Відомі формулювання законів управління проектами були зроблені у вербальній формі і без строгого математичного підтвердження. Для подальшого розвитку теорії управління проектами і переходу від якісних до кількісних оцінок проектів запропоновано використовувати апарат ланцюгів Маркова. Виконано дослідження із застосуванням математичних моделей і доведено, що у такий спосіб формуються нові знання, які орієнтовані на розв'язання нагальних проблем практики

Ключові слова: управління проектами, дискретні стани, ланцюги Маркова, позначений граф, перехідні ймовірності

Известные формулировки законов управления проектами были сделаны в вербальной форме и без строгого математического подтверждения. Для дальнейшего развития теории управления проектами и перехода от качественных к количественным оценкам проектов предложено использовать аппарат цепей Маркова. Выполнены исследования с применением математических моделей и доказано, что таким образом формируются новые знания, которые ориентированы на решение насущных проблем практики

Ключевые слова: управление проектами, дискретные состояния, цепи Маркова, помеченный граф, переходные вероятности

DEVELOPMENT OF THE MODEL OF INTERACTION AMONG THE PROJECT, TEAM OF PROJECT AND PROJECT ENVIRONMENT IN PROJECT SYSTEM

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1. Introduction

A generalization of experimental and theoretical knowledge of the processes and events in the sphere of project management appears in the models, methods, techniques and mechanisms that reflect the models of development and transformation of project systems [1]. For the first time, the hypothesis about the nature of the phenomenon (processes) is nominated based on the information, which is available in response to the demands of practice [2]. Then, the hypothesis is tested experimentally, the law is formulated. The law allows reflecting the essence of all phenomena and processes [3]. An existence of law allows getting a new class of data, which are studied and processed, that can be used as a basis for further research and can increase our knowledge about this class of systems [4]. However, some structures that represent the algorithms of actions of the best practices can acquire the status of rules [5]. The rules are brought to the formal investigation of the laws of algorithms (for example, the rule of "Six Sigma").

Study of the theoretical foundations of project management with the use of mathematical models is the actual direction of research, as thus new knowledge that focuses on solving urgent problems of practice is generated.

2. Literature review and problem statement

A development of project management is realized, mainly, at the expense of the lessons and the best practical examples. Thus, the standards and recommendations for methods of project management are offered, as a rule, the templates, algorithms or recipes of activities. This approach isn't universal. At the same time, there are laws that were formulated in the different spheres of knowledge, which reflect the specificity of some class of systems. A level of sci-

entific knowledge is determined by the degree of abstraction of knowledge expressed in the form of laws. Such laws exist in the scientific domains of project management. The authors of these laws offered a verbal definition of the laws that were presented in the paper [3]:

– the law of initiation of the project: "The project, the project team and its turbulent environment constitute a system, in which existing correlations determine the result of project";

– the law of "the powers of dream" (the law of planning): "A planning of project starts from the result";

– the law of competitive relations in the market conditions: "A market selects the brainiest, strongest, fastest";

– the law of control parameters of the process of the project: "The estimated benefits and actual losses in the project are proportional to the level of risk (of adventurism)";

– the law of the regular improvement of the process of the project: "A creativity of propositions, which consider the improvement of the projects, depends on the level of funding";

– the law of completion of the projects: "The projects are completed with the different results relative to the expectations".

The development of the theory of project management is carried out by summarizing successful projects and the search for new approaches to abstract representation of objective laws of project implementation. The paper [1] presents the theory of development of project management based on knowledge convergence. The authors propose a model of the genome of methodologies for management of projects, programs and portfolios of organization projects.

The paper [2] focuses on the application of strategic management theories to Project Management and Project Portfolio Management research, specifically the Resource-Based View, Dynamic Capabilities, and Absorptive Capacity. These research experiences outline the successful application of strategic management theories to a wide range of contexts, using diverse methodologies at a variety of levels of analysis. The findings indicate a broad potential for further fruitful research stemming from the relatively recent application of strategic management theories to Project Management and Project Portfolio Management research.

Often to resolve the contradictions of project management new concepts are offered. Thus, the paper [4] gives a definition of ambidexterity. Ambidexterity is the ability of an organization (in this case the project as a temporary organization) to be able to both use existing knowledge ("exploitation"), and generate new knowledge ("exploration") in the delivery of a project. The work addressed a theory manage problem (how to manage knowledge and learning), and a theoretical one (how to conceptualize ambidexterity-in-action).

The uncertainty and complexity of the project management arise in large part because of the human factor and the delicate understanding of more complex behavioral aspects [5]. For example, the sensation is considered project participants through the variations of emotions in the continuation of the project life cycle [6]. Sometimes the use of conventional instruments is not implemented in the projects, and only the practice of questioning is used [7]. At the same time, there are studies which reveal sub consciousness many artifacts commonly associated with projects and their management [8].

The development of the theoretical aspects of project management is determined by the area of knowledge of the

project team forming [9], the modern concept of "Lifelong learning" [10], the process approach to the description of the project [11], as well as a focus on the application of international standards [12]. For example, the paper [13] proposed the theoretical basis of the analysis of the project's success, which implements an approach based on knowledge in the field of project management. The need to manage programs in the reform of complex systems on the example of Ukraine's financial system generates seven key success methodologies that allow to develop a program strategy turbulence environment conditions [14].

Analysis of recent publications reveals a lack of studies that develop the theory of project management. Despite the general considerations on the theoretical models, it should be noted that the theoretical basis of this research requires further development and validation of quantitative estimates. The transition from the qualitative performance evaluations for quantitative assessment of the project can be carried out with the help of mathematical models. But now there is no model that reflects the quantitative parameters of the project. This study shows the typical structures of interaction of the main entities of the project – the team to execute the project and its environment, which allowed the use of the Markov chain for the display system.

3. Research goal and objectives

The aim of this study is to develop the theoretical foundations of project management, identifying and using the patterns that are inherent in this emerging defined as the branch of knowledge. The focus of the study is the definition of the unique properties of the project system at the stage of the initiation of projects.

To achieve this goal the following objectives were set:

1. Make a study of project management laws by the decomposition of the system for the main constituent elements and relationships between them to construct a Markov's chain.

2. Make the identification of the Markov model that was developed and prove its ability to use cognitive properties for the theoretical study of the system.

3. Develop the general principles of selection of transition probabilities in the cognitive model that is displayed as a Markov chain.

4. Execute simulation of the behavior of the project system at the step of initiation of projects to confirm the hypothesis that the team, the project and its environment determine the effectiveness of projects.

4. The characteristics of project activity

Each project includes the phases of the project and operational activity that are realized in a changing environment [1]. At first, a plane of project is worked out in the form of some combination of documents. A realization of the plan of the project arises simultaneously with the execution of many works that transform the initial state of the system to a new state under the given conditions regarding quality, costs of resources and time. The result of the project is some product or system that produces a product. The continuous improvement of this system is realized in the phase of operational activity [3]. The environment of

project can contribute or prevent realization of the project at all phases of life cycle [12].

A globalization of economic, a development of international relations in the sphere of trade and production create the conditions for the increase of demands that consumers lay to the quality of the product. The consumers dictate their requirements to the quality of raw materials, components and goods in the conditions of market economy. The consumers demand conformity of goods and processes of production with the international standards in order to confirm that production is organized in such way that the proclamation quality of wares are provided really. The standards, which confirm the level of different aspects of work of enterprise, are the standards ISO 9000 – this is a series of international standards of management of quality and confirmation of quality, which was adopted in more than 90 countries [13].

A quality takes one of the central positions in the methodology or in the project management. Thus, the initial phase of initiation of the project, which is done in the conditions of high uncertainty, is the basis of formation of quality. An existing idea of project is transformed into the vision of project, which involves building a valid model of product, using the available and the most effective methods and ways of converting resources into the products for the solution of the main purpose of project under the existing time constraints, resources, quality taking into consideration the technologies that are used [14].

5. The basing of the law of initiation of project

A management of any system implies an activity, which is associated with changes in the structure of the system or its parameters. The objects of management are the technical systems (machine tools, machines, devices) and the systems of organizational management. The organizational management of the system and its parts involves three levels of decision management solutions. The purposes and solutions that define the relation of the results of the project with the external environment are implemented at the macro level. The organizational management of the knowledge, resources, time, quality and staff is carried out at the level of realization of the project. The technological management is aimed at the production processes and work of the project.

The law of initiations of the project says that the project, the project team and its turbulent environment determine the result of the project due to existing links in the project system [3].

This statement follows from the axiom, which declares that during the initiation of projects the teams of the project, concretely the project implement the communication between themselves and the external environment. Thus, the communication links, which are the basis of any structures of organizational and technical management, are the essential properties of the systems of project management side by side with the characteristics of efficiency of separate processes.

The law of initiation of the project brings together into one system three consolidated essentials: the project, the turbulent environment and the teams of the project. Each of these essentials as the result of decomposition can be represented as a separate system, which includes the elements and the correlations between them (Fig. 1).
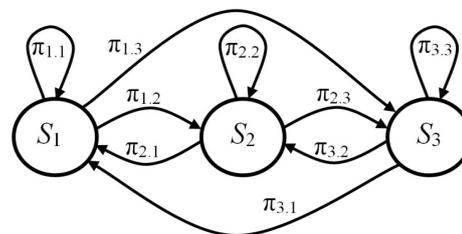

Fig. 1. The probability distribution of states in countering environment

There is the homogeneous Markov chain with discrete conditions and time, which includes condition: S_1 – the project; S_2 – the team of the project; S_3 – the external environment of the project; π_{ij} – the probabilities of transitions into other conditions. It should be noted, that in the system that is being examined side by side with physical characteristics of the communications, the model displays a secondary projection of these communications to the space of knowledge.

The paper presents a hypothesis that is accepted to the interpretation of the parameters of the Markov chain. The probabilities of conditions of the system $p_i(k)$: {i=1, 2, 3} on each step k characterize the time of sojourn of the system in each of the conditions S_i: {i=1, 2, 3}. This means, if the value is $p_3(k)\rightarrow0$, the time of communications with the environment would tend to zero and the project is carried out without the assistance or braking from the side external environment of the project.

Similar provisions can be used also for all other conditions of the system. In general, the functionality of the system $f(S_i)k\Rightarrow F(k, \|\pi_{ij}\|)$ depends on the control actions that are formed during the interaction of elements of the system and are expressed in a unique combination of values of the matrix of transition probabilities. Moreover, two similar projects, which are performed by the same team, also will be unique because their turbulent environment will never be the same in these projects.

6. The description of the system using the Markov chain

The distribution of probability of subsequent conditions of the Markov chain depends on only the current condition and doesn't depend on all previous conditions [10]. The sphere of values of random variables {S_k} is called the space of state of the chain, and the number k is called the number of the step. A marked graph of the conditions represents the Markov chain in which the vertices correspond to the conditions of the chain, and arcs correspond to non-zero probabilities of transitions (Fig. 1). Communications system includes three states (processes) shown in the directed graph Markov chain (Fig. 1). These discrete states correspond to the essence of the project environment: S_1 – project, S_2 – project team, S_3 – environment project. For any state s{s∈1, 2, 3} total communication time T_S from other states can be represented as the sum of the length of time communications with these conditions t_{sj} {s∈1, 2, 3; j∈1, 2, 3}

It is known, that all possible transitions from some condition to another condition make the entire group of events – one of the transitions must be implemented:

$$T_s = \sum_{j=1}^{n=3} t_{sj}, \qquad (1)$$

where t_{sj} – residence time in communication project $s{\rightarrow}j$ from the state s; n=3 – the number of possible conditions of the system.

Each communication numbered state $s{\rightarrow}j$ is performed for a specific time t_{sj} the performance of the project. In this sense

$$\pi_{sj} = \frac{t_{sj}}{T_s}$$

is the probability (frequency) of communications for the transition $s{\rightarrow}j$ for some state s.

The sum of all transition probabilities for some state s is unity:

$$\sum_{j=1}^{n=3}\pi_{sj} = \sum_{j=1}^{n=3}\frac{t_{sj}}{T_s} = \frac{1}{T_s}\sum_{j=1}^{n=3}t_{sj} = 1. \qquad (2)$$

Thus, these transition probabilities π_{sj} for any state s{s1, 2, 3} that are in each row of the matrix of transition probabilities (2) form a group of incompatible events. This property π_{sj}{s$\in$1, 2, 3; j$\in$1, 2, 3} lets you explore the behavior of the system by varying π_{sj}, which changes the level of excellence in design communications system. For example, a project that corresponds to the S_1, is set $\pi_{1.1}{>}0.75$, it will meet the highest cost resource time. That is almost the entire life time in the state S_1 will be spent on internal communications. Similarly you can determine the value of other transition probabilities given time value used resource for various combinations of unique designs for customer and project team (Table 1).

Table 1

Setting values of transition probabilities

The nature of communication s→j and time resource cost	The value of transition probabilities π_{sj}
The biggest waste of time	0.8−1.0
Essential resource hover time	0.8−0.64
Moderate amount of time	0.64−0.2
Low cost resource time	0−0.2
Spending time no resource	0

The above Table 1 rule for determining the transition probabilities can find the source data to model the nature of the change probabilities of the system for any projects in the degree of communication.

The sum of probabilities of all conditions at each step is equal to [15]:

$$\sum_{i=1}^{m}p_i(k) = 1, \qquad (3)$$

where $p_i(k)$ – probability i condition at step k.

In the Markov chain distribution of the probability of conditions {$p_1(k)$, $p_2(k)$, $p_3(k)$} changes when it changes time (step k). Thus, the calculation of the distribution of probabilities at the next step (k+1) is performed by the well-known formula of total probability

$$\begin{Vmatrix}p_1(k+1)\\p_2(k+1)\\p_3(k+1)\end{Vmatrix}^T = \begin{Vmatrix}p_1(k)\\p_2(k)\\p_3(k)\end{Vmatrix}^T \cdot \begin{Vmatrix}\pi_{1.1} & \pi_{1.2} & \pi_{1.3}\\ \pi_{2.1} & \pi_{2.2} & \pi_{2.3}\\ \pi_{3.1} & \pi_{3.2} & \pi_{3.3}\end{Vmatrix}. \qquad (4)$$

If the matrix of transition probabilities has been given $\|\pi_{ij}\|$ and the distribution of probabilities of conditions {$p_1(k)$, $p_2(k)$, $p_3(k)$} at the step k is known, then the new distribution of the probabilities of conditions $\|p_i(k{+}1); i{=}1, 2, 3\|$ can be found using the formula (4).

7. Analysis of results of Markov chains to model the interaction of basic essences projects

In some cases, despite the randomness of the process, there is a possibility to a certain extent to manage the laws of distribution or the parameters of the transition probabilities. It is obviously, the model can be adapted to the changing characteristics of the environment using the controlled Markov chains, so you can use them in the decision-making systems.

At this stage, we examine a hypothetical project system in the context of our hypothesis, which is based on the fact that the Markov chain has cognitive properties. Thus, the specific values are assigned to elements of the matrix of transition probabilities. These values are based on certain conditions that will allow us to identify the regularities in the behavior of the system (Fig. 2 to Fig. 4).

7. 1. The probability distribution of states for loyal impact environment

Define the conditions for the basic variant of the project system which is consistent with the data in Table 1. Let the main time costs are related to the project (state S_1). The transition probabilities for the state S_1 are shown in the first row of the matrix (5). Features of the project team (state S_2) are presented in the second row of the matrix (5). In the state S_2 largest relative time is used by the project team, therefore, the variable $\pi_{2.2}$ is set to 0.65 ($\pi_{2.2}{=}0.65$). The transition probabilities of communication processes with the environment of the project are $\pi_{2.3}{=}0.15$. Communication processes of interaction of the project team with the project are equal $\pi_{2.3}{=}0.15$. The project system, in case of the loyal cooperation between the project in the whole and the environment of the project, is characterized by a decrease in the time that the system spends on their internal needs, so the value of $\pi_{3.3}$ is equal to 0.25.

Taking into account the above-mentioned arguments, we obtain a matrix of transition probabilities for the basic version of the system design.

Taking into account the arguments which were mentioned above, it becomes possible to obtain the primary version of the matrix of transition probabilities:

$$\|\pi_{ij}\| = \begin{Vmatrix}0.75 & 0.15 & 0.10\\ 0.20 & 0.65 & 0.15\\ 0.30 & 0.45 & 0.25\end{Vmatrix}. \qquad (5)$$

The results of the simulations are shown in Fig. 2. The formula (4) was used for the calculations.

For the basic variant of the project system, the distribution of the state probabilities is determined in the 15th step by the relation $p_1(k){>}p_2(k){>}p_3(k)$. This means that the largest part of the time resource will be spent on the project and the project team or its environment will not delay the implementation of the project.
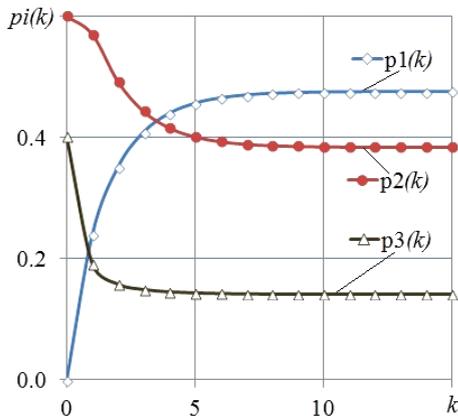
Fig. 2. The change of the state probabilities in the case when the project system contains the loyal environment

7. 2. The probability distribution of states in countering environment

However, in real projects, one always has to deal with the external resistance. In order to display these trends in cognitive model, it is necessary to minimize the interaction between the project system and environment. Compared to the (5), only the transition probabilities in the third stock (for the third state S3) have been changed and a new matrix of transition probabilities has been obtained:

$$\left\|\pi_{ij}\right\| = \begin{Vmatrix} 0.75 & 0.15 & 0.10 \\ 0.20 & 0.65 & 0.15 \\ 0.05 & 0.05 & 0.90 \end{Vmatrix}. \tag{6}$$

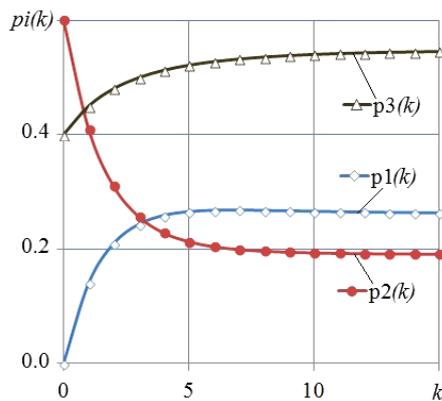The results of the simulations are shown in Fig. 3. The formula (4) was used for the calculations.

Fig. 3. The change of the state probabilities in the case when the project system operates in counteracting environment

For the new variant of the project system, the distribution of the state probabilities is determined in the 15th step by the relation $p_3(k) > p_1(k) > p_2(k)$. This means that the system spends much time and resources on interaction with the environment of the project. As a result, there was a delay in the implementation of the project.

The results of the modeling reflect an essential property of the system of project management at the stage of initiation: the trajectory of the project activity depends on the characteristics of the system. The expenditures of time on communication are acceptable under the condition of loyal interaction with the environment of the project (Fig. 2). A counteraction of the environment leads to considerable efforts to overcome this resistance (Fig. 3).

7. 3. The distribution of state probabilities for the entities of the system project, where there is a loyal interaction with the environment and the project team communicates effectively in the project system

Let us determine the behavior of the project system in case when a much more competent team is involved in the project. For this case, in the matrix (5) it is necessary to change the second line. If a more competent team will be involved, it will reduce the time that the team will spend on themselves. It means that the value $\pi_{2.2}$ will decrease and communication links between the values $\pi_{2.1}$ and $\pi_{2.3}$ will increase. As a consequence, a new matrix of transition probabilities is obtained (7):

$$\left\|\pi_{ij}\right\| = \begin{Vmatrix} 0.75 & 0.15 & 0.10 \\ 0.40 & 0.30 & 0.30 \\ 0.30 & 0.45 & 0.25 \end{Vmatrix}. \tag{7}$$

The results of the simulations are shown in Fig. 3. The formula (4) was used for the calculations.
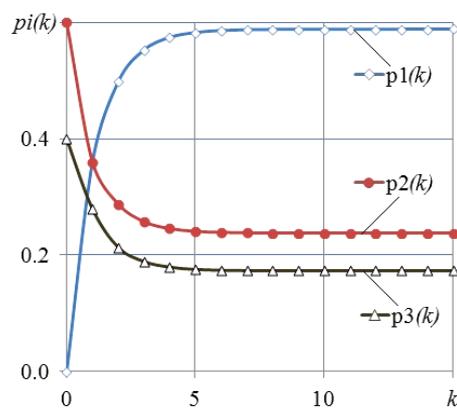

Fig. 4. Changing of probability state of entities of the project when the project system operates in counteracting environment

The simulation results show that the change of the transition probabilities π_{ij} significantly modifies the parameters of the project system and the trajectory of the project. The results have been obtained by using a cognitive model (Fig. 2–4) which does not conflict with the definition of the law of initiation of the project. The Project Management Framework at the stage of initiation includes the main entities, such as the project team, the project and the environment of the project. These entities are constantly influencing each other. This new understanding of the project systems, based on the theory of project management, determines the development of modern approaches as the basis for the development of new practices in the project management.

8. The discussion and perspectives of the further researches

A scientific component of the theory of project management has taken a further development in the form of a law, which was grounded by the authors of the paper on the basis of the new evidential base. The influence of the system and

its other characteristics on the progress of the project can be evaluated using the Markov model that was worked out. The main result of the research is that the project system, which includes the project, its environment and the team, determines the result of the project. This is the definition of the law of initiation of the project. This means that the alteration of the probabilities of conditions of the project reflects the progress and effectiveness of the project.

The new unified Markov model of the stage of initiation of projects has been created, which allows reflecting the probabilities of conditions of the system by a complete group of incompatible events, one of which is realized. A mathematical description of the model using the Markov chains has been done, that allows determining the quantitative parameters of the trajectory of different projects. An employment of the Markov model allows identifying the existing contradictions and conflicts in the project management.

As is known, the theory of project management explores the phenomenon and essence, communication patterns and processes of project management/program/portfolio throughout the life cycles of both managed social or organizational and technical systems with features unique, limited resource, time and quality. Project approach focuses on achievement of useful results. At the same time, scientific results and specific laws related to the subject area of the project management in any other fields are not considered.

Investigated patterns of interaction of fundamental entities of any project using a cognitive model based on the Markov chain indicate that the impact of projects greatly depends on the stochastic characteristics of the system. Practical aspects of the use of the results for certain projects are related with the "tune" of the model to the real system by experimentally determining the transition probabilities of the Markov chain. Thus, it reflected the uniqueness and specificity of any project system.

Because the level of scientific knowledge in any human's activity is determined by the degree of abstraction of knowledge, which is expressed in the form of laws, further researches must be focused on the revelation and grounding of any other hypothesis, axioms, laws and rules of project activity. In the context of outlined researches, the elaboration of methods of theoretical and experimental determination of values of transition probabilities, which actually allow fulfilling the "study" of the Markov model for reflection of real projects should be fulfilled.

9. Conclusions

In the paper, the validity of the law of initiation of projects is investigated. This law is one of the main approaches to the formation of modern project management practices. A number of factors and conditions form a complex configuration of communications in the project system, which changes the management of the system in time.

As a result of the research:

1. It is shown that the process of implementation of the projects development has a typical structure of communications, which suggests the possibility of using a homogeneous Markov chain with discrete states and times to simulate these systems. This approach allows moving from qualitative to quantitative estimate of the characteristics of projects using the theory of Markov chain that reflects the probabilistic nature of project management processes. At the same time, three main entities were defined in the system of the project as discrete states: the team, the project and its turbulent environment. These basic essences of the system are staying in permanent interaction during the step of initiation of projects.

2. On the basis of identification of the Markov model which was developed, the hypothesis about the possibility of referring this model to the class of cognitive models is accepted. The cognitive properties of the model may be expressed in the fact that the transition probabilities in a given system may be determined not only for real project system, but also as parameters of the virtual system. Thus, by changing the values of the transition probabilities on the basis of certain conditions, it is possible to simulate the projects effectiveness.

3. The general rules for selection of transition probabilities in a Markov chain which was developed were offered. The communications system processes, including time-consuming, were detected. This allows defining the transition probabilities as a proportional quantity to the time-consuming. These intervals of transition probabilities were proposed: $\pi_{sj} \in [1,0-0.8-0.64-0.2-0]$. Interval $\pi_{sj} \in [1,0-0.8]$ corresponds to the highest time consumption.

4. The simulation results do not contradict one of the basic concepts of project management, which is as follows: the team, the project and its environment have a major impact on the trajectory of project development. A quantitative assessment of the effectiveness of the project for the different characteristics of the environment, of the project and the project team was obtained. Calculations were performed using a cognitive model presented in the form of a Markov chain.

5. The results obtained form the basis for the practical application in project management. Further research should be focused on theoretical and experimental determination of transition probabilities, which allows to "tune" the Markov chain to the realization of a particular project.

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