Розроблено метод трансформації в ланцюг Маркова відомої рольової моделі команди проекту Р. Белбіна. Запропоновано описати взаємодію між виконавцями проекту у формі орієнтованого графа рольової моделі. Показано, що орієнтований граф становить основу для побудови ланцюга Маркова. Розроблено метод ітераційного рішення системи рівнянь, що описують ланцюг Маркова. Досліджено практичні аспекти діяльності команд на основі рольових комунікацій при реалізації проектів

Ключові слова: рольова модель, дискретні стани, ймовірності переходів, ланцюги Маркова, траєкторія проекту

Разработан метод трансформации в цепь Маркова известной ролевой модели команды проекта Р. Белбина. Предложено описать взаимодействие между исполнителями проекта в форме ориентированного графа ролевой модели. Показано, что ориентированный граф составляет основу для построения цепи Маркова. Разработан метод итерационного решения системы уравнений, описывающих цепь Маркова. Исследованы практические аспекты деятельности команд на основе ролевых коммуникаций при реализации проектов

Ключевые слова: ролевая модель, дискретные состояния, вероятности переходов, цепи Маркова, траектория проекта

UDC 005.8

DOI: 10.15587/1729-4061.2017.103231

DEVELOPMENT OF THE MARKOV MODEL OF A PROJECT AS A SYSTEM OF ROLE COMMUNICATIONS IN A TEAM

D. Lukianov
PhD*
E-mail: lukianov@bsu.by

K. Bespanskaya-Paulenko
PhD, Associate Professor*
E-mail: bespanskaya@bsu.by

V. Gogunskii
Doctor of Technical Sciences, Professor**
E-mail: vgog@i.ua

O. Kolesnikov
PhD, Associate professor**

A. Moskaliuk
PhD**

K. Dmitrenko
Assistant**
E-mail: katerina.dmitrenko@gmail.com

*Department of General and Clinical Psychology
Belarusian State University
Nezavisimosti ave., 4, Minsk, Belarus, 220030

**Department of Systems Management Life Safety
Odessa National Polytechnic University
Shevchenko ave., 1, Odessa, Ukraine, 65044

1. Introduction

Three main entities of project systems: a team, a project and its environment, determine success of project implementation [1]. Turbulent environment creates a set of random perturbations [2]. Fulfillment of project-related tasks is always associated with the risk-reducing activity [3]. Therefore, the main task of project teams is to find innovative solutions and methods for solving the problems posed by the environment and the project [4]. However, we cannot deny the occurrence of contradictions in a team project [5].

In modern project management, there are two basic approaches to the formation of teams [6]. The first is based on strengthening and development of teams formed in a natural way (team building). The second is focused on a competence provision of the project work and a role division in a team by the project manager [7]. The task of these approaches is to increase professionalism and competence of a team through a combination of the roles of all participants and formation of conditions for rational interaction between members of the project team [8].

Contradictions between practical needs in the team organization of projects implementation and the lack of acceptable models for quantitative assessment of interaction between the members of a project team determines the relevance of research in terms of provision of teamwork effectiveness. Development of mathematical models that implement the role paradigm of a team activity will allow us to perform proactive (predicted) improvement of teams.

2. Literature review and problem statement

Organization and management of interaction in projects is the cornerstone of their successful implementation. Thus, Apple (the United States) uses totally star teams. However, bonuses are given only for team achievement: nobody's personal work is appreciated if the whole team fails to receive such high assessment [9].

Another approach to the selection of "proper" employees was invented by founders of the startup company "Boundless" (USA) dealing with creation of free lecture notes for students [10]. This experience created the basis for the formation of the invincible team. For this purpose, representatives of four types of personalities are needed: the Beast, Lara Croft, the Architect and the Most Interesting Man in the World. The Beast has the character, similar to X-people from a famous cartoon; it aims to be the best, acts beyond human abilities. Lara Croft is an adventurer and an analyst; she creates goals and projects for herself and for increasing the company's values, is a motivated researcher, works for satisfaction of her own interest. The Architect is an inspired character from the Matrix, understands the general picture of a project, can clearly articulate a high-level strategy. The Most Interesting Man in the World is the interlocutor, peacemaker, he adds depth to the corporative culture, has experience in overcoming challenges, keeps positive attitude to colleagues. These specialists have led the company to success [10].

In article [11], it is proved that in the case of implementation of unique projects, there is always a conditioned lack of knowledge within a team. Management of united competencies of a whole team is of crucial importance for success of projects – especially for large projects [6]. The problem of evaluation of the general competence of a team, depending on the level of professional training of individual project participants is considered in [7]. Formation of ships' crews based on the individual psycho-types is examined in research [12]. The authors of [12] divide the candidates for team members by the Hippocrates classification into 4 types: sanguine, phlegmatic, choleric and melancholic – a rational combination of crew members by introversion and extroversion indicators makes it possible to form "ideal teams" [12].

All the above-mentioned methods of team formation are focused on adjustment of people's qualities to the type of expected activity. One of the most accepted models is the role model [13]. Its essence is that in any team, there is a specific set of roles that are performed by the members of a team. If roles coincide with the interests of performers, the team works in coherence [9]. That is, such a model is the most acceptable. Existing descriptions of the role model are performed in the notes of qualitative representation of outcomes of the teamwork. Therefore, it is necessary to construct a model with quantitative parameters.

To construct the cognitive role structure of a model, we will characterize "9 roles" according to R. Belbin. These descriptions may be used as "control cards" for a particular team.

1. *Mastermind of a team*. Seeks to unite and harmonize relationships between group members. Takes the position of a person who understands concerns of others, seeks to help and smoothes out conflicts. This person is kind by nature, is eager to establish informal relationships. However, he may be sometimes indecisive in difficult or critical situations.

Markers: "I am very interested in your point of view. Each person has good qualities you may address. I try to be flexible".

2. *Generator of ideas*. An original thinker who gives life to new ideas. Independent scientist with developed imagination, but like other people has negative traits – may be oversensitive to criticism. To achieve success, the generator of ideas needs constructive relationships with the manager or the group coordinator.

Markers: "Ideas are born in dreams. Where there is a problem, there is a solution. The bigger the problem, the more interesting the challenge is".

3. *Coordinator*. Typically, the formal leader of a group. Manages and directs a group to achieve goals. Can determine in advance, which of the employees is good enough to perform necessary tasks. He is usually calm, confident and efficient. However, he is sometimes prone to excessive dominance, and a group becomes continuation of his strong "ego".

Markers: "Mind the ultimate goal. Has anyone anything to add to this? I believe we should give a chance to someone else".

4. *Communicator*. Like the generator of ideas, brings in new ideas, borrowed from the outside, due to his wide contacts. Flexible, looks for opportunities. Usually talks on the phone or is somewhere at a meeting. Prevents development of group sluggishness. Negative features of character include laziness, self-satisfaction and, sometimes it takes a crisis or pressure of circumstances to motivate him.

Markers: "We can make a fortune out of it. Other people's ideas should be taken with pride. Opportunities appear as a result of other people's mistakes".

5. *Peacemaker*. Energetic team member, capable of implementing ideas. Sees the world as a project that requires implementation. Loyal in relationships with team members. Usually confident, dynamic, emotional and impulsive. The engine of a group, but may be irritable, unrestrained, inconsiderate.

Markers: "If you say: "I'll do it, I believe that it will be so. Treat your colleagues as you would be treated. Please respect opinions of others. I may be harsh, but I am right".

6. *Specialist*. Professional, independent, aims to become an expert in his field. Has high professional expertise and knowledge, is proud of his work. Works only in his narrow professional field.

Markers: "Choose a job to your liking, and you will never have to work. True professionalism is one's own reward. The committee is twelve people who do the work of one person".

7. *Implementer*. Can transform a strategic plan into specific managerial tasks that are reasonable to address. A good organizer, methodical and pragmatic. He is identified with a group, loyal and honest employee. However, he may be inflexible, firm.

Markers: "A day of practice is worth a year of theory. If it is hard to do, then do it immediately. If it is impossible to do, it will take a little more time. Errare humanum est, but companies don't tend to forgive mistakes".

8. *Controller*. Perfectly knows how to create reports about the work of a group. Concerned about precise execution of obligations, tries not to overlook even the smallest details. Insists on keeping precise schedule of works, but may become excessively anxious.

Markers: "Inscriptions, made in small print, should always be read. There is no excuse why you can not be the best. Has anyone checked it?".

9. *Analyst*. Evaluates proposals and takes the position of an observer for project promotion. Prevents a group from moving the wrong way. Cautious, impartial, has analytical mind. He might seem indifferent, uninterested, sometimes becomes overcritical.

Markers: "Have we used all opportunities? It seems to be the best option for these terms and resources. Decisions should not be based on enthusiasm".

Complexities of interactions between team members in project management are caused by the existence of a set of external and internal factors [14]. The turbulence of the project environment and uniqueness of the tasks, performed by a project team, make it impossible to separate and carefully study the individual elements of the system [15]. The design systems have emergency properties – they have certain characteristics not possessed by its elements, as well as the sum of elements. These features determine the necessity of studying the phenomena in design systems not for individual elements, but rather for a project as a whole [16]. Thus, to represent the trajectory of projects development in the phase space of probability of states, it is proposed to apply phenomenological models [17]. To the class of such models we may include the Markov chains that allow us to represent a link between output and input parameters without taking into account the physical essence of processes in the system. The Markov chains reproduce the topological structure of relationships between the elements of projects. In this case, parametric "tuning" to certain projects is carried out through determining conditional transition probabilities between the elements of the system based on practical data [18].

The peculiarities of realization of the "learning for life" paradigm were shown thanks to the cognitive properties of the Markov chains [16]. The features of project management with the use the Markov model are explored in paper [17]. The task of initiating projects on labor protection using the Markov model was examined in article [18]. In paper [19], the Markov model reflects the system of changes in states of patients in projects involving provision of medical services. The Markov model is used to evaluate the quality of educational institutions [20]. These studies are based on decomposition of the investigated systems into certain discrete states with the construction of a diagram of transitions between these states. Differences in creation of the mentioned models are shown in various methods for determining conditional probabilities of transitions between discrete states. That is, the specificity of displaying different objects with the homogeneous Markov chains with discrete states and discrete time is determined by the methods for calculation of transition probabilities.

The models allow solving the problems of achieving set goals in terms of limited temporal, financial, material, human, and other types of resources. So, it is time is to create a method of transformation of the known graphic representations of projects into the Markov model that reflect essential properties of projects [21]. The interaction of projects participants is the most important condition for successful implementation of the project activity, which is generally regarded as the characteristic of the level of competence and skill of the project manager and his team.

3. The aim and objectives of the study

The aim of present study is to develop a model of interaction between members of a project team based on role characteristics using a Markov chain.

To achieve the set goal, the following tasks had to be solved:

– to develop a cognitive scheme of interaction of project performers, which were defined by Belbin in the role structure of projects;

– to develop a method for transformation of a cognitive scheme of interaction of project into a Markov chain;

– to perform formalization of definition of transition probabilities of the Markov model with regard to time, spent on the realization of communications between the elements of the system;

– to explore the features of practical determination of the trajectory of projects development under conditions of different role characteristics of the project team participants.

4. Creation of a role model and description of the Markov chain

Imagine a role model for team work using ten discrete states, which correspond to discrete constituents of the system. To construct the Markov model of interaction in a project team as communications between states of the design system, note the basic transitions between these states (Fig. 1).

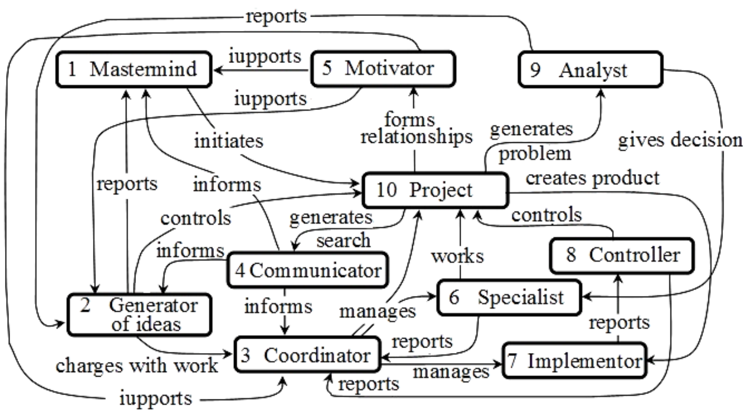

Fig. 1. Graphic representation of cognitive structure of role model in a project

Cognitive structure of the role interaction between the performers of projects is a similarity of the directed graph with vertices that correspond to the states of a project, and arcs that represent communication links between project participants [21]. Cognitive structure includes 10 peaks, as the basic states of the organization of team work in projects (Fig. 2). Actually, the states of the system and transitions between these states are displayed. If we accept that the sum of probabilities of all states is equal to unity, as well as the fact that transitions from each state are incompatible with events, this graph may be transformed into a Markov chain with discrete states [22]. For this purpose, we shall supplement the directed graph that represents cognitive features of teamwork with links of delays in each of the 10 states. As a result of this transformation, we will obtain a graph of the Markov chain (Fig. 2).

Let us describe a Markov chain by using the method of probabilities of states [22]. Probabilities of transitions are shown in the marked-out graph (Fig. 2). By a step, we will imply a cycle of execution of actions that include a set of certain operations [23]. In first approximation, we accept that all steps may be equivalent.

Identifiers S_i, {i=1,..., 10} designate the possible states of the system. They form a model of 10 states, which form a complete group of incompatible events. This model represents the Markov chain, since both in the processes of project management, and in the Markov chains, there might be changes in probabilities of states of the system by steps k. There are probabilities of transitions to other states, the sum of transition probabilities from a certain state is equal to the unit, and the sum of probabilities of all states at each step is also equal to the unit [16]. There is similarity of topological structure of transitions [18].

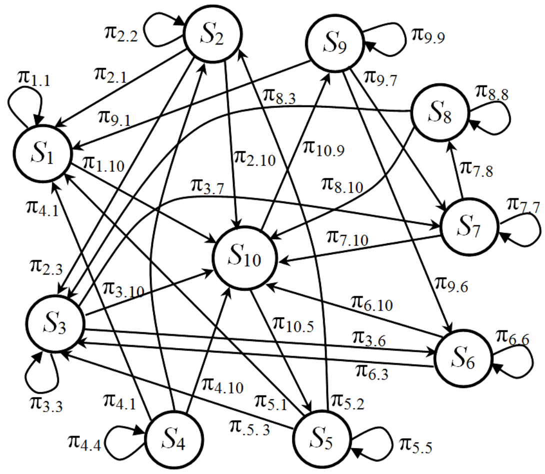

Fig. 2. Marked-out graph of the Markov chain that represents internal communications in the role model of a project

The sum of transition probabilities π_{ij} from a certain state $i \in (1, 2, ..., m)$ to other states $j \in (1, 2, ..., m)$ is equal to unity [14]:

$$\sum_{j=1}^{m} \pi_{ij} = 1, \ \{i = 1, 2, \cdots, m\}, \tag{1}$$

where m=10 is the number of possible states of the system.

General solution of the system of equations describing the Markov chain is shown in Fig. 2, it can be written in the form [22]:

$$\begin{Vmatrix} p_1(k+1) \\ p_2(k+1) \\ p_3(k+1) \\ p_4(k+1) \\ p_5(k+1) \\ p_6(k+1) \\ p_7(k+1) \\ p_8(k+1) \\ p_9(k+1) \\ p_{10}(k+1) \end{Vmatrix}^T = \begin{Vmatrix} p_1(k) \\ p_2(k) \\ p_3(k) \\ p_4(k) \\ p_5(k) \\ p_6(k) \\ p_7(k) \\ p_8(k) \\ p_9(k) \\ p_{10}(k) \end{Vmatrix}^T \cdot \begin{Vmatrix} \pi_{1.1} & \pi_{1.2} & \pi_{1.3} & \pi_{1.4} & \pi_{1.5} & \pi_{1.6} & \pi_{1.7} & \pi_{1.8} & \pi_{1.9} & \pi_{1.10} \\ \pi_{2.1} & \pi_{2.2} & \pi_{2.3} & \pi_{2.4} & \pi_{2.5} & \pi_{2.6} & \pi_{2.7} & \pi_{2.8} & \pi_{2.9} & \pi_{2.10} \\ \pi_{3.1} & \pi_{3.2} & \pi_{3.3} & \pi_{3.4} & \pi_{3.5} & \pi_{3.6} & \pi_{3.7} & \pi_{3.8} & \pi_{3.9} & \pi_{3.10} \\ \pi_{4.1} & \pi_{4.2} & \pi_{4.3} & \pi_{4.4} & \pi_{4.5} & \pi_{4.6} & \pi_{4.7} & \pi_{4.8} & \pi_{4.9} & \pi_{4.10} \\ \pi_{5.1} & \pi_{5.2} & \pi_{5.3} & \pi_{5.4} & \pi_{5.5} & \pi_{5.6} & \pi_{5.7} & \pi_{5.8} & \pi_{5.9} & \pi_{5.10} \\ \pi_{6.1} & \pi_{6.2} & \pi_{6.3} & \pi_{6.4} & \pi_{6.5} & \pi_{6.6} & \pi_{6.7} & \pi_{6.8} & \pi_{6.9} & \pi_{6.10} \\ \pi_{7.1} & \pi_{7.2} & \pi_{7.3} & \pi_{7.4} & \pi_{7.5} & \pi_{7.6} & \pi_{7.7} & \pi_{7.8} & \pi_{7.9} & \pi_{7.10} \\ \pi_{8.1} & \pi_{8.2} & \pi_{8.3} & \pi_{8.4} & \pi_{8.5} & \pi_{8.6} & \pi_{8.7} & \pi_{8.8} & \pi_{8.9} & \pi_{8.10} \\ \pi_{9.1} & \pi_{9.2} & \pi_{9.3} & \pi_{9.4} & \pi_{9.5} & \pi_{9.6} & \pi_{9.7} & \pi_{9.8} & \pi_{9.9} & \pi_{9.10} \\ \pi_{10.1} & \pi_{10.2} & \pi_{10.3} & \pi_{10.4} & \pi_{10.5} & \pi_{10.6} & \pi_{10.7} & \pi_{10.8} & \pi_{10.9} & \pi_{10.10} \end{Vmatrix}, \tag{2}$$

where T is the sign of transposition of columns; π_{ij} are the transition probabilities

The sum of probabilities of all states $p_i(k)$ at every step k is also equal to unity [22, 23]:

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

where $p_i(k)$ is the probability of the i-th state at step k; $i \in (1, 2, ..., m=10)$.

By step k, we imply a certain controlling impact, which transfers the system to a new state [13].

Determining in formula (1) of all elements π_{ij} and values of original probabilities of states $\{p_1(k), p_2(k), ... p_{10}(k)\}$ allows us to calculate magnitudes $\{p_1(k+1), p_2(k+1), ... p_{10}(k+1)\}$.

5. Identification of the Markov chain by the characteristics of communications

Interactions in the system at project management are shown in the directed graph (Fig. 2). For any discrete state $s\{s \in 1, ..., 10\}$, the total time T_s of communications with other states may be imagined as the sum of durations of communications with these states $t_{sj}\{s \in 1, ..., 10; j \in 1, ..., 10\}$ [24]:

$$T_s = \sum_{j=1}^{n=10} t_{sj}, \tag{4}$$

where t_{sj} is the time of a project staying in communication $s \to j$ from state s.

During project implementation, the system may be in each communication $s \to j$ for certain time t_{sj}.Values $\pi_{sj}=t_{sj}/T_s$ make sense of probability of transition from the state $s \to j$.

The sum of all transition probabilities for a certain state s is equal to unity:

$$\sum_{j=1}^{n=10} \pi_{sj} = \sum_{j=1}^{n=10} \frac{t_{sj}}{T_s} = \frac{1}{T_s} \sum_{j=1}^{n=10} t_{sj} = 1. \tag{5}$$

Thus, transition probabilities π_{sj} for any state s{sÎ1, ..., 10}, which are represented in each row of the matrix of transition probabilities, form incompatible group of events. Such property π_{sj} $\{s \in 1, ..., 10; j \in 1, ..., 10\}$ allows us to explore behavior of the system at different variants of source data of a project. By changing π_{sj}, it is possible to change characteristics of the system.

In a general case, transition probabilities π_{sj} $\{s \in 1, ..., 10; j \in 1, ..., 10\}$ "set" the Markov model to the real object. In this case, to determine transition probabilities π_{sj},, two approaches are usually used. The first one implies involving experts who, based on their experience, perform assessment of values of transition probabilities [19]. In the second case, a questionnaire survey method is applied, which allows determining magnitudes of probabilities of states $p_1(k), p_2(k), ..., p_n(k)$, which subsequently serve as the basis for finding the values of transition probabilities [20]. We propose a new, third method when the values of transition probabilities are determined by a manager based on the characteristics of communications in the system taking into account consumption of temporal resources for the fulfillment of operations (Table 1).

Table 1

Determining the values of transition probabilities π_{sj}

Character of communication $s \to j$ by consumption of temporal resource	Transition probabilities π_{sj}
Highest level of time consumption	0.8–1.0
Medium level of time consumption	0.3–0.7
Lowest level of time consumption	0.1–0.2
Insignificant time consumption	0.01–0.1
No time consumption	0

The rules for determining the values of transition probabilities, given in Table 1, allow us to find the source data for modeling changes in the probabilities of states of the system for projects at any combinations of resourcing and levels of competence of a project team. The values of transition probabilities $\pi_{i,j}$ are determined from Table 1. Based on the matrix of transition probabilities, provided that the original state of the system is known, we can find all probabilities of states of the system $p_1(k)$, $p_2(k)$,..., $p_{10}(k)$ after any k-th step by dependence (1).

Thus, for "tuning" the Markov chain with discrete states and time to represent the properties of particular systems, it is necessary to determine all elements π_{ij} in the matrix of transition probabilities between various states [22].

6. Results of modeling a role structure of the project implementation

Given the missing links, we will obtain such solution for the acceptable matrix of transition probabilities that reflects basic variant of the role structure of the project implementation:

$$\begin{Vmatrix} p_1(k+1) \\ p_2(k+1) \\ p_3(k+1) \\ p_4(k+1) \\ p_5(k+1) \\ p_6(k+1) \\ p_7(k+1) \\ p_8(k+1) \\ p_9(k+1) \\ p_{10}(k+1) \end{Vmatrix}^T = \begin{Vmatrix} p_1(k) \\ p_2(k) \\ p_3(k) \\ p_4(k) \\ p_5(k) \\ p_6(k) \\ p_7(k) \\ p_8(k) \\ p_9(k) \\ p_{10}(k) \end{Vmatrix}^T \times$$

$$\times \begin{Vmatrix} 0.40 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.6 \\ 0.05 & 0.4 & 0.15 & 0 & 0 & 0 & 0 & 0 & 0 & 0.40 \\ 0 & 0 & 0.40 & 0 & 0 & 0.20 & 0.25 & 0 & 0 & 0.15 \\ 0.05 & 0.35 & 0.15 & 0.45 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0.05 & 0.30 & 0.10 & 0 & 0.55 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0.20 & 0 & 0 & 0.60 & 0 & 0 & 0 & 0.20 \\ 0 & 0 & 0 & 0 & 0 & 0.40 & 0.60 & 0 & 0 & 0 \\ 0 & 0 & 0.45 & 0 & 0 & 0 & 0 & 0.35 & 0 & 0.20 \\ 0 & 0.25 & 0 & 0 & 0 & 0.35 & 0 & 0 & 0.40 & 0 \\ 0 & 0 & 0 & 0.20 & 0.10 & 0 & 0.20 & 0 & 0.10 & 0.40 \end{Vmatrix}. \quad (6)$$

The elements of probability matrix that are given in (6) were obtained based on data from Table 1. Based on (4) and (5), we will note that the lines of the matrix of transition probabilities are independent. Each line describes characteristic of a certain state (role) in terms of communications with other states. Thus, for the state "Specialist", it means that communications with "Coordinator" ($\pi_{6.3}$=0.2) and "Project" ($\pi_{6.10}$=0.2) should be related by time consumption to the lower level, according to Table 1. Time consumption for personal work is $\pi_{6.6}$=0.6, which corresponds to the interval of average consumption. As the given example shows, transition probabilities for each state are conditional characteristics that represent distribution of time consumption among all communications from this state. In this case, distribution of time consumption depends on the competence of the performer of a particular role. Based on the specified conditions, we determined conditional transition probabilities for all states.

Fig. 3 shows results of modeling of states of the system for the matrix of transition probabilities, which is the basis in the present study.

For a certain level of competence and organization of the team, which correspond to the totality of values of transition probabilities, determined by Table 1, it is possible to draw the following conclusions. The highest probability after step 10 corresponds to state 10 "Project" (Fig. 3). Next, the most significant are the roles of performers: 3 – "Coordinator", 8 – "Controller" and 7 – "Implementer". The role of "Specialist" can also be attributed to the most time-consuming roles in a project team (curve 6). Probabilities of states for the roles "Communicator" and "Generator of ideas" at step 15 become virtually the same. All other states are at the level of insignificant time consumption.

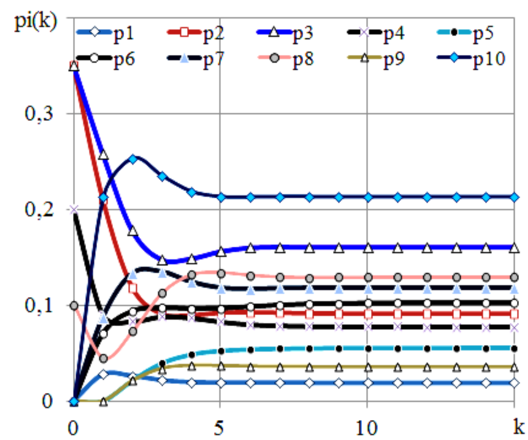

Fig. 3. Change in the probabilities of states of the system by the basic variant: p1 — master mind; p2 — generator of ideas; p3 — coordinator; p4 — communicator; p5 — motivator; p6 — specialist; p7 — implementer; p8 — controller; p9 — analyst; p10 — project

As is known, a main cause of failures in most projects is the application of inadequate methods of management. Failures are caused by structural or parametric project characteristics that are not specified in time [25]. Under such conditions, the classic "waterfall" approaches to management of complex systems are not effective.

To assess the distribution of probabilities of states of the system with other characteristics of team members, we will make some changes to the matrix of transition probabilities only for one member of the team in the role of "Specialist". Let $\pi_{6.3}$=0.05 and $\pi_{6.10}$=0.05, hence, it follows from (3) that $\pi_{6.6}$=0.9. Such probability characteristics of the competence of a performer of the role "Specialist", according to data from Table 1, represent his state as the one associated with a relatively high time consumption for personal work. That is, all time resource is used to search for solutions. All other transition probabilities will remain the same as in the basic variant (6). For these modified data (7), we will obtain results that represent the role of "Specialist" in the activity of a project team (Fig. 4).

Modification of the Markov model will take the following solution:

$$\begin{Vmatrix} p_1(k+1) \\ p_2(k+1) \\ p_3(k+1) \\ p_4(k+1) \\ p_5(k+1) \\ p_6(k+1) \\ p_7(k+1) \\ p_8(k+1) \\ p_9(k+1) \\ p_{10}(k+1) \end{Vmatrix}^T = \begin{Vmatrix} p_1(k) \\ p_2(k) \\ p_3(k) \\ p_4(k) \\ p_5(k) \\ p_6(k) \\ p_7(k) \\ p_8(k) \\ p_9(k) \\ p_{10}(k) \end{Vmatrix}^T \cdot \begin{Vmatrix} 0.40 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.6 \\ 0.05 & 0.4 & 0.15 & 0 & 0 & 0 & 0 & 0 & 0 & 0.40 \\ 0 & 0 & 0.40 & 0 & 0 & 0.20 & 0.25 & 0 & 0 & 0.15 \\ 0.05 & 0.35 & 0.15 & 0.45 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0.05 & 0.30 & 0.10 & 0 & 0.55 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0.05 & 0 & 0 & 0.90 & 0 & 0 & 0 & 0.05 \\ 0 & 0 & 0 & 0 & 0 & 0.40 & 0.60 & 0 & 0 & 0 \\ 0 & 0 & 0.45 & 0 & 0 & 0 & 0 & 0.35 & 0 & 0.20 \\ 0 & 0.25 & 0 & 0 & 0 & 0.35 & 0 & 0 & 0.40 & 0 \\ 0 & 0 & 0 & 0.20 & 0.10 & 0 & 0.20 & 0 & 0.10 & 0.40 \end{Vmatrix}. \quad (7)$$

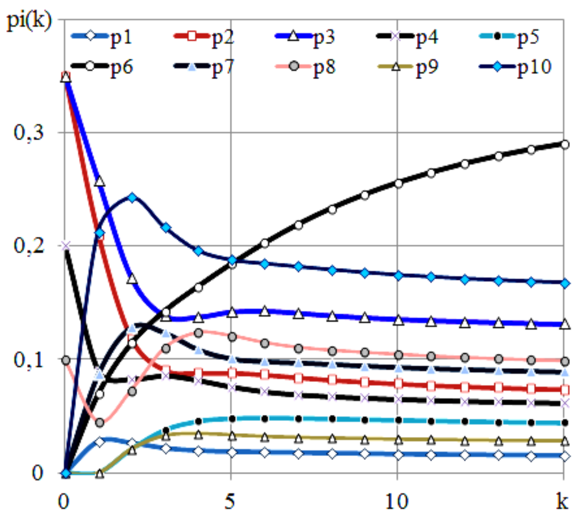

Fig. 4. Change in the probabilities of states of the system with a modified variant of the level of competence of a team member by the role "Specialist": p1 – mastermind; p2 – generator of ideas; p3 – coordinator; p4 – communicator; p5 – motivator; p6 – specialist; p7 – implementer; p8 – controller; p9 – analyst; p10 – project

Under these conditions, the role of "Specialist" becomes one of the defining roles in the implementation of successful team performance (Fig. 4, curve 6). In this case, a character of change in other probabilities of states of the system also becomes different from the basic variant, shown in Fig. 3.

7. Discussion of results of representation of projects with different role characteristics of project team members

The developed approach to the transformation of a team role model of R. Belbin into a Markov chain will allow us to make substantiated conclusions not only on the effectiveness of teams, but also to assess a contribution of each team member [18]. For this purpose, it is necessary to perform identification of values of transition probabilities for each team member by any of available methods. This will make it possible to tune the Markov model so that it could represent a real picture of the system in order to identify "bottlenecks" in the communication system of a real team [19].

When interpreting data on the development of a project's trajectory at different role characteristics of participants of a project team, it is necessary to take into account that probabilities of state of the system $p_1(k)$, $p_2(k)$,..., $p_{10}(k)$ represent probabilities of incompatible events from a whole group. For all states $s\{s\in 1,..., 10\}$, the total time T of project implementation at each step k may be represented as the sum of duration of communications in these states $\tau_s(k)$ $\{s\in 1,..., 10\}$:

$$\Theta = \sum_{s=1}^{n=10} \tau_s(k), \quad (8)$$

where Θ is the total duration of a project; $\tau_s(k)$ is the time of project being in $s\{s\in 1,..., 10\}$ at step k.

The system can enter each of states $s\{s\in 1, ..., 10\}$ at step k for a certain time $\tau_s(k)$ during project implementation. The value of $p_s(k)=\tau_s(k)/\Theta$ makes sense of probability of the project entering state $s\{s\in 1,..., 10\}$ at step k.

The sum of all probabilities of states in accordance with (2) is equal to unity:

$$\sum_{s=1}^{n=10} p_s(k) = \sum_{j=1}^{n=10} \frac{\tau_s(k)}{\Theta} = \frac{1}{\Theta} \sum_{j=1}^{n=10} \tau_s(k) = 1. \quad (9)$$

Because the specified probabilities of states $p_s(k)$, $s\{s\in 1, ..., 10\}$ are determined by (2), taking into account (8) and (9), they form an incompatible group of events. It allows correlating magnitudes $p_s(k)$ to the duration of project implementation.

Thus, a duration of participation of a specialist in a project changes monotonously to the magnitude equal to $p_6(k)=0.11$ (Fig. 3). This is equivalent to 11 % of the total costs for the basic variant of the role model of project implementation. In this case, the highest probability at step 15 is correlated to state 10 ("Project") – 20 % of total time consumption for the project. The role "Coordinator" needs 17 % of the time, allocated to the project. A general picture of differences in results of modeling of the basic (variant 1) and modified (variant 2) Markov model with the sample of values of probabilities of states $p_s(k)$ $\{s\in 1,..., 10; k=15\}$ is shown in Fig. 5.

Results of modeling reveal that if there are other characteristics of team members that represent changes in the matrix of transition probabilities, the overall picture of distribution of probabilities of states in the system also changes. In variant 2 of the model, the following competence characteristics are accepted for a team member in the role of "Specialist": $\pi_{1.6}=0.05$; $\pi_{6.10}=0.05$ and $\pi_{6.6}=0.9$. At these input data, we obtained results that differ from the basic variant 1 (Fig. 5). These results represent the essential property of teamwork: effectiveness of projects depends on the coherence of roles of all performers.

Theoretical part of the present research is based on the hypothesis that the role structure of project teams may be represented using the Markov chains. We imply by the states of the Markov chains the role preferences of performers. Obtained results do not contradict the accepted hypothesis. It was shown that the transformation of the role model of R. Belbin into a Markov chain is an effective method for phenomenological representation of project structure based on the role characteristics of project performers. It was proven that the use of the Markov chains is acceptable in order to represent projects based on the role characteristics of participants of project teams.

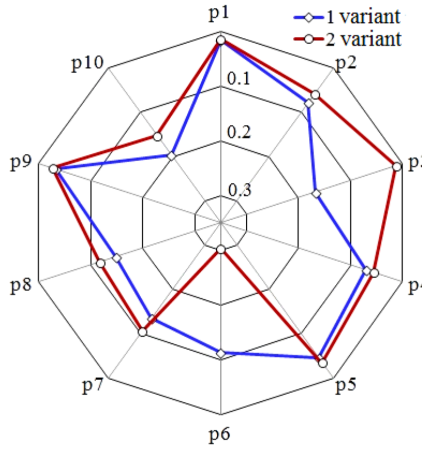

Fig. 5. Comparison of data of modeling for the basic (1) and modified (2) variants of the Markov model: 1 — basic variant; 2 — modified variant; p1 —master mind; p2 — generator of ideas; p3 — coordinator; p4 — communicator; p5 — motivator; p6 — specialist; p7 — implementer; p8 — controller; p9 — analyst; p10 — project

The proposed transformation of a team role model of R. Belbin into a Markov chain allows passing from qualitative assessments of the course of projects to quantitative characteristics of the system. In this case, quantitative assessment compiles a multi-vector picture of change in the probabilities of states of the system's elements in steps, which is inherent to prediction systems [22].

8. Conclusions

The study was conducted as a theoretical basis for the substantiation of the method of transformation of the role model of R. Belbin into a Markov chain.

1. The cognitive scheme of interaction between project performers taking into account the role of characteristics of each participant of a project team was synthesized. It was shown that the model of R. Belbin should be supplemented with entity "Project" as one of the key discrete states of a project system. It was proved that role distribution in a project team forms a system of communication between participants of a project team. These internal communications within a project team determine a topological structure of the project in the form of a directed graph.

2. The method of transformation of the project role structure into the Markov model was developed. Construction of this model starts with determining the states and representation of communication links with the formation of a directed graph of the role structure of projects. Next, the matrix of transition probabilities for a graph of the project is created. This allows us to pass to the development of analytical stepwise solution of the system of equations of the Markov chain. An important stage is to establish the method for determining transition probabilities. Finally, the Markov chain is "tuned" so that it represents the properties of a particular object to perform calculations using the developed model.

3. It is demonstrated that the key process, which allows passing from a graphical representation of the role model to the Markov chains, is determining transition probabilities. Practical recommendations for determining the values of transition probabilities for different states of the system are given. It is shown that the transition probabilities of states of the system may be determined based on the assessment of time consumption for particular role communications of a project.

4. The practical aspects of determining a trajectory of project development were examined. Evaluation of results of change in the distribution of probabilities of states of a project system in coordinates of probabilities of states and steps revealed a significant impact of the competence level of team members on projects.

Results of research might form a basis for the creation of models of the projects, which include its role structure and represent competence characteristics of participants of a project team.

References

1. Kolesnikova, K. V. The development of the theory of project management: project initiation study law [Text] / K. V. Kolesnikova // Management of development of complex systems. – 2014. – Issue 17. – P. 24–30. – Available at: http://journals.uran.ua/urss/article/view/38688/35053
2. Bushuyev, S. Proactive Program Management for Development National Finance System in Turbulence Environment [Text] / S. Bushuyev, R. Jaroshenko // Procedia – Social and Behavioral Sciences. – 2013. – Vol. 74. – P. 61–70. doi: 10.1016/j.sbspro.2013.03.044
3. Van der Hoorn, B. Playing projects: Identifying flow in the 'lived experience' [Text] / B. van der Hoorn // International Journal of Project Management. – 2015. – Vol. 33, Issue 5. – P. 1008–1021. doi: 10.1016/j.ijproman.2015.01.009
4. Turner, J. P. Manual on project-oriented management управлению [Text] / J. P. Turner. – Moscow: Publishing Grebennikov House, 2007. – 552 p.
5. ISO 21500:2012. Guidance on project management [Text]. – International Organization for Standardization, 2012.
6. Docenko, N. Management of competence at multiproject team building [Text] / N. Docenko, L. Sabodash, I. Chumachenko // Eastern-European Journal of Enterprise Technologies. – 2013. – Vol. 1, Issue 10 (61). – P. 16–19. – Available at: http://journals.uran.ua/eejet/article/view/6784/5963
7. Reich, V. Context-personal evaluation of the competence of project managers using the theory of fuzzy sets [Text] / V. Reich, O. Biryukov // Project management and development of production. – 2009. – Issue 1 (29). – P. 151–169.
8. Otradskaya, T. Development of parametric model of prediction and evaluation of the quality level of educational institutions [Text] / T. Otradskaya, V. Gogunskii, S. Antoshchuk, O. Kolesnikov // Eastern-European Journal of Enterprise Technologies. – 2016. – Vol. 5, Issue 3 (83). – P. 12–21. doi: 10.15587/1729-4061.2016.80790

9. At 125%: why people in Apple and Google are more productive than you [Electronic resource]. – Available at: http://ideanomics.ru/articles/8938
10. Dias, Ariel. The 4 Personality Types Every Startup Needs [Electronic resource]. – Available at: http://onstartups.com/tabid/3339/bid/94858/The-4-Personality-Types-Every-Startup-Needs.aspx
11. Lukyanov, D. V. The hypothesis of a predetermined lack of knowledge and competencies in project teams [Text] / D. V. Lukyanov, E. N. Dmitrenko // Ways of implementation of credit-modular system. – 2015. – Issue 10. – P. 17–21. – Available at: http://storage.library.opu.ua/online/periodic/kms_2015_10/017-021.pdf
12. Shakhov, A. V. Formation of the crew on the basis of simulation [Text] / A. V. Shakhov, S. A. Kramskoy // Eastern-European Journal of Enterprise Technologies. – 2011. – Vol. 1, Issue 5 (49). – P. 69–70. – Available at: http://journals.uran.ua/eejet/article/view/2369/2171
13. Belbin, R. M. Teams of managers. Secrets of Success and the Causes of Failures [Text] / R. M. Belbin. – Moscow: HIPPO, 2003. – 315 p.
14. Kolesnikov, O. Development of the model of interaction among the project, team of project and project environment in project system [Text] / O. Kolesnikov, V. Gogunskii, K. Kolesnikova, D. Lukianov, T. Olekh // Eastern-European Journal of Enterprise Technologies. – 2016. – Vol. 5, Issue 9 (83). – P. 20–26. doi: 10.15587/1729-4061.2016.80769
15. Sherstyuk, O. The research on role differentiation as a method of forming the project team [Text] / O. Sherstyuk, T. Olekh, K. Kolesnikova // Eastern-European Journal of Enterprise Technologies. – 2016. – Vol. 2, Issue 3 (80). – P. 63–38. doi: 10.15587/1729-4061.2016.65681
16. Gogunskii, V. «Lifelong learning» is a new paradigm of personnel training in enterprises [Text] / V. Gogunskii, O. Kolesnikov, K. Kolesnikova, D. Lukianov // Eastern-European Journal of Enterprise Technologies. – 2016. – Vol. 4, Issue 2 (82). – P. 4–10. doi: 10.15587/1729-4061.2016.74905
17. Kolesnikova, K. V. Modeling of semistructured project management systems [Text] / K. V. Kolesnikova // Odes'kyi Politechnichnyi Universytet. Pratsi. – 2013. – Issue 3 (42). – P. 127–131. doi: 10.15276/opu.3.42.2013.25
18. Gogunskii, V. Developing a system for the initiation of projects using a Markov chain [Text] / V. Gogunskii, A. Bochkovsky, A. Moskaliuk, O. Kolesnikov, S. Babiuk // Eastern-European Journal of Enterprise Technologies. – 2017. – Vol. 1, Issue 3 (85). – P. 25–32. doi: 10.15587/1729-4061.2017.90971
19. Rudenko, S. V. Development of the Markov model state changes in patients projects providing medical services [Text] / S. V. Rudenko, M. V. Romanenko, O. G. Katunina, K. V. Kolesnikova // Management of development of complex systems. – 2012. – Issue 12. – P. 86–90. – Available at: http://journals.uran.ua/urss/article/view/41121/37470
20. Rudenko, S. V. Implementation of the project management of the institution's image in the realities of China [Text] / S. V. Rudenko, Feng Ma, S. M. Glowatska, K. V. Kolesnikova // High Technology in Machine build. – 2015. – Issue 1 (25). – P. 141–149.
21. Koshkin, K. V. Cognitive models of management of housing and communal services as an active system [Text] / K. V. Koshkin, S. A. Makeev, G. B. Fomenko // Management of development of complex systems. – 2011. – Issue 5. – P. 17–19. – Available at: http://urss.knuba.edu.ua/files/zbirnyk-5/17-19_1.pdf
22. Kolesnikova, E. V. Transformation of cognitive maps in the model of Markov processes for software projects [Text] / E. V. Kolesnikova, A. A. Negri // Management of development of complex systems. – 2015. – Issue 15. – P. 30–35. – Available at: http://urss.knuba.edu.ua/files/zbirnyk-15/30-35.pdf
23. Hunter, J. J. The computation of key properties of Markov chains via perturbations [Text] / J. J. Hunter // Linear Algebra and its Applications. – 2016. – Vol. 511. – P. 176–202. doi: 10.1016/j.laa.2016.09.004
24. Milios, D. Markov Chain Simulation with Fewer Random Samples [Text] / D. Milios, S. Gilmore // Electronic Notes in Theoretical Computer Science. – 2013. – Vol. 296. – P. 183–197. doi: 10.1016/j.entcs.2013.07.012
25. Stanovskii, O. L. Dynamic models in the method of project management [Text] / O. L. Stanovskii, K. V. Kolesnikova, O. Yu. Lebedeva, I. Kheblov // Eastern-European Journal of Enterprise Technologies. – 2015. – Vol. 6, Issue 3 (78). – P. 46–52. doi: 10.15587/1729-4061.2015.55665