Construction project management technology based on the theory of system stability

N V Tsopa¹ *, V V Malakhova¹, and M S Fedorkina¹

¹Academy of Construction and Architecture, V.I. Vernadsky Crimean Federal University Simferopol, Russia

E-mail: Natasha-ts@yandex.ru

Abstract. The paper substantiates possibility and necessity of applying the system stability theory to the management of a construction project. Stability theories of automatic control systems are considered. Sustainability of construction projects is considered based on the sustainability theory of organizational systems. The indicators that characterize the degree of stability of the construction project are determined. The main indicators of project sustainability are Net Present Income, project payback period, internal rate of return and project profitability. A mechanism for calculating these indicators before and after the application of the project management technology is presented. Approbation of the proposed project management technology based on sustainability indicators was carried out on the example of the construction of the "Villa Rose" cottage village. In the process of management, risks were identified at the stages of project implementation with the help of independent experts. The integral indicator of the project risk has been determined and the project risk management strategies have been selected.

1. Introduction

Ensuring the sustainability of an investment construction project is associated with usage of risk-based methods within project management. The project management methodology, based on the concept of project management, allows to achieve goals and objectives of the construction project efficiently and on time, taking into account implementation of production program of a construction enterprise. In this regard, the development and implementation of a modern construction project should be carried out taking into account the requirements of project management methodology. At the same time, it is necessary to ensure sustainability of a construction project, which will increase its manageability. Under a construction project in this study, we understand the system of formulated goals for the implementation of the construction project, the totality of technological and organizational documentation, technological processes, necessary material, financial, labor resources, management decisions and measures for their implementation [1].

Beginning of the formation of systematic research dates back to the 50s of the 20th century, and is associated with the works of L. Bertalanfi, the author of the general theory of systems [2]. Most western scientists approach the problem of management within the framework of the enterprise management methodology in conditions of risk and uncertainty. The most outstanding works are by S. Beer [3, 4], M. Porter [5, 6], J. Stiglitz [7]. A number of key management aspects are considered in such specialized journals as International Journal of Management and Decision Making and International Journal of Management and Enterprise Development [8-10]. The works of G.P.
Schedrovitsky were devoted to the study of questions of logic and methodology of systemic structural studies [11].

The scientists who study the system stability problems are exploring the apparatus of catastrophe theory, nonequilibrium dynamics and synergetics; they tend to rely on study of nonlinear processes in the natural sciences and on the idea that there is a certain universal algorithm of self-organization and complex systems’ development. So, the basis of the system (cybernetic) approach is the assumption that any system is considered as a set of interconnected elements, which has input, output, communication with external environment and feedback [12, 13].

The systematic approach predetermines “the study of a specific control object as a system that includes all the constituent elements or characteristics of an organization as a system: the characteristics of input, process, output” [14].

The cybernetic approach consists of substantiating informational nature of control, in recognizing the universality of control laws for various nature systems, in identifying and organizing feedback mechanisms operating in control systems, in optimizing system behavior based on feedbacks and in accordance with predetermined goals [15].

Thus, the essence of the systematic approach is as follows: setting goals and establishing their hierarchy before the start of any management activity; obtaining maximum effect in the sense of achieving goals by comparative analysis of alternative ways and methods of achieving goals and making choices; quantitative goals assessment and means of achieving them, based on a comprehensive assessment of all possible and planned results of activities.

The objective of this study is to substantiate the technology for managing construction projects based on the theory of system stability. In the framework of the mentioned objective, the following tasks have been solved: theories of stability of automatic control systems are considered; the indicators characterizing the stability degree of a construction project are determined.

2. Methods and materials

The problem of stability and instability is widely covered in the theory of dynamical systems described by differential equations. The concept of stability is defined differently - according to Lagrange, Poisson and Lyapunov, depending on the aspect of considering the dynamic behavior of a phase trajectory or a set of nearby trajectories [16, 17].

According to Lyapunov’s theory of stability of systems, the system seems to be a kind of continuous evolutionary structure and its development can be described in general terms by a system of differential equations [18] (1):

\[ \dot{x}_i(t) = f_i(t, x_1, ..., x_n), i = 1, n, \]

where \( x_i \) – the desired functions, depending on the variable \( t \), which in a general form expresses all those independent parameters of the vital functions of the system. \( x_i \) represents the desired parameters of the system, this indicator may be profit, social status of employees, recognition of the company in society and much more, i.e. \( x_i \) – it is a vector indicator that can be in both quantitative and qualitative terms. The initial position of the system is known where \( x_i(t_0) = x_{i0}, i = 1, n \).

In the study of management processes stability, two tasks are solved:

1. All parameters are given and, therefore, the characteristic equation coefficients are known. It is required to analyze the stability of the control process at the given parameter values.

2. Not all parameters are specified, but only some of them. It is required to determine the ranges of unknown parameters at which the controlled process will be stable [19].

In Lyapunov's theory of stability, one decision is studied for stability.

Let \( z(t, t_0, z_0) \) - be a solution to the system, and it exists on \( [t_0, \infty) \). Then, if there are still some conditions \( z(t, t_0, z_0) \) the solution is called stable if for any \( \varepsilon(0 < \varepsilon < H) \), where \( H – \) the radius of the ball in the Euclidean space \( R_n \), in which the system acts, there is \( \delta = \delta(\varepsilon, t_0) > 0 \) such where all solutions \( x(t, t_0, x_0) \) to the task are infinitely extendable to the right, as soon as \( |x_0 - z_0| \leq \delta(\varepsilon, t_0) \) and for these solutions, inequality
Sustainable system development is presented in figure 1. When using this definition of stability, the stability of a certain class of decisions (but not of all of them) makes sense. In an investment and construction project, sustainability will directly depend on the scope and direction of decisions. In particular, if we take the system of differential equations linear, then the stability of one solution gives rise to the stability of any other and the stability of the whole system can be stated.

![Figure 1. Introducing Sustainable System Development.](image)

Lagrange Stability. For systems of an autonomous system described by a differential equation of the form \( \frac{dx}{dt}=F(x) \), where \( x(t) \) is a dimensional state vector, \( F(x) \) is a vector function that maps \( N \) is dimensional space into itself, a point \( x_0 \) and a phase trajectory emanating from it \( x(t) \) are called Lagrange stable, if the state \( x(t) \) always, for all \( t>0 \), remains in some limited region of the phase space. In other words, there exists a constant \( R \) such that for all \( t>0 \) we have \( \|x(t)\|<R \).

Poisson stability. The phase space point \( y \) is called \( \omega \) - limiting point of the phase trajectory \( x(t) \), if it is possible to indicate a sequence of time moments \( t_k \rightarrow \infty \), then \( \lim x(t_k) = y \). Point \( z \) is called \( \alpha \) - limiting point, if it is possible to indicate the following time consequence \( t_k \rightarrow -\infty \), that \( \lim x(t_k) = z \). The set of \( \omega \) - limiting points forms \( \omega \) - limiting set of the given trajectory \( \Omega_{\omega} \), and the set of all \( \alpha \) - limiting points \( A_{\alpha} \). A trajectory \( x(t) \) is called Poisson stable if its every point is \( \alpha \) -limiting and \( \omega \) -limiting: \( x(t) \in \Omega_{\omega} \cap A_{\alpha} \).

It is obvious that any steady-state oscillation regime of nonlinear systems is represented by trajectories that are Poisson stable. However, not every Poisson-stable trajectory represents a dynamic regime, which from a physical point of view can be considered established, because the Poisson stability property says nothing about neighboring trajectories’ behavior – whether they attract or move away from the original trajectory. It is known that trajectories corresponding to establishment processes (transient processes) are not Poisson stable. It is obvious that any steady-state oscillation regime of nonlinear systems is represented by trajectories that are Poisson stable. However, not every Poisson-stable trajectory represents a dynamic regime, which from a physical point of view can be considered established, because the Poisson stability property does not say anything about the way the neighboring trajectories behave – whether they attract or move away from the original trajectory. It is known that trajectories corresponding to establishment processes (transient processes) are not Poisson stable.

An important characteristic of a stable trajectory in this case is its property to return to an arbitrarily small neighborhood of each of its points an infinite number of times. The return of the trajectory to the neighborhood of the starting point arbitrarily chosen on it is called the Poincare return. However, the mentioned stability concepts of automatic control systems, the dynamics of which are described by a system of differential equations, and their mathematical criteria for analyzing stability, are quite difficult to apply to the processes of development and implementation of construction projects, which are essentially deterministic or probabilistic event processes.

Moreover, the main ideas of this approach were applied in the theory of organizational systems stability, where the stability of an organizational structure is directly related to the stability of the
system itself. From the system stability it follows that organizational structure that has achieved it is also stable, and a transition to another structure for managing the system is only a question of the degree of functioning or stability quality. However, the converse statement is not true in the general case. Therefore, it can be assumed that stability of an organizational structure of a project does not lie in the stability of its implementation forms, in fact it is in the stability of the system’s manageability, in the reaction quality degree of an organizational structure’s management system to changes in the environment in order to prevent the collapse of the managed system, the parameters of its functioning beyond the initially defined framework. Moreover, the organizational structure seems to be a dynamic system that can be changed by the influence of external environment.

The object of study in sustainability problem of construction projects is the system’s internal organizational structure. The organizational structure of the system after its appearance acts to achieve its goals, provides sustainable development; but, at a certain evolutorial level, it is necessary not to only adapt the management structure, but also completely change the management principles, which entails elimination of the old organizational structure and the construction of a new one; that requires implementation of the sustainability principles during the liquidation and emergence of the organizational structure, i.e. at the boundary points of the structure.

Thus, the organizational structure of a system is a structural formation of interactions between the subsystems of the construction project in order to achieve controllability of the system, which is expressed in the ability to transfer the system from one position A to another position B for a given set of t; the quality of an organizational structure is expressed through stability and effectiveness of manageability of the system. The organizational structure of the system can be considered as a stable one if the management system, the distribution of powers for decision-making is able to respond quickly to environmental changes and to ensure sustainable controllability of the system and its reorganization.

A formal system for stability assessing in an organizational structure can be constructed as follows. Let there be a system of subsets \((E, T)\), where \(E = \{e_1, e_2, ..., e_m\}\) - is a finite set of elements, \(T\) – is a number of nonempty subset s of the set \(E\), which serves as authority volume on specific organizational elements. The levels of an organizational system are presented in the form of ranks of distributed powers. The relationship between the system and the organizational structure is ensured through a system of vector weight functions, which vary depending on sustainable development of the system and represent the significance of certain powers, their impact on the system:

\[
w(e) = (w_1(e), w_2(e), ..., w_r(e)) \in \mathbb{R}^r, r \geq 1,
\]

where \(r\) – is number of organizational structure ranks.

To the organizational structure of the system \(Z'(W)\) to be sustainable, it is sufficient to present the equality \(P(W) = S(W)\), where \(Z'(W)\) - is organizational stability radius; \(P(W)\) - is Pareto set of weighted vector functions representing the significance of the elements’ powers of the organizational structure (optimal Pareto set of powers); \(S(W)\) - is semi-efficient set of distributions.

For the stability radius of the organizational system structure the following is true:

\[
\rho(W) \geq \Phi(W) = \min_{i^0 \in P(W)} \max_{i^* \in P(W)} \min_{t^0 \in N} \max_{t^* \in N} \frac{\tau_i(t^0, t^* , W)}{\Delta_i(t^0, t^*)}
\]

The disadvantage of this approach is that when assessing the sustainability of a construction project and the organizational structure that provides it, it is possible to get some n-dimensional space that can indicate what development parameters of the construction project should be (for example, a level of borrowed funds, ratio of debt and non-debt securities, etc.) with other parameters specified (for example, a value of current assets, etc.); and what will change with an increase in any element of this group by a certain amount, what are the consequences of this for the whole project.
The degree of project sustainability is often characterized by break-even boundaries and limit values of such parameters of a construction project as production volume, price per 1 sq. meter etc. In addition, a sensitivity analysis is often used to assess project sustainability, which consists of studying changes in the integral indicators of project effectiveness depending on changes in individual parameters (investment costs, production volume, production costs, interest for a loan, price or inflation indices, delayed payments, estimated duration period, etc.).

The following indicators of construction project implementation can be used: performance indicators (net present value, internal rate of return, profitability index, payback period, return on investment) and annual project indicators (book profit, net profit, balance of accumulated real money).

Sensitivity analysis involves calculating the base model made on the permissible values of the input variables of the project, for which the net present value NPV is determined. This value is the basis for comparison with the allowable possible changes that are to be analyzed. Using this method, stability assessment is carried out by sequentially unit changes in the variables, on the basis of which the new value of the used efficiency criterion, for example NPV, is recalculated. After that, the percentage change in the criterion relative to the base case is estimated and the sensitivity indicator is calculated, that is the ratio of the percentage change in the criterion to the change in the value of the variable by one percent [20].

The next step in conducting a sensitivity analysis is to determine the limit values of the project $F'_{marg}$, i.e. such values for which the net present value becomes zero:

$$NPV (F'_{marg})=0,$$

$$E'_{NPV} = \frac{(NPV_1 - NPV_2)}{(NPV_1 + NPV_2)/2}$$

where $E'_{NPV}$ - is elasticity of net present value according to the i-factor;

$F'^i_1$ - is initial value of i – factor;

$F'^i_2$ - is final value of i – factor.

After determining a critical value of each variable, an analysis of its importance for the project is carried out and the most and least risky variables are identified. The less a project is sensitive to changes in variables, the more stable it is.

Despite all its advantages, the method of sensitivity analysis has a significant drawback - one-factor characteristic, i.e. its orientation to change only one factor of a project; that causes underestimation of possible relationship between individual factors or to underestimation of their correlation.

The measure of stability is here interpreted as the safety margin between the planned value of the variable parameter and its limit value, i.e. the value at which the value of the net present value of the project becomes equal to zero. In this case, stability assessment means assessing the breakeven of the project when varying its parameters. The analysis of approaches to sustainability determining in a construction project showed that the development sustainability and project implementation are not given proper attention. In accordance with the ISO 9001/2000 international quality management standards, project implementation processes are considered as an interconnected network of basic, supporting processes, organizational management processes, risk management mechanisms and other business processes. At the same time, sustainability presupposes adaptation mechanisms, primarily, to the influence of external and internal risks [21-22].

3. Results and discussion
Thus, according to the results of the study, it can be asserted that the construction project management technology from the perspective of sustainability should take into account achievement of the specified results, compliance with the project deadlines under the given restrictions. Approbation of
the proposed construction project management technology was carried out on the example of the construction project of the "Villa Rose" cottage village.

In order to increase the sustainability of the project and to minimize project risks, risks were identified at different stages of project implementation with the help of independent experts. The main risks in the pre-investment phase of the project were identified as follows: errors in the project plan’s strategy; problems of obtaining a building permit; errors in the design development and estimate documentation. At the stage of project implementation, the most significant and probable risks appeared: failure to meet construction deadlines due to the fault of the general contractor and subcontractors; changes in prices for raw materials, energy, components. At the stage of completion of the project, the most significant risks were revealed in reducing the consumers’ solvency and in increasing competition in this market segment. A generalized calculation of the project’s risk is presented in table 1.

**Table 1. Distribution of project risk by stages of project implementation.**

| №   | Type of project risk                          | Weight $W_1$ | Probability $P_1$ |
|-----|-----------------------------------------------|--------------|-----------------|
| 1   | Pre-investment phase                           | 1            | 5.37            |
| 2   | Project implementation phases                  | 0.316        | 3.63            |
| 3   | Project completion phase                       | 0.192        | 1.37            |
|     | **Integral indicator of project risk**         | **1.508**    | **13.1**        |

The integral risk indicator for the project is 13.1% and it is included in the minimum risk zone of 0 - 25%. In order to increase the sustainability of the project, we have applied the main management strategies, taking into account the revealed project risks: evasion, transfer, acceptance and mitigation, refusal to implement the project (table 2-3).

**Table 2. The choice of a project risk management strategy for the construction of the Villa Roses cottage village at pre-investment phase.**

| №   | Type of project risk                          | Probability | Project Risk Management Strategy | Probability |
|-----|-----------------------------------------------|-------------|----------------------------------|-------------|
| 1   | Errors in the project plan’s strategy         | 0.34        | Mitigation strategy              | 0.13        |
| 2   | Errors in the design development and estimate documentation | 0.34 | Evasion strategy | 0.18 |
| 3   | Problems of obtaining a building permit       | 0.47        | Acceptance strategy              | 0.47        |

**Table 3. The choice of a project risk management strategy for the construction of the Villa Roses cottage village at implementation and completion phase.**

| №   | Type of project risk                          | Probability | Project Risk Management Strategy | Probability |
|-----|-----------------------------------------------|-------------|----------------------------------|-------------|
| 1   | Failure to meet construction deadlines due to the fault of the general contractor and subcontractors | 0.32        | Transfer strategy                | 0.17        |
| 2   | Changes in prices for raw materials, energy, components | 0.45        | Mitigation Strategy              | 0.24        |
| 3   | Increasing competition in this market segment | 0.15        | Acceptance strategy              | 0.15        |
| 4   | Reducing consumers’ solvency                  | 0.27        | Acceptance strategy              | 0.27        |

Thus, after the implementation of strategic measures to manage project risks, the final integral risk indicator for the construction project of the Villa Roses cottage community was 7.32%. This made it possible to increase the project’s sustainability and was reflected in the Performance Indicators (Figure 2.).
Figure 2. Indicators of project sustainability before and after application of project management technology.

4. Summary
Accordingly the final project risks may be those of late completion, and exceeding its cost and not achieving the specified quality of results. So, to ensure sustainability of a construction project, it is necessary to provide a managerial solution to the following tasks in a timely manner:

1) to provide reserves in the minimum necessary volumes, to make reserves to eliminate consequences of the risk factors;

2) to determine terms and timing of projects: to take into account not only the technological relationships and duration of the main work, but also the processes of organizational management of a project, elimination of consequences of risk factors, as well as returns associated with the necessity to repeat a number of project activities if inconsistencies are obtained with the given requirements;

3) to determine the volumes, sources and dynamics of financing the implementation of a construction project.

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