technologies as key components of economic processes informatization require further development of principles and conceptual provisions of enterprises' management systems functioning. This creates the basis for improving algorithms and optimization in the managerial decision-making, with the use of new tools provided by cloud technologies.

Therefore, the problem of interoperability in managerial decisions, made by the enterprise management system, encompasses teams of specialists, geographically responsible contractors, technical objects and technologies, as well as communication relations between them provided by information flows. Traditional requirements for managerial decision-making remain relevant, among them are: reliable information, quick decision-making, promptness of information transfer, intensification of decision-making processes and cycles, risk reduction and achievement of social and economic effects of the system, taking into account its state (Kolyada, 2011; Piskunova, 2010l Naveed Q.N, 2019).

Based on the above, it should be concluded that the enterprise management system belongs to dynamic systems of the stochastic type. The management process carried out by the system can be formalized as a random sequence of operations to achieve the enterprise's ultimate goal. If we put this sequence in correspondence with the state variables of the control system that arise under the influence of the orderly interaction of technologies, processes, and other elements of the system, then its managerial influence will be a Markov process. This process is characterized by a finite set of states and continuous time, which is conditioned by the system of data collection from remote and tracked objects, technologies of their management, information exchange between objects, redistribution of tasks, and their planning taking into account availability of certain services in the object's coverage area. The control system can solve complex problems that require significant computing resources (for example, real-time video processing when the local wireless network uses cloud computing resources).

Research methods and models

Development of an enterprise management system functioning model in the conditions of cloud technologies

The management patterns determine the most essential links and relationships between various management aspects within the enterprise and with the environment's elements. Theoretical research showed that there is a regular dependence of organizational forms and management methods on the organizational structure of management, material, and technical basis and the level of modern information systems implementation and types of cloud and other technologies.

The process of managing all spheres of enterprise is cyclical and occurs in time and space. It is determined by the conditions of interoperable information systems, which consist of components that make up random information resources (software components, databases, knowledge bases, data files, etc.). The latter interact basing on information sharing.

Thus, the control cycle is characterized by the following main types of determiners: period and information flow. The management cycle duration is determined by the technologies used, their operational modes, the information processing time, development and decision making, and organization of decision implementation. A fundamental model of the management system functioning reflects the generalization of the above (Figure 1).

The model reflects the continuous process of interaction between the management object and the management system as well as the multivariate response of the mentioned object to the decisions made. Once the decision is made, the information field informs the management object of the occurring changes.

The proposed model assumes the development of several mathematical models for probabilistic indicators calculation of the enterprise management system functioning in the use of cloud technologies. Namely, they are probability calculation models of error-free decision-making; decision-making efficiency assessing models; models of decision making for a certain time with a parallel method of enterprise management system elements.

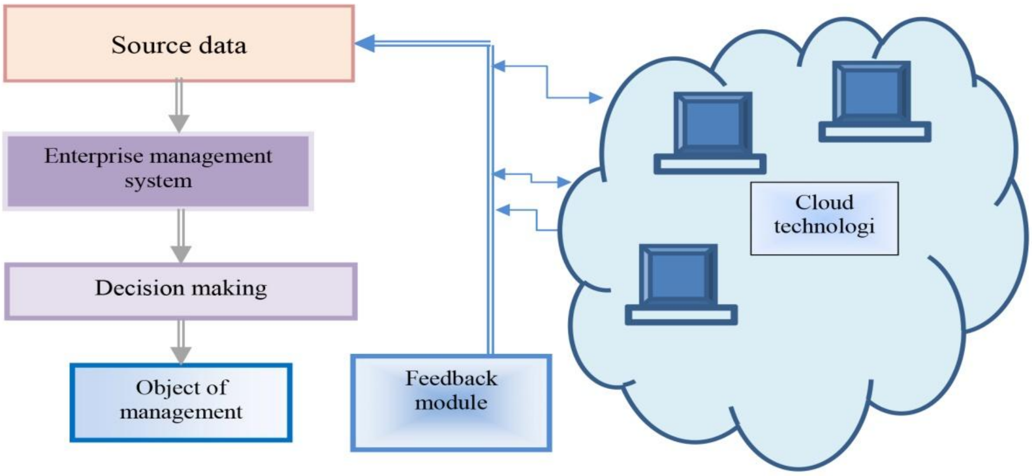

Figure 1. The basic model of the enterprise management system functioning in the use of cloud technologies

Calculation of probabilistic estimation of a successful managerial decision-making efficiency

Due to the properties of the Markov process noted above, the mathematical model of the control function is obtained in the form of two distributions: a discrete distribution of operations performed over a fixed time interval {0, t}; continuous distribution of the fixed number of operations. Using the distributions, you can calculate some indicators that will characterize the effectiveness of management.

To simplify the management function model calculation, we have introduced the following conditions: the number of management operations that provide the final goal is known and equal to n; the operation intensity is constant and remains the same for each operation, λ = const; the first operation execution begins with receiving the information produced by information technology in conventional time ($t_0 = 0$); each subsequent operation begins immediately and only at the moment of the previous operation completion, which allows the mode and conditions for the information technologies functioning and their provision of information exchange; moving to the next operation with an unfinished previous one is impossible.

The end of the i-th operation ($i = 1, 2 \dots n-1$) does not stop the management process. After the n-th operation execution at time $t_n = t$ of interval {0, t} the management process is considered complete. Time distribution τ of performing the i-th operation over a time interval {ti-1; ti} is subject to an exponential law.

$$p_i(\tau) = 1 - e^{-\lambda\tau} \tag{1}$$

where τ is the time of operation, h.; λ is the intensity of operation, 1/h. Figure 2 shows a graph of the control object state. The vertices of the graph correspond to two object states: S0 – operation failed; S1 – an operation performed.

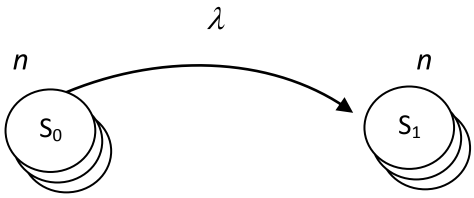

Figure 2. A graph of the control object state

Accordingly, such a control object reflexivity can be shown by *n* arcs according to the number of operations on the graph vertices and by only one arc of transition from S_0 to S_1 state. The Kolmogorov differential equation system for the graph (Figure 3) will have the following form

$$\begin{cases} n\dfrac{dp_0}{dt} = -\lambda p_0 \\ n\dfrac{dp_1}{dt} = -\lambda p_0 \end{cases} \tag{2}$$

Let us integrate system (2) for the initial conditions $p_0(0) = 1$; $p_1(0) = 0$. We receive

$$\begin{cases} p_0(t) = e^{-\frac{\lambda}{n}t} & (3) \\ p_1(t) = 1 - e^{-\frac{\lambda}{n}t} & (4) \end{cases}$$

Received function (3) is a function of time distribution of the management operations sequence non-execution, i.e. the probability that the decision is not fulfilled. Function (4) is an integral function of time distribution of successful execution of all *n* scheduled management operations and characterizes the probability of reaching the end goal. That is, function (4) is a stochastic function of successful control. The final management stochastic function can be written in this form

$$F(n,t) = 1 - e^{-\frac{\lambda}{n}t} \tag{5}$$

where λ is the intensity of operations, 1/h; *n* is the number of operations; *t* is the time of execution of *n* operations, h. As can be seen from the received results, the higher the number of operations, the less the likelihood of processing the operations in full within a certain time, which makes it difficult to make decisions according to the situation. From the obtained model (5) it is possible to calculate the value of mathematical expectation (probability time) of the execution time of all *n* operations by the formula:

$$M_t = \frac{\lambda}{n}\int_0^{\infty} t \cdot e^{-\frac{\lambda}{n}t} dt = \frac{n}{\lambda} \tag{6}$$

where M_t is the probable time of performing *n* operations, h.; *n* is the number of operations; λ is the intensity of operations, 1/h. (according to the level of management systems and technologies development). Dispersion of the execution time of *n* operations is calculated by the formula

$$D_t = \frac{\lambda}{n}\int_0^{\infty} t^2 \cdot e^{-\frac{\lambda}{n}t} dt = \frac{n^2}{\lambda^2} \tag{7}$$

where D_t is the dispersion of the execution time of *n* operations, h.^{2}; *n* is the number of operations; λ is the intensity of operations, 1/h.

For the practical application of the obtained model (4), it is advisable to turn to the inverse function. As a result we obtain

$$t = -\frac{n \cdot \ln(1 - F(n,t))}{\lambda} \tag{8}$$

where t – a sequence of operations' execution time, h.; n is the number of operations; $1 - F(n,t)$ is a set probability of performing operations; λ is the intensity of operations, 1/h. Figure 3 shows the dependence of the standard decision-making time on the determined probability ($\lambda = const$).

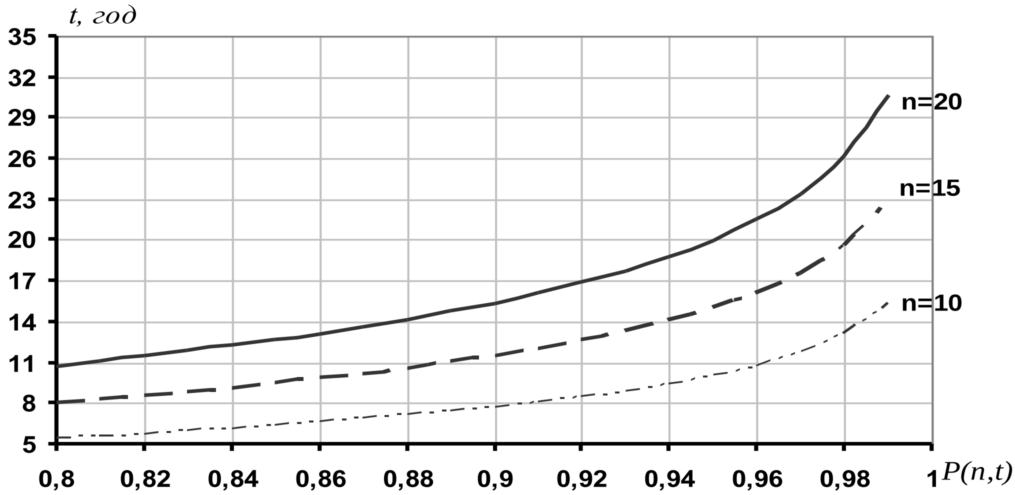

Figure 3. Dependence of the standard decision-making time on the determined probability

The graphical dependence obtained shows that the higher the requirement for the standard decision completeness, the more time it takes. According to the formula (8), it is possible to predict the execution time of operations sequence with a given probability of their execution.

Thus, we have defined the function of successful execution of operations (5) and obtained a formula for calculating the probable time for performing sequential operations with the given probability (8).

In the conditions of a dynamic environment, scientific and technological progress, and economic instability, decision-making efficiency is an important factor in achieving the ultimate goal of a high-tech management system. In calculating the decision-making model efficiency, we used principles and assumptions generally accepted in the theory of probabilities and graph theory, as well as existing principles and methods of enterprise management based on modern cloud technologies. As much as we detail the time spent in the stochastic model that we are calculating, we will limit ourselves to the study of the basic phase states of the decision-making process. This will allow for the most complete consideration of the influence of the basic parameters over time and to obtain simple enough formulas for practical application. Suppose that T is a random time to make a decision, from the initial moment t = 0 is getting information about the situation change (in the external environment) up to the present moment *t* is bringing the solution to the enterprise infrastructure, so that $0 \leq T \leq t$. That is, we consider *T* a random function of the form

$$T = T_1 + T_2 + T_3 + T_4 = \sum_{i=1}^{4} T_i \tag{9}$$

Where T_1 is the random time required to analyze information received, h.; T_2 is the random time needed to assess options, h.; T_3 is the random time required to decide on the main plan and sequence of actions, h.; T_4 is the random time it takes to bring the solution to the executors, h. The constituents of formula (9) are detailed as follows

$$\begin{cases} T_1 = T_{11} + T_{12} + T_{13} + T_{14} \\ T_2 = T_{21} + T_{22} + T_{23} \\ T_3 = T_{31} + T_{32} + T_{33} + T_{34} \\ T_4 = T_{41} + T_{42} + T_{43} \end{cases} \qquad (10)$$

where T_{11} is time to analyze the main goal, h.; T_{12} is time to analyze the place in the external environment (in the system), h.; T_{13} is time to coordinate issues with cooperating businesses, h.; T_{14} is time to organize the ongoing activities of subordinate infrastructures, h.; T_{21} is time to analyze information about competitors' businesses (firms), h.; T_{22} is time to gather more information, h.; T_{23} is time to transfer additional information to higher infrastructure, h.; T_{31} is time to process all information received, h.; T_{32} is time to fully analyze information and develop options for possible events in the external environment, h.; T_{33} is time for comparative analysis of the developed options for possible events in the external environment, h.; T_{34} is time for additional analysis of the remaining options and the choice of alternatives, h.; T_{41} is time for approval of the decision made, h.; T_{42} is time to finalize an agreed (alternative, if needed) optimum decision and make a final decision, h.; T_{43} is time to transfer the final solution to the infrastructure (executors), h. We assume that the time distribution of the constituent phases of the T_{i} decision-making process is subject to exponential law, so that

$$f(t_i) = \lambda_i e^{-\lambda_i t} \qquad (11)$$

Where λ_i is the intensity of decision-making stages T_i, 1/h.; t is a time of decision-making, h. We also introduce the condition that the intensity (λ_i) of decision-making stages (T_i) are different for each stage and are expressed by the average value of their components intensity (T_{ij}) in the form

$$\lambda_i = \frac{n_i}{\sum_{i=1, j=1}^{n,m} \frac{1}{\lambda_{ij}}} \qquad (12)$$

Where n_i is a number of decision-making stages; λ_{ij} – the intensity of the decision-making stage components (T_{ij}), 1/h. Let us consider the option of preparing managerial decision making by the method of parallel operation of the enterprise management system elements, which is ensured by the use of the latest information technologies.

Evaluation of the managerial decision-making efficiency by the method of parallel operation

of the enterprise management system elements

With the parallel method of operation of the enterprise management system elements, a random decision-making process based on a Markov process model can be constructed as a graph of phase states (Figure 4).

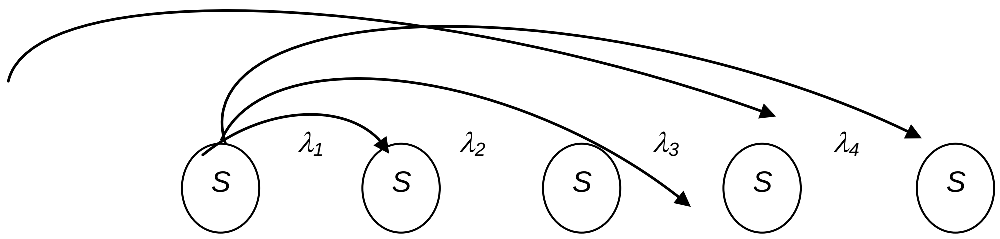

Figure 4. A graph of phase states of the managerial decision-making process stages

By transitivity property graph (Fig. 3) becomes a graph (Fig. 5).

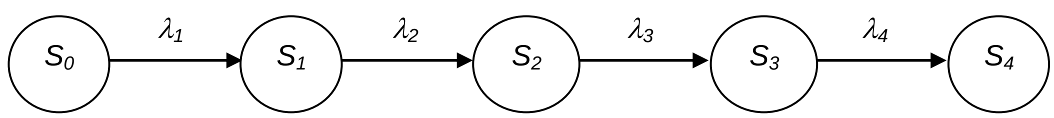

Figure 5. A graph of phase states of the managerial decision-making process stages

In figure 4 and figure 5: S0 – the information is received on changing circumstances, early analysis of information; S1 – the information is analyzed, beginning of the options assessment; S2 – options are assessed, the beginning of management decision making; S3 – the decision is made, the start of bringing it to infrastructures (executors); S4 – the solution is obtained by the infrastructure to carry out.

The system of differential equations of probabilistic states corresponds to the marked state graph

$$\begin{cases} \dfrac{dp_0}{dt} = -\lambda_1 p_0 \\ \dfrac{dp_1}{dt} = \lambda_1 p_0 - \lambda_2 p_1 \\ \dfrac{dp_2}{dt} = \lambda_2 p_1 - \lambda_3 p_2 \\ \dfrac{dp_3}{dt} = \lambda_3 p_2 - \lambda_4 p_3 \\ \dfrac{dp_4}{dt} = \lambda_4 p_3 \end{cases} \quad (13)$$

Equations (13) are integrated sequentially one by one under the initial conditions

$$p_0(0) = 1; \quad p_1(0) = p_2(0) = p_3(0) = p_4(0) \quad (14)$$

where $p_i(0)$ is the probability of the state phases of decision making at t = 0. The system's solution will take the form

$$p_4(t) = 1 + A_1 e^{-\lambda_1 t} - A_2 e^{-\lambda_2 t} + A_3 e^{-\lambda_3 t} - A_4 e^{-\lambda_4 t} \quad (15)$$

Where

$$A_1 = \frac{\lambda_2 \lambda_3 \lambda_4}{(\lambda_1 - \lambda_2)(\lambda_1 - \lambda_3)(\lambda_1 - \lambda_4)} \quad (16)$$

$$A_2 = \frac{\lambda_1 \lambda_3 \lambda_4}{(\lambda_1 - \lambda_2)(\lambda_1 - \lambda_3)(\lambda_1 - \lambda_4)} \quad (17)$$

$$A_3 = \frac{\lambda_2 \lambda_2 \lambda_4}{(\lambda_1 - \lambda_2)(\lambda_1 - \lambda_3)(\lambda_1 - \lambda_4)} \quad (18)$$

$$A_4 = \frac{\lambda_1 \lambda_2 \lambda_3}{(\lambda_1 - \lambda_2)(\lambda_1 - \lambda_3)(\lambda_1 - \lambda_4)} \quad (19)$$

The function $p_4(t)$, p4 (t), which determines the probability of an absorbing state, is nothing more than an integral function of the decision-making time distribution. Generally, the number of phase states (except for the initial one) may be different. This is due to the number of components in formula (9) and the specific problem. For random n (let us replace, as usual, p p by F), formula (15) takes the form

$$F(n,t) = 1 + \sum_{i=1}^{n} (-1)^n \cdot e^{-\lambda_i t} \cdot \frac{\prod_{j=1}^{m} \lambda_j}{\prod_{i \neq j}^{n} (\lambda_i - \lambda_j)} \qquad (20)$$

where n is the number of decision-making phases; λi, λj is the intensity of decision-making stages, 1/h.; t is a time of decision-making, h.

From the obtained formula (2.20) the mathematical expectation (average value) of the time of managerial decision-making is calculated. The mathematical expectation is calculated by the formula

$$M_t = \int_0^\infty t \cdot f(n,t) dt = \sum_{i=1}^{n} \frac{1}{\lambda_i} \qquad (21)$$

where Mt is the probable average value of decision-making time, h.; λi is the intensity of decision-making stages, 1/h.

In our case (for formula (9)) the probable average value of decision-making time is calculated by the formula (according to formula (21)

$$M_t = \frac{1}{\lambda_1} + \frac{1}{\lambda_2} + \frac{1}{\lambda_3} + \frac{1}{\lambda_4} \qquad (22)$$

$\lambda_{i\ i}$ is the intensity of decision-making stages, 1/h.

The obtained formula (20) allows us to calculate the probability of an event, which is in that the random decision-making time (*T*) will not occur before a predetermined value (*t*), i.e.

$$F(n,t) = P(T \leq t) \qquad (23)$$

Provided that $\lambda = \lambda_j = const$ (λ_i are equal), formula (2.20) becomes (a partial case)

$$F(n,t) = 1 - e^{-\lambda t} \cdot \sum_{i=1}^{n-1} \frac{(\lambda t)^n}{n!} \qquad (24)$$

In this case, the mathematical expectation of the managerial decision-making time will take the form

$$M_t = \frac{n}{\lambda} \tag{25}$$

Thus, according to the formulas (20) and (24), the probability of managerial decision-making for a certain time by the method of parallel operation of the enterprise management system elements is calculated.

Practical aspects of the usage of cloud technologies in the enterprise activity management system

Practical aspects of the usage of cloud technologies in the enterprise activity management system are based both on theoretical studies and expert evaluation of the results of the enterprises' activity obtained from the introduction of the latest systems. In particular, the use of cloud technologies provides the tools to combine the extensive capabilities of managing computing resources (if this function is necessary for the user) with cost savings in maintaining the physical and hardware infrastructure of the information and computing system.

For users, the benefits of using cloud services are the ability to obtain the necessary service on terms that are personally defined by them in the context of interaction with the components of the cloud environment system (Figure 6) (Chervyakova, et al.,2015) which is the basis of a hybrid enterprise information system.

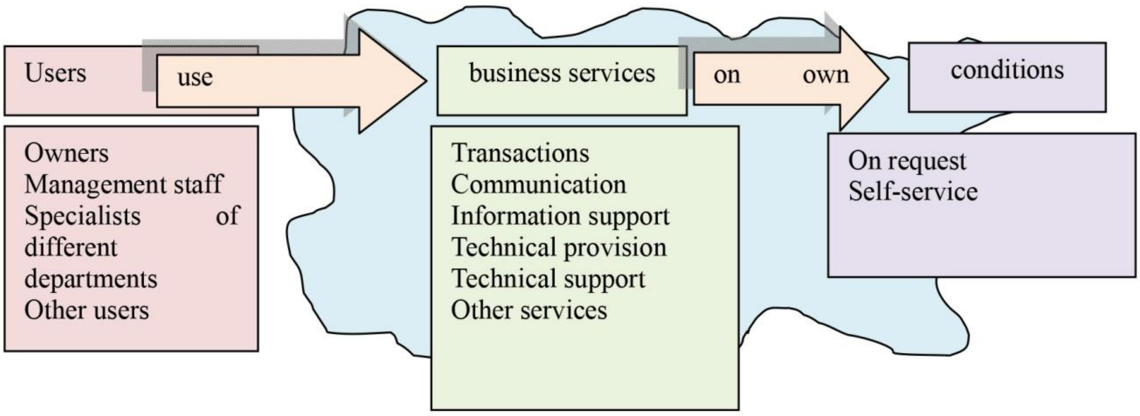

Figure 6. Terms of use of cloud technologies by users

Therefore, the main ways to improve the reliability of the information management system of the enterprise are to systematically control the progress of the management tasks, the introduction of organizational measures to increase the responsibility of employees of the personnel management service for the reliability of information, and quality of management activity. Based on the above, we can distinguish the general principles of the construction of modern automated control systems. These principles are grouped due to the following features: functional, technological, ergonomic, and social-economic (Table 1).

Table 1. Basic principles of building automated enterprise management systems

Name of group of principles	Components of a group of principles
Functional	System approach; continuous development of the system; the emergence of new tasks; maximum end-user targeting; problem orientation; principles of reliability, compatibility, and flexibility
Technological	A considerable number of modes of functioning of automated control systems; creation of local databases; maximum focus on paperless technology; unity of information base; maximum “embedding” of elements of new information technology
Ergonomic	“Affordable” or “friendly” interface; adaptation to the level of user training; easement of use of information
Social-economic	The efficiency of the management system; redistribution of functions, rights, and responsibilities; regulation of procedures performed by employees of one department

The automated control systems developed by the above principles provide the basis for more efficient use of cloud technologies in organizational systems. Also, the important benefits of operating the automated control systems of enterprises with the use of cloud technologies are economic benefits. According to our studies of practical aspects of Khmelnytsky enterprises using expert evaluation methods, we concluded that the planned introduction of automated control systems based on the latest digital technologies allows us to obtain the following results (Table 2) (Voynarenko, 2018).

Table 2. The effects of the introduction of automated control systems based on the latest digital technologies

Indicator	Average value
Reduction of operating and management expenses	10 -80 %
Working capital savings	20-40 %
Reduction of the implementation cycle	10-20 %
Reduction of reserve stock	10 - 20 %
Receivables reduction	8 -10%
Acceleration of cash flow in the calculations	25-35 %

These economic effects are due to the fact that cloud technologies allow to save on the acquisition, maintenance, modernization of software and equipment, as well as the maintenance of special departments for the use and maintenance of software and technical complexes. The results of the use of cloud technologies increase the efficiency and effectiveness of management decisions, the initial management of the IT infrastructure; unlimited data storage is used; the conditions of availability of data from different devices and jobs to data systems are determined; data loss protection is enhanced; it becomes possible to perform many activities; the control of the whole process expands.

Conclusion

Our research is devoted to the construction of scientific and methodological approaches to improve the quality of functioning of the information system of enterprise management based on the use of the latest technologies. The solution of the problems outlined by us is because at the present stage of development of science and technology, globalization of the world economy acquires the dominant positions of the tendencies of forming a heterogeneous environment, digitization of economic processes and development of cloud technologies and their introduction into the systems of enterprise management in various industries. Such conditions fundamentally change the system of managerial decision-making in the enterprise, which requires the search for new scientific and methodological approaches in the study of the management process, which are based on the use of economic-mathematical methods and models. It will give the management of the enterprise a reliable tool for effective organization of the management process and reasonable decision-making of management decisions, reduction of errors in the implementation of management tasks in different directions of the enterprise’s activity.

In the process of research, the sequence of construction and the overall structure of the enterprise management system based on the use of cloud technologies were determined, which allowed building a mathematical model for calculating the probability of making an error-free decision, evaluating the efficiency of decision-making, a model of making a management decision for a certain time with the parallel method of operation of elements of the enterprise management system.

The conclusions obtained as a result of the study of practical aspects in the chosen direction, confirm the hypotheses about the cost-effectiveness of cloud technologies: the transition of capital costs in operating ones; reduction of operating expenses; payment on a pay-as-you-go basis; reducing IT infrastructure maintenance costs; reducing the cost of additional hardware.

The use of the obtained scientific and practical results is possible at enterprises with different forms of ownership, in different branches of the national economy. The value of the proposed scientific and methodological approaches is that, without modification, they can be applied to perform the relevant calculations in such important fields as energy, mechanical engineering, financial services, etc.

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