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MULTI–CRITERIA EVALUATION OF IT INVESTMENTS BASED ON COMPLEX MODELING AND CALCULATION OF THE ENTERPRISE INFORMATION SYSTEM TOTAL COST OF OWNERSHIP

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Abstract

Under the conditions of the current financial and economic challenges, the task of optimizing the resources of enterprise information systems (EIS), including for companies performing the functions of investment (financial) intermediation, is extremely acute. The analysis showed that the main reason for the difficulties in assessing the effectiveness of the EIS and choosing the optimal way to develop, implement and operate a new EIS is the lack of methodological tools and mechanisms for analyzing these processes. In world practice, one of the existing indicators for analyzing investments in EIS is the total cost of ownership (TCO). The value of the TCO should be monitored throughout the life cycle of the EIS based on the specifics of the functioning of the particular sector companies. An important feature of the TCO is the ability to estimate the total costs of acquiring and using IT, followed by an analysis of the effectiveness of their use scenarios. However, to date, there are no methods for calculating TCO taking into account multivariate scenarios of possible development of EIS. The paper presents a new methodology for multi-criteria evaluation of the effectiveness of IT investments using the TCO indicator, as well as on the basis of complex modeling of the processes of proactive management of the life cycle of EIS. The paper provides a meaningful and formal description of the problem of multi-criteria evaluation of the effectiveness of IT investments in the creation, operation and modernization of existing and prospective EIS for business of financial (investment) intermediaries. The article presents a specific multi-stage algorithm for solving the problem under study.

Keywords: enterprise information system, financial (investment) intermediaries, total cost of ownership, complex modeling, proactive lifecycle management, multi-criteria synthesis

1. Introduction

In the market economy and a highly competitive environment, financial (investment) intermediaries, like any company, seek to strengthen their position in the market by resorting to improving the quality of financial services and products provided, introducing innovations and increasing business efficiency. One of the components for achieving the above goals is the close integration of the business of financial intermediaries with information technology (IT), including the use of enterprise information systems (EIS)(Zakharov, 2022). At the same time, the question of the contribution of EIS and related IT to the core activities of the company engaged in investment mediation, and the evaluation of the effectiveness of EIS, including the return on investment, is of particular important under the current conditions.

Business and governments are ready to pay equally as many information resources as they need for information support of management activities (Lomachenko & Kokodey, 2019). At the same time, they proceed from such classical performance indicators currently used in the computer services market as the return-on-investment indicator (ROI), the quality-of-service indicator (QoS). Excess information resources and redundant IT are frozen investments and resources (moreover, lost resources, given the rapid moral aging of hardware and software and equipment). On the other hand, insufficient resources are a lost profit.

Currently there is a trend of increased steady growth of investments in IT, including in EIS. This applies to both large and medium and small businesses (SMB). Against the background of this increased demand, the IT services market is being formed, where market consolidation has been taking place recently.

In the conditions of the currently observed financial and economic instability, the task of optimizing EIS resources, including for companies engaged in investment intermediation, is extremely acute. Enterprises strive to survive as much as possible from existing assets. Some time ago, the main principle of doing business was expansion, the vast majority of companies sought to increase the number of assets without taking into account their quality. Now issues related to improving business efficiency and reducing costs have come to the fore. This requires mechanisms that allow companies to adapt to new conditions. All these problems affect the information component of any enterprise. Questions related to the economic efficiency of the EIS are of interest to all company' departments.

Section 2 provides an overview of the current state of research in the subject area under consideration. Section 3 presents the methodology developed by the authors for solving the problems of formal description of the problems of proactive life cycle management of complex objects and EIS. In section 4, the formal formulation of the problem under consideration is carried out. Section 5 describes the main steps of the multi-criteria evaluation algorithm of the effectiveness of IT investments in the creation, operation and modernization of existing and prospective EIS for business of financial (investment) intermediaries. Section 6 presents the scientific results and directions for further research.

2. State of the Art

It is worth noting that at present EIS are very complex technical and technological systems. The process of the EIS life cycle has many development scenarios. At all stages of the existence of the EIS, many questions arise. Within the framework of this article, it is proposed to consider the process of proactive (proactive) management of the life cycle of EIS within the framework of the structural dynamics management model of complex organizational and technical objects, which include modern business systems (Ivanov et al., 2020; B. V. Sokolov et al., 2021).

The analysis showed that the main reason for the difficulties in assessing the effectiveness of the EIS and choosing the optimal way to develop, implement and operate a new EIS is the lack of methodological tools and mechanisms for analyzing these processes. In world practice, one of the existing indicators for analyzing investments in EIS is the total or total cost of ownership of EIS (TCO) (Skripkin, 2002; Zelentsov et al., n.d.).

The value of the TCO should be monitored throughout the life cycle of the EIS. The choice of the stage: implementation, commissioning and the time to reach full capacity before the end of operation implies a period of time. Thus, time should be entered as a parameter of the TCO indicator. In this case, the generalized formula for calculating the TCO can be written as follows:

$$TCO(t) = \sum_{i=1}^{N} Dir_i(t) + \sum_{j=1}^{M} InD_j(t) \quad (1)$$

where $Dir_i(t)$ is the direct expenses, $InDir_j(t)$ is indirect expenses.

Along with the TCO, other indicators of economic efficiency are also used, which include the Return on Investment (ROI) indicator, the Return on Assets indicator, the Share Price indicator, the indicator of One-Time Costs for the introduction and acquisition of hardware and software.

An important feature of the TCO is the ability to estimate the total costs for the acquisition and use of IT, followed by an analysis of the effectiveness of scenarios for their use. The TCO methodology makes it possible to identify excess items of expenditure and makes it possible to assess the return of funds invested in the EIS. In the methodology developed by the authors of the paper, costs are divided into two types: direct and indirect.

Direct expenses include: expenses for the purchase of hardware and software, for user training, for the services of third-party organizations, for the payroll of the information service department; for the labor of the company's management apparatus, for electricity and others. Indirect costs include: costs for self-support of users, for mutual support of users, losses from system downtime and others. In general, the TCO indicator does not allow us to assess the direct economic effect of the implementation of EIS, therefore, the Return-on-Investment indicator (ROI) is used to solve this problem. And in the framework of the methodology the result of the calculation is the indicator of Return-on-Investment in the EIS of an enterprise, as well as financial intermediators. With the help of this indicator, it is possible to assess the economic effect of investing in IT. The main difficulty of this technique is to determine the direct benefits received by the company from the implementation of EIS. When analyzing these benefits, the business areas and goals that stand in the implementation of the EIS are highlighted, and then the benefits received by the enterprise from their achievement are calculated. This can be both an improvement in the quality of service, and the possibility of developing and producing new products that give this organization a competitive advantage in the market. In the methodology, the TCO indicator plays an important role, since it reflects the actual costs of EIS.

At the same time, it should be emphasized that the calculation and multi-criteria analysis of TCO and ROI indicators should be carried out taking into account the multivariate alternative scenarios associated with the creation and operation of EIS (Landmesser, 2014). To do this, as studies have shown, it is necessary to conduct complex modeling of the processes under consideration (Mikoni et al., 2018; Zakharov, 2022)

3. Methodology

The relevance and novelty of the issues considered in the proposed article lies in the fact that currently, formal methods of assessing the economic efficiency and profitability of investing in EIS are practically not used for the IT industry, especially for financial intermediaries, which have business specific features.

The purpose of the proposed research is to increase the efficiency of business processes based on the elaboration of a set of models and algorithms for calculating and analyzing the total cost of ownership (TCO) of the enterprise's EIS components. This goal assumes the solution of the following tasks: analysis of existing approaches to assessing the effectiveness of the use of EIS components by financial intermediaries; justification and relevance of the use of TCO calculation methods for evaluating IT infrastructure components; research and analysis of existing principles, regulations and laws on management accounting (MA), financial accounting (FA) and tax accounting (TA), to identify data sources for calculating TCO; description and development of conceptual models of data sources for calculating TCO based on the management and accounting of a company; description of the process reengineering the existing accounting model of the company's IT infrastructure to obtain data for calculating the TCO.

Separately, it is worth highlighting the problem of the formulation of the TCO calculation algorithm within the framework of the problem of proactive control of the structural dynamics of the EIS. Let us briefly dwell on the features of the formulation and solution of this problem.

4. Problem statement

The analysis of foreign and domestic experience in the creation and development of EIS shows that these processes are quite long in time and are accompanied, along with an increase in the efficiency of functioning (by improving management processes), by the expenditure of various types of resources (financial, material, information, etc.). At the same time, in practice (especially in market conditions), there is an economic unevenness and disparity of various programs for allocating funds for the design, development, operation and improvement of the main elements and subsystems of the EIS. In this situation, different ratios between the effects and costs received within these systems at any given time correspond to each specific variant of the creation and application of EIS. Recently, there has been increased interest in the study of issues related to the assessment and analysis of the effectiveness of the life cycles of EIS, the choice of the most preferred options for managing the development of EIS. Further, the life cycle of the EIS will be understood as the sequence of phases of the development of these systems from the moment of formation of their appearance to the time of their decommissioning (transition to a new EIS).

Let us carry out a set-theoretic formulation of the problem of proactive management of the life cycle of EIS, which can be considered as a problem of proactive management of the structural dynamics of EIS from a formal point of view. Previously performed studies have shown that a dynamic alternative multigraph (DAMG) of the following type is appropriate for a formal description of the specified structural dynamics (Garaix et al., 2010; Ivanov et al., 2020; Ivanov & Sokolov, 2012; Ticha et al., 2019):

$$G_{\chi}^{t} = \left\langle X_{\chi}^{t}, F_{\chi}^{t}, Z_{\chi}^{t} \right\rangle \quad (2)$$

where χ is the index characterizing the type of the EIS structure, χ = { Top, Bp, Tech, Pmo, Io, Org } is a set of indexes corresponding to the topological structure (Top), the structure of business processes (Bp), the structure of management technology, the structure of software, mathematical, information and organizational support (Pmo, Io, Org), $t \in T$ *is* a set of time points; $X_{\chi}^{t}=\{x_{\chi l}^{t}, l\in L_{\chi}\}$ – the set of elements that make up the structure G_{χ}^{t} (the set of vertices of the DAMG) at time t; $F_{\chi}^{t}=\{f_{<\chi,l,l'>}^{t}, l,l'\in L_{\chi}\}$ –– the set of arcs of the DAMG type G_{χ}^{t} reflecting the relationship between its elements at time t; $Z_{\chi}^{t}=\{f_{<\chi,l,l'>}^{t}, l,l'\in L_{\chi}\}$ – a set of parameter values that quantitatively characterize the relationship of the corresponding elements of the DAMG.

In addition, a set of permissible (based on the meaningful formulation of each specific task of proactive control of the structural dynamics of the EIS) mapping operations of the above-mentioned DAGs on each other is given:

$$M_{<\chi,\chi'>}^{t}: F_{\chi}^{t}\rightarrow F_{\chi'}^{t} \qquad (3)$$

as well as the operations of composition of these mappings at time t:

$$M_{<\chi,\chi'>}^{t}=M_{<\chi,\chi_1>}^{t}\circ M_{<\chi,\chi_2>}^{t}\circ\ldots\circ M_{<\chi'',\chi'>}^{t} \qquad (4)$$

Taking into account the above, a multistructural state can be determined by a subset of the Cartesian product of a set of elements., on which the corresponding EIS structures are built:

$$S_{\delta}\subseteq X_{\text{Топ}}^{t}\times X_{\text{Бп}}^{t}\times X_{\text{Тех}}^{t}\times X_{\text{Пмо}}^{t}\times X_{\text{Ио}}^{t}\times X_{\text{Ор}}^{t},\ \delta=1,\ldots,K_{\Delta} \qquad (5)$$

A set of multistructural states (Gnidenko et al., 2019) of EIS is introduced, which is written as follows:

$$S=\{S_{\delta}\}=\{S_1,\ldots,S_{K_{\Delta}}\} \qquad (6)$$

We will introduce many more valid operations for mapping multistructural states of EIS to each other:

$$\Pi_{<\delta,\delta'>}^{t}: S_{\delta}\rightarrow S_{\delta'} \qquad (7)$$

It is assumed that each multistructural state of EIS at time t is set as a result of the composition operation of the corresponding DAMS describing each type of structure (see formula 5).

The graphical interpretation of the considered tasks of proactive control of the structural dynamics of the EIS in this case is reduced to the search for such a multistructural state of $S_{\delta}^{*}\in\{S_1, S_2,\ldots, S_{K_{\Delta}}\}$ and such a sequence (composition) of performing operations of the form (7) in time $\Pi_{<\delta_1,\delta_2>}^{t_1}\circ\Pi_{<\delta_2,\delta_3>}^{t_2}\circ\Pi_{<\delta',\delta>}^{t_f}$, which ensures the selection and implementation of the optimal (from the point of view of the generalized efficiency indicator) control program structural dynamics of EIS life cycle, which ensures the transition of the dynamic system (1) from a given to the required multistructural state (Boltyanskii et al., 1960). This generalized indicator, formed on the basis of the fuzzy-probability convolution proposed in (Spesivtsev et al., 2022), includes, together with the indicators of the differential and integral throughput of the EIS, also the indicators of TCO and ROI of the life cycle of the EIS.

Along with the graphical interpretation of the problem under the study, the following set-theoretic description can also be proposed: the need to develop principles, approaches, models, methods, algorithms that allow finding such $<U_{*}^{t},\ S_{\delta}^{*t_f}>$ under which the following conditions are met:

$$J_q\left(X_{\chi}^{t},\Gamma_{\chi}^{t},Z_{\chi}^{t},F_{<\chi,\chi'>}^{t},\Pi_{<\tilde{\delta},\tilde{\tilde{\delta}}>}^{t},\Xi_{\chi}^{t},t\in(t_0,t_f]\right)\rightarrow \underset{<U^{t},S_{\delta}^{*t_f}>\in\Delta_g}{extr}$$

$$\Delta_g=\left\{<U^{t},S_{\delta}^{t_f}>\middle| R_{\beta}\left(X_{\chi}^{t},\Gamma_{\chi}^{t},Z_{\chi}^{t},F_{<\chi,\chi'>}^{t},\Pi_{<\tilde{\delta},\tilde{\tilde{\delta}}>}^{t},\Xi_{\chi}^{t}\right)\le\tilde{R}_g;\right. \qquad (8)$$
$$\left.U^{t}=\Pi_{<\delta_1,\delta_2>}^{t_1}\circ\Pi_{<\delta_2,\delta_3>}^{t_2}\circ\Pi_{<\tilde{\delta},\delta>}^{t_2};\ \beta\in\mathbf{B}\right\}$$

where U^t — control actions that allow synthesizing both the structure of the EIS and the processes of its creation and functioning; J_q – cost (TCO ROI), time, resource indicators characterizing the quality of the EIS, q = Q = {1,...,l} – a set of indicator numbers; – a set of dynamic alternatives (a set of structures and parameters of EIS, a variety of options for their creation and functioning); B – a set of numbers of space-time, technical and technological constraints that determine the processes of implementation of EIS; – set values; T = (t_0, t_f] is the time interval at which the considered EIS are synthesized (designed, created, operated and upgraded) (B. V. Sokolov et al., 2020).

5. Solving the problem

At the first stage of solving the proposed generalized task of proactive management of the life cycle of the EIS, it is necessary to consider the formation of the methodological foundations of its research.

The scale and complexity of the problem under consideration in this regard requires the choice of an appropriate methodology, as which the methodology of modern generalized system analysis should be chosen (Boris V Sokolov et al., 2015), which is one of the main directions of the implementation of the system approach, in which a constructive solution of heterogeneous and different problems is carried out on the basis of a harmonious combination of formal mathematical and logical heuristic methods. level tasks of multi-criteria analysis and synthesis of EIS at various stages of their life cycle. In relation to modern EIS, the main stages of the generalized system analysis of this synthesis problem can be distinguished:

- retrospective critical comparative analysis of existing domestic and foreign developments in the field of creation and application of EIS;
- evaluation the effectiveness of the existing EIS;

- formulation of the generalized problem of synthesis of the appearance of the "new" EIS, determining the time of transition from the "old" EIS to the "new" EIS, determining technologies and programs for proactive management of this transition;
- analysis the goals and objectives that need to be solved by the EIS at a new stage of its development, the formation of a system of performance indicators of the functioning of the created EIS at various stages of its life cycle (including TCO and ROI indicators);
- analysis of the main spatial-temporal, technical, technological, cost and resource constraints associated with the process of creating and applying EIS;
- analysis (construction) of alternative options for the structure of a promising EIS;
- multi-criteria evaluation of the specified variants of the EIS structure and selection of the most preferred ones;
- formation, evaluation and selection of optimal evolutionary plans for the transition from the existing EIS to the created ("new", promising) EIS without reducing the effectiveness of their use.

The constructive solution to the problem of finding and choosing the best options for the creation and development of EIS involves, firstly, the creation of an appropriate polymodel complex (Ivanov, 2009)opt describing various aspects of the life cycle of the existing and created EIS, secondly, the development of methods, algorithms and techniques for multi-criteria synthesis of the structure of a promising EIS, and, thirdly, the development of a multi-stage interactive procedure search for a solution to the problem of synthesis of EIS and their development programs.

The analysis of numerous publications on the problems of proactive management and integrated (system) modeling of complex organizational and technical systems , which include EIS, showed (Bakhmut et al., 2019; Larichev et al., 2002; B Sokolov et al., 2022) that it is advisable to implement the concept of the considered modeling within the framework of an integrated decision support system (IDSS). In general, the specified system should include: simulation system, computational logic system, intelligent application software packages, expert system, instrumental CASE-design automation tools. At the same time, based on the dynamic interpretation of the processes occurring at different stages of the life cycle of the EIS, it is advisable to choose a dynamic alternative system graph as the main mathematical structure. describing these processes.

The analysis of the possible ways to solve the problem of polymodel multicriteria synthesis of EIS structures shows that the following three areas of research are the most promising (Bakhmut et al., 2019).

Within the framework of the first approach (**option I**), the task of synthesizing the appearance of the EIS and selecting programs for the transition from the "old" to the "new" EIS is formalized as a single-criteria optimization task on a simulation model describing the processes of functioning of these EIS at various stages of their life cycle. Further, an informal decomposition of the general task (model) into particular tasks (and corresponding analytical models) is carried out, taking into account various aspects of the functioning of the EIS with the necessary degree of detail. At the same time, the dimension of each of the constructed analytical models (AM) describing these aspects of the EIS activity is many times smaller than the dimension of the original simulation model (SM). The final coordination (coordination) of AM and SM is carried out on the basis of the Pareto principle during the iterative exchange of information between these models, as well as interactive collaboration with a decision maker (DM) (Ushakov, 2020).

Within the framework of the second approach (**option II**), the task of multi-criteria optimization of the processes of creating and applying EIS on a set of models is being formulated (B. Sokolov, Pavlov, et al., 2020). At the same time, the formation and narrowing of the set of non-dominant alternatives (the Pareto set) is carried out interactively with the active involvement of DM. In this case, it is proposed to consider discrete mathematical programming models, queuing models, simulation models and development management models as basic models. The contraction of the Pareto set on discrete models is carried out iteratively by cutting off part of the elements of this set. Such a clipping is based on a mathematical study of the properties of the Pareto set and obtaining additional information from the DM (the power of the set, the range of changes in the values of the indicators, the degree of their inconsistency are estimated).

If the power of the Pareto set becomes acceptable, then the variants of EIS structures selected on static models are consistently checked for acceptability on queuing models and simulation models. In the event that the constraints specified in these models are not met, then the corresponding variants of structures are not considered further. The synthesis process ends with the definition of transition programs from the existing to the prospective EIS. The final choice of one of the listed approaches to solving the problem of polymodel multicriteria synthesis of EIS structures and corresponding programs for their development is determined taking into account numerous factors, including the composition and structure of the initial data used in the formulation and solution of the problem, the time allotted for the solution.

It should be pointed out that at each of the stages of the proposed iterative procedure for the synthesis of appearance, technologies and programs for the creation and application of EIS, among the quality indicators taken into account when implementing certain optimization procedures, there are indicators of TCO and ROI.

In the works (B. Sokolov, Pavlov, et al., 2020; B. V. Sokolov et al., 2021), another variant of solving the class of efficiency theory problems under consideration (**option III**) is proposed, which is based on the dynamic interpretation of the processes of multicriteria structural and functional analysis and synthesis of structures, technologies and programs of proactive management of EIS and includes the following main steps.

Step 1. Formation, analysis and interpretation of the initial data used in the generation (synthesis) of scenarios (technologies) of integrated (system) modeling (IM) processes of proactive management of the life cycle of EIS, construction or correction of the description of models used in the structural and functional synthesis of the appearance of EIS.

Step 2. Planning the process of solving the problem of generating (synthesizing) scenarios (technologies) of EIS integrated modeling. Determination of the time and other resources required to solve the problem of analysis and synthesis of effective variants of IM EIS technologies.

Step 3. Construction and approximation of the reachability set (reachability areas, RA) of logical-dynamic models (LDM) describing the processes of proactive management of the life cycle of the EIS), with the help of which variants of these scenarios are implicitly specified.

Step 4. Orthogonal design on the RA of the set, with the help of which the requirements for particular indicators of the effectiveness of proactive management of the life cycle of the EIS are set. As a result (B. Sokolov, Zakharov, et al., 2020), a set of inconclusive solutions (a set of nondominable, effective alternatives, a set of V. Pareto) is formed. The final choice of effective technologies for proactive management of the EIS lifecycle should be made from the specified set (Fig. 1).

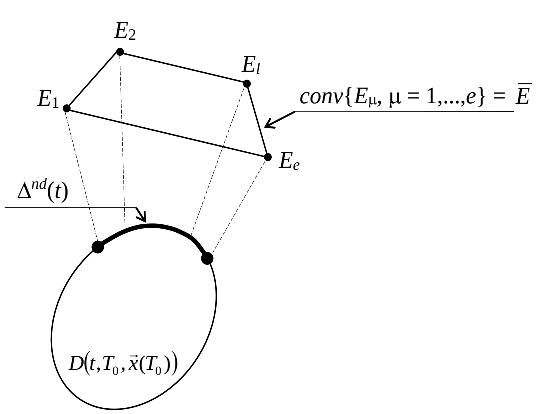

Fig. 1. Construction of a set of inconclusive solutions (a set of nondominable alternatives, a set of V. Pareto), which is highlighted by a bold line

Step 5. Formation and interpretation of output results, their presentation in a form convenient for subsequent use (for example, for the development of adaptive plans for proactive management of EIS).

Figure 2. shows an example of constructing a set of inconclusive solutions (a set of non-dominant alternatives, a set of V. Pareto), for the case when a set of requirements change dynamically and options for proactive EIS management technologies.

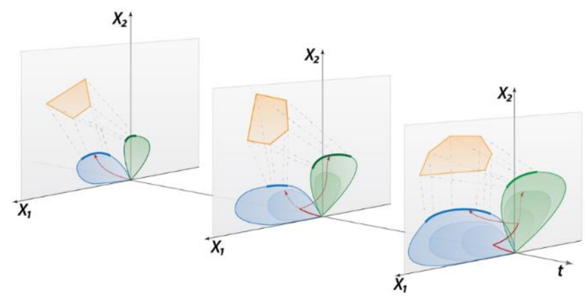

Fig. 1. Sets of inconclusive solutions (sets of nondominable alternatives, marked with bold lines) for the structural dynamics of both the target set and the MD characterizing possible KM technologies

6. Conclusion

The paper provides a meaningful and formal description of the problem of multi-criteria evaluation of the effectiveness of IT investments in the creation, operation and modernization of existing and prospective EIS for business of financial (investment) intermediaries. At the same time, a constructive solution to the problem of multi-criteria evaluation of the effectiveness of IT investments, as well as the search and selection of the best options for the creation and development of EIS involves, firstly, the construction of an appropriate polymodel complex describing various aspects of the life cycle of the existing and created EIS based on specific business process of financial intermediaries, and secondly, the development of methods, algorithms and techniques for multi-criteria synthesis of structure, technologies and programs for the development of promising EIS, and, thirdly, development of a multi-stage interactive procedure for finding a solution to the problem of synthesis of EIS and their development programs.

The article presents a specific multi-stage algorithm for solving the problem under study. The novelty of the proposed approach lies in the fact that it allows for the simultaneous polystructural synthesis of the appearance of the “new” EIS, the determination of the transition time from the “old” EIS to the “new” EIS, the definition of technologies and programs for proactive management of this transition, as well as the synthesis of corrective actions in the presence of disturbing influences.

The main direction of further research is the development of models for the operational correction of program management of operations, resources and flows in EIS at various stages of the life cycle.

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