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# A Model For Financing the Development of Information Management Systems Using Multi-criteria Data Analysis

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## ABSTRACT

This study aims to develop a model to determine the optimal financing required for the development of an information control system (ICS). The model will be based on monitoring and dynamically adjusting certain parameters to solve the task. The model will describe the dynamic development of the IMS (information management system) in a situation center using a system of nonlinear differential equations. An original approach to formalizing the process of financing IMS development is presented, accounting for budget planning and compliance with financial milestones. The model provides an analytical and visual representation of the current state of IMS development, useful for operational management purposes. The development process is managed under conditions of uncertainty and incompleteness of data on the readiness of IUS components, including their manufacturing technologies. The effectiveness of a modified "soft computing" method for handling poorly formalized uncertainty is investigated. It has been shown that implementation of "soft management" of financing can reduce the development risks and create a promising decision-making system within budgetary constraints. A mathematical three-dimensional model can be applied to other areas where it is necessary to monitor the state of an object over time. This model is also interesting from the perspective of mathematical control theory, an interdisciplinary tool for developing alternatives to traditional control methods.

***Keywords:*** expert systems; risk; business processes; fuzzy control; situational centers

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## INTRODUCTION

Models of intellectual decision support for the development of information technology systems for various purposes, in conditions of uncertainty about the availability and condition of components, are necessary to increase the level of competitiveness and technological development [1, 2]. In particular, in the information society, situational centers (SC) for various purposes are the objects of this kind of modeling.

Effective financial management is becoming critical for the survival and development of companies. Traditional approaches focused on short-term financial stabilization are proving insufficient in the face of systemic risks [3]. The development of situational control centers based on multi-criteria data analysis is a financially sound response to these challenges.

Situation centers are key nodes for crisis management, strategic planning, and operational control across a wide range of domains. The development and modernization of situation centers are a strategic necessity in the era of digital transformation, growing threats, and management complexity dictated by a combination of external challenges (cyber threats, competition, efficiency) and internal factors (obsolescence, new technology opportunities).

At the same time, SC development is a complex process with many interdependent criteria, including cost (especially important with a limited budget), productivity, reliability, security, scalability, compatibility, implementation time, staff qualifications, etc. In some cases, the uncertainty associated with development processes is not probabilistic in nature (e.g. data incompleteness, expert assessment inaccuracy, changing requirements, qualitative factors), making the use of probabilistic methods ineffective and, in some cases, impossible. Traditional methods for selecting a development option are often subjective and do not adequately account for the complexity of relationships.

Many connections, properties, and components in complex technical systems, especially in SC complexes, require the development of new methods for organizing processes to update the functional characteristics of SC at all stages of systems' life cycles. This requires a significant financial commitment. It should also be noted that the development of a complex technical system in the context of instability in the modern economy requires not only theoretical justification of the methods, but also the possibility of practical implementation to eliminate systematic errors in forecasting, which directly affects the deadlines for the completion of facilities.

Since development is an integral element of the life cycle of the SC itself, when forming a development program (plan), it requires an analysis of many alternative solutions and an assessment of their consequences, which necessitates the creation of specialized software to automate these processes, and first of all, a model of the development process.

Regulation SC development must be implemented through both accurate assessments (of the entire system and its individual parts) and mathematical modeling to determine the optimal combination of elements and build the SC structure within the specified time and financial constraints [4].

In [5], academician V. L. Makarov substantiates the expediency of formalizing the development complex production and economic systems through of a "post-industrial process management model for coherent economic systems". An integral part of the effective development of V.L. Makarov software is not only the search for new technical, hardware, and software solutions necessary for this, but also the development of a proactive financing mechanism within the framework of such a model. Such a model, according to the academic, will provide regulation of incentives and support measures, and, consequently, comprehensive control over the development process. This should lead to comprehensive optimization (including in the transactional sphere) aimed at "achieving virtual cognitive interoperability of any types of subject-based activities in the economy" and ensuring "the formation of demand for industrial products through price manipulation".

When developing SC for various purposes, mainly to ensure the safety of critical infrastructure facilities, it is necessary to promptly influence certain production processes through financial investments.

In particular, it is necessary to optimize various costs and expenses so that they do not extend the deadlines for the completion of the facility or its general condition into the area of increased risks. As shown by the classification and analysis of project risks in [6], successful project implementation requires specialized approaches, including methods and tools to reduce risks, as well as effective risk management in this area of investment activity.

Various technical projects require comprehensive communication with both internal and external environments. The solution in such cases is often the use of digital doubles. However, this approach has its drawbacks. The difficulties associated with status assessments, communication, and efficiency can lead to higher costs of creating and maintaining such software packages.

The existing models and methods of managing the process of creating SC, as a rule, are based on the principles of comprehensive analysis and synthesis of design solutions. In [7–9], the risk indicator is considered a universal indicator of the effectiveness of creating a complex technical system (CTS). In this case, risk is understood as a probabilistic measure of the deviation of the characteristics of the system being created from the values specified in the terms of reference, considering both the current characteristics of the production process of creating a CTS, primarily its technological readiness, as well as financial and time constraints.

In [10, 11], a comprehensive criterion for evaluating the effectiveness of creating a JTS was proposed, taking into account three key parameters: technical characteristics, time and cost. The comprehensive criterion helps make optimal design decisions when developing CTS and assesses the possibilities of upgrading existing systems. However, a significant disadvantage of this criterion is its inability to determine or evaluate (pick 1) the technical feasibility of the components, given data uncertainty.

In [12, 13], it was proposed to use the original, so-called search potential to form the optimal appearance of a promising radar while minimizing the cost of manufacturing equipment. At the same time, the effectiveness of this indicator is significantly reduced in the absence of reliable empirical data or the necessary expert assessments for its use.

The above limitations became the subject of research by academician Yu. I. Shokin, in his works on the application of risk analysis in technical systems [14], noted the difficulty of accounting for fundamental uncertainty of the future, which reduces the effectiveness of classical decision-making methods based on risk forecasting results. As a further development of the theory of risk analysis, Yu. I. Shokin suggested using digital twin technology, which would enable evaluation of the development process with any amount of information at each stage, while accounting for the fact that risk is not a static quantity.

In the classical probabilistic approach, the risk associated with decision-making is estimated using the loss function $z = f(x, y)$, where $x \in \mathbb{R}^n$ represents the decision, $y \in \mathbb{R}^n$ are the possible future values of variables describing the state of the system. If the vector y is random, the losses are a random variable, the distribution law of which is determined by the choice of control. Any optimization task related to estimating losses based on the decision must take into account not only expected losses, but also the risks posed by the decision itself.

A risk measure (as a functional in the space of distributions) is called coherent if it is positively homogeneous, invariant with respect to shifts, monotonic, and subadditive. The convexity of the risk measure follows from subadditivity and positive uniformity. With this in mind, coherence is sometimes understood as a measure of risk that is convex and invariant with respect to shifts.

The possible inadequacy of the risk measure prevents us from applying the Lebesgue integral directly to estimate the mathematical expectation. Shock integration helps to avoid difficulties (see [15]).

It is known (e.g., [16]) that the classical estimate of *VaR* is not subadditive, and *CVaR* (conditional *VaR*) is coherent. If the loss distribution is sufficiently "good" (for example, normal), *VaR* and *CVaR* give the same result. If the loss distribution has a heavy tail, VaR underestimates the risk relative to CVaR and, therefore, cannot serve as a sufficiently reliable measure.

Cybernetic approaches to understanding risk are well-known; in particular, [17] proposed the structure of a mechanism consisting of several levels of risk management.

A soft assessment of enterprise risks through a chain of fuzzy assessments has shown high practical importance, (see [18]). However, as the number of trust levels increases, membership functions become increasingly blurred and may lose their informative value. Using a neural network solves computational problems to a certain extent, but it forces the developer to choose between interpretability and accuracy. In addition, implementing the aforementioned method requires a sufficient statistical dataset or a large volume of expert information. The approach proposed in this paper can be used to address financial risks from an operational management perspective. With insufficient information and high variability, this method may require significant modifications.

In conditions where there is a lack of information not only about the future state of the system but also about its current state (for example, due to the unavailability of operational monitoring), the potential for an improved risk analysis method is significantly reduced. Thus, in case of low controllability of development processes, an error in forecasting leads to a delay in development deadlines and non-compliance with the requirements of the terms of reference, which is especially common in large and long-term projects.

Thus, the development model should take into account both the main factors that have the greatest impact on the state of the SC project, and take into account only an adequate number of components and connections in order to obtain acceptable logically interpretable results when solving the task of planning the deadlines for the completion of an object with limited finances for the implementation of the terms of reference of this project. High uncertainty in the interaction of many enterprises (the possibility of deceiving the counterparty, disruption of logistics, financial instability) dictates difficult conditions for creating optimal financial protection for the project [19] The optimal "financial cushion" should protect the customer and contractor from legal consequences for failure to deliver critical infrastructure facilities, which can lead not only to financial losses of companies, but also criminally responsible.

## RISKS AT THE DEVELOPMENT STAGE

On the one hand, the risk is determined by the current economic and political situation, which defines the business environment as chaotic and rapidly changing on the other hand, by the possibility that the necessary functional characteristics may not be achieved within a given time frame. We are considering the optimal financing procedure that allows us to reduce both risks.

To this end, the formalization of development processes should consider the following events, which are characterized by a high degree of uncertainty:

- delays in the installation and commissioning of equipment due to uncertainty in the economic and financial field (logistics problems, price changes, credit rates);

- malfunctions during operation (due to errors in calculations, unpredictability of the external environment, or due to difficulty in predicting internal trends of the system);
- unforeseen expenses related to the manufacturing of equipment (changes in supply and demand on the market, changes in credit policies).

In addition, the scientific and methodological apparatus should account for the fact that the entropy of this uncertainty decreases over time. However, uncertainty is crucial for reducing risk when forming a software development program, particularly at the initial, so-called conceptual stage of development, when entropy is at its maximum.

The IMS development model, which does not account for financing as a means of adjusting the development process, leads to a significant increase in the risk of disruption due to an incorrect choice of technical and technological solutions.

The integration of financial indicators (e.g. lead time, additional investments) into a multi-criteria assessment of the IMS trajectory provides an economically sound (and not only technically optimal) development path with maximum return on investment. "Soft management" of finances minimizes risks and effectively allocates budgets to adapt to unanticipated circumstances.

## MATHEMATICAL MODEL

The apparatus of differential equations allows us to formalize the dynamic nature of risk adequately. Differential equations accurately describe how uncertainty changes over time. They associate this process with changes in the system state and the effects of information accumulation.

Representing a system with a dynamic model enabling modeling of unique, unprecedented situations, which is especially important when developing complex new systems, where each block represents a largely unique development. This enables risk analysis in situations where traditional statistical approaches are not applicable due to a lack of representative historical data.

For example, let's look at the risks associated with the development of SC IMS.

We will evaluate the readiness of the SC components at a given time $t$ using the complex indicator $G(t) \in [0;1]$, which combines an assessment of the completeness of all (design, sketch, technological, and testing) functional characteristics at all stages of the IUS development lifecycle for all modules. We will assume that failure to achieve the required level of readiness at one stage stops the change in readiness at all subsequent stages up to that point.

We will assume that $G(t) = 1$, if the module was fully described and designed at the first stage of the IMS development, all modules of this type were manufactured and assembled at the second stage and successfully passed the tests. It is assumed that $G(t) < 1$, if at least one of these processes is not performed properly.

Since the cost of work, as a rule, is insufficiently determined, especially with a large forecasting horizon, as shown in [20], it is necessary to consider not the cost, but the so-called budget. In this example, the target budget comprises the budgets allocated to each stage of development.

We denote by $C = C(G(t))$ the budget balance at the time when the readiness level is estimated at $G(t)$.

Financing is carried out in stages and depends on the system's level of readiness. Accordingly, the value of $C$ varies abruptly. At the initial stage, we have $C = a_1$, where $a_1$ is the amount of funds allocated for the design. If $G = 1$, no further financing is required, so in this case $C = 0$.

The risk *R(t)* is estimated by the conditional probability that at the time of the planned completion of development *T*, readiness *G(T)* will be below the acceptable threshold of readiness for non-fulfillment of the scheduled task, and is represented by a function of the current state of development

$$R(t) = F\left(t, G, C, \hat{\varepsilon}\right) \quad (1)$$

taking into account the assessment of possible work-impeding disturbances $\hat{\varepsilon}$, associated with unaccounted-for factors affecting readiness (personnel changes, changes in unification, etc.).

It is assumed that the work completion rate satisfies the logistic equation, adjusted for disturbances $u(t)$ the budget balance, and the amount of additional (managed) financial resources allocated to eliminate unaccounted delays and costs. Thus,

$$\ddot{G}(t) = \left(1 - \dot{G}(t)\right)\dot{G}(t) - \varepsilon(t) + C\left(G(t)\right) + u(t). \quad (2)$$

The initial pace of work is determined by financing. With this in mind, the readiness function satisfies the initial conditions of the form

$$\dot{G}(0) = g(C). \quad (3)$$

Equation (2) is an autonomous second-order differential equation. Its structure reflects the fundamental properties of development processes: the first term describes logistical growth — a characteristic slowdown in the pace of development as the project nears completion. The remaining terms model the balance between perturbations, budget, and financial management impacts.

The values of $\varepsilon(t)$ are determined by a Gaussian random process in which the expectation value and variance tend to zero as *t* approaches the completion date $T$. The latter requirement reflects an increase in predictability in the final stages than in the initial phase, which is characterized by maximum uncertainty.

The *C(t)* function is a contractually regulated financing schedule where payments are rigidly linked to the achievement of specific readiness thresholds. This is expressed in the fact that *C(t)* is a piecewise constant (stepwise) function that "jumps" to the next value when *G* reaches the specified control points (for example, 30%, 60%, 90% readiness).

The relationship between funding and the rate of readiness growth is non–linear: with insufficient funding, the pace of the development process decreases; with excessive financing, it does not increase due to saturation. Despite the discrete, "stepwise" nature of payments, their impact on the dynamics of development is manifested continuously and nonlinearly through changes in availability. When funds are limited, the pace of work slows significantly due to resource limitations, whereas when funding exceeds the optimal level, growth asymptotically approaches a limit determined by technical and organizational factors.

The proposed model is based on the provisions formulated in [5, 7, 8, 14, 20]:

- the level of uncertainty is greatest at the very beginning of development (at the design stage), and, consequently, the risk is maximum at the initial stages;
- in the early stages, the change in readiness is characterized by slow growth;
- as data accumulates, uncertainty decreases, which leads to a reduction in risk by reducing the mathematical expectation of damage and its measure of dispersion;
- as data accumulates, the change in availability asymptotically tends to a certain value that characterizes the full and optimal loading of the production line;
- the remaining budget affects the ability to eliminate emergency and crisis situations, which directly affects the rate of change in the availability of IMS components. Lack of funding leads to a pause in the development of new components.

In addition, it is worth considering securing additional funding to address unforeseen consequences if the current budget is insufficient.

If we discard the term $u(t)$, in equation (2), the Riccati equation with a stochastic component arises with respect to $\dot{G}(t)$ (see [17]).

Let us qualitatively describe the results of the study of solutions to equation (2).

Let us assume:

$$c(t) = -\varepsilon(t) + C(G(t)) + u(t).$$

At $0 < c < 0.25$, the following situations are possible:

- a small budget will lead to a slower rate of change in readiness, and may even cause the growth of readiness to stop;
- in the case of a typical budget, the rate of readiness growth will be slow;
- in the case of a larger budget, the pace may not increase, but it will gradually approach a certain point.

For $c > 0.25$, there is only one possible situation in which the budget may not be sufficient to fully organize the development process (i.e., development will stop at one of the life cycle stages).

An increase in unforeseen factors ε increases the probability of of the project not being completed by the deadline.

## RESULTS AND DISCUSSION

An original approach to formalizing the financing process for IMS development is presented, accounting for budget planning and compliance with financial milestones. Specifically, for the proposed equations, so-called soft project financing management has been found effective in situations where there is incomplete knowledge of IMS SC's technical parameters is incomplete, based on feedback. This helps keep the phase trajectory within a safe area, either by attracting additional funds for the development project or by saving the project.

The purpose of this control is to ensure system's trajectory remains within an acceptable range. Soft methods are used for this purpose [21–24].

## CONCLUSIONS

The numerical solution of the equations that comprise the model demonstrates that it adequately represents the financing process for the development and modernization of a complex technical system.

The model allows us to create phase trajectories in the (readiness-budget-risk) space, predicting readiness and budget states, and assessing the risk of delays in development deadlines.

To construct, a mathematical formalization of the IMS development process is proposed as a three-dimensional dynamic system. The analysis of phase trajectories allows us to reliably assess the current risk of failure to complete the development project and the consequences of specific management decisions under conditions of uncertainty in the initial data and incomplete information about the relationships among functional characteristics, financing options, and the technical feasibility of IMS components.

Operational risk monitoring is necessary to adjust control actions on time performance to reduce the likelihood of delays. Thus, probability serves as a dynamic metric that responds to changes in project parameters in real-time.

A description of applying a soft computing method to evaluate optimal SC development options for various purposes, based on a comprehensive risk indicator, is being prepared for publication.

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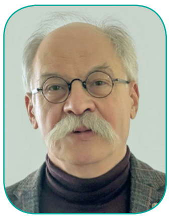

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***Authors' declared contribution:***
**I.V. Trundaev** — development of the mathematical structure of the model and the evaluation method.
**V.B. Gisin** — comparative analysis of advantages and disadvantages of existing risk assessments.
**A.V. Timoshenko** — identification of critical factors for solving the applied problem and development of the theoretical basis of the concept of the article.
**V.A. Pankratov** — problem statement, development of a theoretical framework, and analysis of existing approaches to the process of SC modernization.

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