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ERGODICITY OF PROJECT MANAGEMENT SYSTEM

К.В. Колеснікова, *Т.М. Олех*, *Ю.С. Барчанова*, *В.Ю. Васильєва*. **Ергодичність систем проектного управління.** Ефективність структур проектного управління залежить від двох факторів: параметричних властивостей, що відображають властивості окремих елементів (або процесів), і структурних властивостей системи, що відображають вплив взаємозв'язків елементів на функціонування всієї системи. Найчастіше розглядаються моделі й методи, що досліджують параметричні властивості системи. Дослідження структурних властивостей системи дозволить створити нові механізми поліпшення проектної діяльності, спрямовані на досягнення ефективного результату проекту. ***Мета:*** Метою роботи є обгрунтування можливості розв'язання задачі аналізу структурних схем проектної діяльності за допомогою аналітичного методу, який базується на урахуванні специфічних властивостей матриць суміжності. ***Матеріали і методи:*** Метод дозволяє не тільки визначати ергодичність системи проектного управління, а й умови існування зворотних і неповоротних структур у орієнтованих графах. ***Результати:*** Запропонований метод може бути використаний для подальших досліджень у галузі проектного менеджменту, а саме для створення та подальшого розвитку моделей та методів структурного і параметричного аналізу організаційно-технічних систем управління проектами, програмами, або портфелями проектів.
Ключові слова: управління проектами, матриця суміжності, матриця досяжності, матриця суперпозиції, розмічений граф, перехідні ймовірності, ергодичність.

K.V. Kolesnikova, *T.M. Olekh*, *Yu.S. Barchanova*, *V.Yu. Vasilieva.* **Ergodicity of project management system.** The structures effectiveness of project management depends on two factors: parametric properties that reflect the properties of separate elements (or processes), structural properties of system that reflect the influence of elements interconnections on whole system functioning. The most frequently observed models and methods study parametric properties of system. The study of structural properties of a system allows building of new mechanisms for project operation improvement that are focused on effective project result achievement. ***Aim:*** The aim of this work is to substantiate the problem solubility for project operation structural schemes analysis using analytical method based on consideration of specific properties of adjacency matrix. ***Materials and Methods:*** The method allows not only ergodicity of project management system determination but existence conditions of reverse and nonrotational structures in oriented graphs. ***Results:*** The proposed method can be used for forthcoming researches in project management area, as in building and further development of models for and methods of structural and parametric analysis of organizational and technical project management systems, programs or pipeline of projects.
Keywords: project management, adjacency matrix, distance matrix, superimposition matrix, graduated graph, transition probabilities, ergodicity.

Introduction. The project participants' interaction is the utmost precondition for the project successful implementation, still project management also containing such organizational and technical components as the planning, monitoring, analysis and results correction [1]. To proactively manage project activities with project efficiency timely assessment essential is to use the mathematical modeling methods. Meanwhile the modern mathematical software can never solve the existing contradiction between the required management effectiveness as to the project, programs or pipeline of projects (PPP) and the objectives aimed onto the skilled support of project decisions making. Thus, the development of theoretical grounds for PPP proactive management models building that is based onto use of models that reflect the studied systems' essential features is an actual project management problem [1…3]. That contradiction is solved through developing the methodology of project management systems' structural and parametric analysis based on the application of structural analysis theoretical principles and application of complex topological structures' mathematical models, reflecting the project management system. Such approach allows the pre-estimation of the PPP successful implementation level.

The organizational and technical systems' project management uncertainty presence is due to several reasons [4, 5]:

— factors' array and their relationship do not allow isolating and investigating in details the project systems' properties departing from their individual elements properties, so all the phenomena occurring at such a system should be considered together;

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— lack of deterministic relationships between project processes' input and output due to the presence in the management system chain of executive links serving as decision-makers or performing tasks that shifts for transition to qualitative analysis of such processes;

— environment's turbulence and the processes' variable nature over time.

Due to these features the similar projects represent semistructured systems. The system factors' array forms a complex system of relations and conditions, causes and effects that change over time. Difficult is to register and understand the events logic at such multifactor systems. However, in practice we constantly have to make decisions about the required steps (which factors should be influenced) for the project improvement; that will be the situation over time when nothing changed; which of the possible actions will be more effective to achieve the goal, etc. [6]. The decision making procedure can be based on cognitive analysis and complex processes modeling [7, 8].

The project management structures' effectiveness depends on two factors: the parametric properties reflecting the individual elements (or processes) features, and the system's structural properties reflecting the effects of the elements relationships on the entire system. Often considered are the models and methods, exploring the system's parametric properties. Study of the system's structural properties will allow creating new mechanisms for project activities improvement to achieve effective results of the project.

The aim of this work is to substantiate the problem solubility for project operation structural schemes analysis using analytical method based on consideration of specific properties of adjacency matrix.

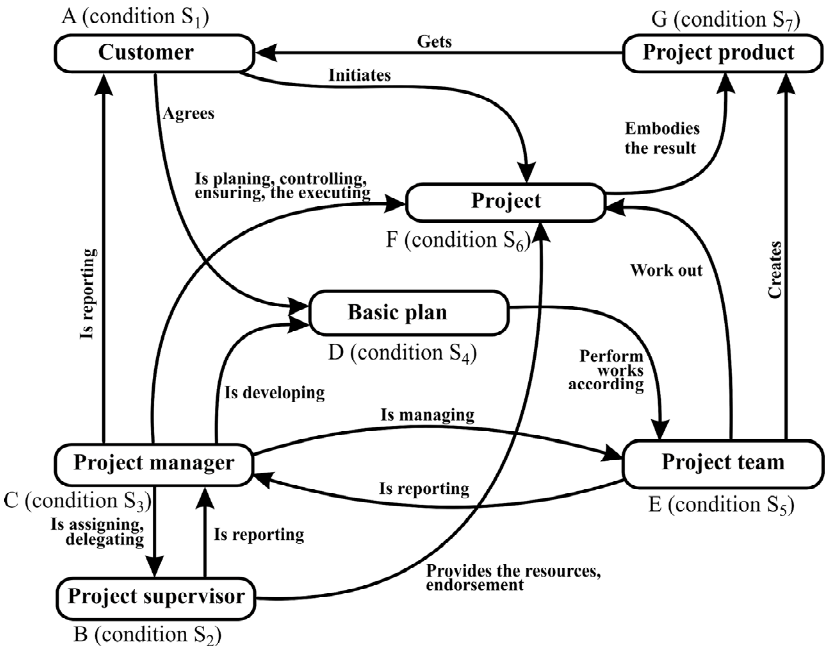
Materials and Methods. In practice, the process matrix is most commonly used to describe block diagrams. And the structures' analysis implies using the adjacency matrix, having some specific properties [10]. If it consistently reduced to levels 2, 3, ..., n, the element c_{ij} of n-th adjacency matrix degree represents the relationship between i-th and j-th vertices through n arcs. With the rise to the adjacency matrix' n-th degree and feedback scheme presence, some diagonal elements become different from zero, that means a link from i-th to the j-th graph vertex. This relationship can exist only in a closed ergodic path [11].

We know that if a system has some ergodic properties, it can be described with an ergodic graph. Ergodic is a graph that includes one ergodic class [11, 12]. Such graphs are described with a strongly related graph. Thus at such a system possible is the transition from one state to another in a finite number of steps. The directed graph makes the basis for building a Markov chain, so all the graph's structural properties are characteristic to Markov chain that can be created on its basis.

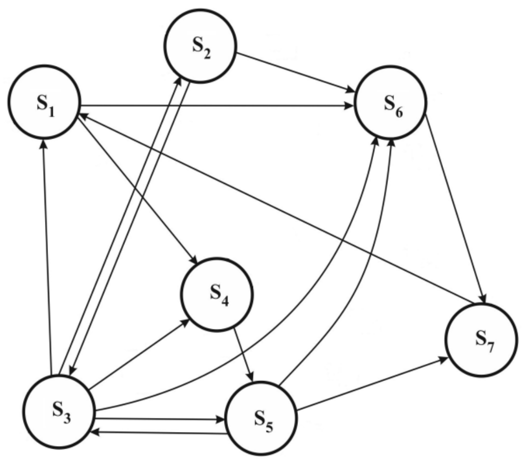
At Fig. 1 a scheme of project main participants' interaction is given. This structure is the basic one according to GOST R 54869-2011. The diagram shows the main transitions between the system states. Such a diagram allows performing a first approximation in qualitative assessment of the project participants' interaction efficiency. So, we shall estimate such scheme ergodicity in the sense of the directed graph ergodic subset [13].

The system, combining some states' set $S\{s_1, s_2, ..., s_m\}$, embodying the vertices of a directed graph and interconnected with directed arcs $G\{g_1, g_2, ..., g_r\}$, can be represented in the adjacency matrix form $[c_{ij}]$, whose rows and columns correspond to the directed graph vertices. The adjacency matrix element value is 1 when there is an arched link between two vertices. If the element value is 0 then a direct link between the vertices of the graph is absent (1)

$$\left\|c_{i.j}\right\| = \left\|\begin{matrix} 0 & 0 & 0 & c_{1.4} & 0 & c_{1.6} & 0 \\ 0 & 0 & c_{2.3} & 0 & 0 & c_{2.6} & 0 \\ c_{3.1} & c_{3.2} & 0 & c_{3.4} & c_{3.5} & c_{3.6} & 0 \\ 0 & 0 & 0 & 0 & c_{4.5} & 0 & 0 \\ 0 & 0 & c_{5.3} & 0 & 0 & c_{5.6} & c_{5.7} \\ 0 & 0 & 0 & 0 & 0 & 0 & c_{6.7} \\ c_{7.1} & 0 & 0 & 0 & 0 & 0 & 0 \end{matrix}\right\| = \left\|\begin{matrix} 0 & 0 & 0 & 1 & 0 & 1 & 0 \\ 0 & 0 & 1 & 0 & 0 & 1 & 0 \\ 1 & 1 & 0 & 1 & 1 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 1 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 \end{matrix}\right\|. \quad (1)$$



a



b

Fig. 1. Diagram of project participants' interaction (a) and the directed graph created on its basis (b): A, B, ..., G —conditions (states) identifiers, S {s_1, s_2, ..., s_7} —system states

For graphs with a small number of states these characteristics can be determined by directed graph's visual analysis. However, in the case of higher dimensions rational is to use automated tools, including analysis and decision making subsystems.

Here represented are the results, where adjacency matrix columns and rows correspond to the indication in letters that match the conditions IDs of interaction patterns between the project participants (Fig. 1). This approach is used in order to emphasize the following system property: the number of adjacency matrix rows and columns does not affect the project logic and may be selected arbitrarily. The initial first degree (1) adjacency matrix contains information about transitions between the first order states. Next are the results of calculations for the adjacency matrix of second (2), fourth (3) and seventh (4) orders (hereinafter the operation of data transferring into Boolean numbers is not performed):

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	a	*b*	*c*	*d*	*e*	*f*	*g*
a	0	0	0	0	1	0	1
b	1	1	0	1	1	1	1
c	0	0	2	1	1	3	2
d	0	0	1	0	0	1	1
e	2	1	0	1	1	1	1
f	1	0	0	0	0	0	0
g	0	0	0	1	0	1	0

(2)

	a	*b*	*c*	*d*	*e*	*f*	*g*
a	2	1	0	2	1	2	1
b	4	2	1	3	3	4	4
c	5	1	5	5	3	10	6
d	1	0	2	2	1	4	2
e	4	2	1	3	4	4	5
f	0	0	0	0	1	0	1
g	1	0	1	0	0	1	1

(3)

	a	*b*	*c*	*d*	*e*	*f*	*g*
a	8	2	6	7	5	13	9
b	19	5	15	17	15	32	25
c	39	15	18	32	30	50	44
d	14	6	5	12	11	17	15
e	20	5	17	19	17	36	28
f	1	0	2	2	2	4	3
g	5	2	2	3	4	5	6

(4)

Let we calculate the distance matrix R^n, representing the sum of Boolean adjacency matrices at 0 to *m* orders. At that we shall use the binary system to display amounts. If all the elements are equal to 0, their sum also equals to 0. Otherwise, the amount is equal to 1.

Now we consider the distance matrix R^2 (5), the transpose distance matrix $(R^2)^T$ (6) and the superposition matrix W^2 (7).

	a	*b*	*c*	*d*	*e*	*f*	*g*
a	0	0	0	1	1	1	1
b	1	1	1	1	1	1	1
c	1	1	1	1	1	1	1
d	0	0	1	0	1	1	1
e	1	1	1	1	1	1	1
f	1	0	0	0	0	0	1
g	1	0	0	1	0	1	0

(5)

	a	*b*	*c*	*d*	*e*	*f*	*g*
a	0	1	1	0	1	1	1
b	0	1	1	0	1	0	0
c	0	1	1	1	1	0	0
d	1	1	1	0	1	0	1
e	1	1	1	1	1	0	0
f	1	1	1	1	1	0	1
g	1	1	1	1	1	1	0

(6)

	a	*b*	*c*	*d*	*e*	*f*	*g*
a	0	0	0	0	1	1	1
b	0	**1**	**1**	0	**1**	0	0
c	0	**1**	**1**	1	**1**	0	0
d	0	0	1	0	1	0	1
e	1	**1**	**1**	1	**1**	0	0
f	1	0	0	0	0	0	1
g	1	0	0	1	0	1	0

(7)

Apparently, the superposition matrix W^2 has a defined path, comprising states *b*, *c* and *e*. The square submatrix $w^* \in W^2$ filled with "1"units can be obtained by reversing the places of columns and rows for states *d* and *e*. The square submatrix $w^* \in W^2$, which consists of items *b*, *c* and *e*, and whose main diagonal contains all "1" units, is reflecting the significant feature of system structure: all elements are interlinked to the forward and reverse directions.

Let we consider the range matrix R^4 (8), transpose matrix $(R^4)^T$ (9) and superposition matrix W^4 (10).

	a	*b*	*c*	*d*	*e*	*f*	*g*
a	1	1	1	1	1	1	1
b	1	1	1	1	1	1	1
c	1	1	1	1	1	1	1
d	1	1	1	1	1	1	1
e	1	1	1	1	1	1	1
f	1	0	0	1	1	1	1
g	1	0	1	1	1	1	1

(8)

	a	*b*	*c*	*d*	*e*	*f*	*g*
a	1	1	1	1	1	1	1
b	1	1	1	1	1	0	0
c	1	1	1	1	1	0	1
d	1	1	1	1	1	1	1
e	1	1	1	1	1	1	1
f	1	1	1	1	1	1	1
g	1	1	1	1	1	1	1

(9)

	a	*b*	*c*	*d*	*e*	*f*	*g*
a	1	1	1	1	1	1	1
b	1	1	1	1	1	0	0
c	1	1	1	1	1	0	1
d	1	1	1	1	1	1	1
e	1	1	1	1	1	1	1
f	1	0	0	1	1	1	1
g	1	0	1	1	1	1	1

(10)

Having effected the transposition of *a* element, we obtain the superposition matrix W^4:

	b	*c*	*a*	*d*	*e*	*f*	*g*
b	**1**	**1**	**1**	**1**	**1**	0	0
c	**1**	**1**	**1**	**1**	**1**	0	1
a	**1**	**1**	**1**	**1**	**1**	**1**	**1**
d	**1**	**1**	**1**	**1**	**1**	**1**	**1**
e	**1**	**1**	**1**	**1**	**1**	**1**	**1**
f	0	0	**1**	**1**	**1**	**1**	**1**
g	0	1	**1**	**1**	**1**	**1**	**1**

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The superposition matrix W^4 contains two closed contours. One of them includes the states *a*, *b*, *c*, *d* and *e*. The second one includes elements *a*, *d*, *e*, *f* and *g* (when inserting the "*a*" condition in adjacency matrix arrangement order after "*c*" element). Each of closed contours is a subset that intersects with another subset. In this case, there exist states (namely, *a*, *d*, *e*), included in both paths, whereby creating the effect of "crossing".

Now we consider the reach matrix R^6(11), transpose matrix $(R^6)^T$ (12) and superposition matrix W^6 (13).

	a	*b*	*c*	*d*	*e*	*f*	*g*
a	1	1	1	1	1	1	1
b	1	1	1	1	1	1	1
c	1	1	1	1	1	1	1
d	1	1	1	1	1	1	1
e	1	1	1	1	1	1	1
f	1	1	1	1	1	1	1
g	1	1	1	1	1	1	1

(11)

	a	*b*	*c*	*d*	*e*	*f*	*g*
a	1	1	1	1	1	1	1
b	1	1	1	1	1	1	1
c	1	1	1	1	1	1	1
d	1	1	1	1	1	1	1
e	1	1	1	1	1	1	1
f	1	1	1	1	1	1	1
g	1	1	1	1	1	1	1

(12)

	a	*b*	*c*	*d*	*e*	*f*	*g*
a	1	1	1	1	1	1	1
b	1	1	1	1	1	1	1
c	1	1	1	1	1	1	1
d	1	1	1	1	1	1	1
e	1	1	1	1	1	1	1
f	1	1	1	1	1	1	1
g	1	1	1	1	1	1	1

(13)

The superposition matrix W^6, obtained after the sixth degree adjacency matrix conversion, represents a closed path. Thus, in this path transitions are possible between any states in a finite number of steps. Based on the research conditions (Fig. 1) the ability to join the system is zero, as well as the ability to release. Thus, confirmed is that the structure of the main project entities' interaction is ergodic and does not include any absorbing elements (case of constructing a Markov chain on this scheme ground).

Conclusions. To solve the problem of project management systems' structural analysis used is the analytical method that takes into account specific characteristics inherent to adjacency matrix. The method allows determining not only the project management system ergodicity, but also the conditions of existence for return and non-return oriented graphs' structures. The suggested method can be used for further researches in the field of project management, namely for the establishment and further development of models and methods applied in structural and parametric analysis of organizational and technical management systems for project, programs or pipeline of projects.

Література

1. Бушуев, С.Д. Развитие систем знаний и технологий управления проектами / С.Д. Бушуев // Управление проектами и программами. — 2005. — № 2(2). — С. 31 — 43.

2. Бушуєв, С.Д. Напрями дисертаційних наукових досліджень зі спеціальності «управління проектами та программами» / С.Д. Бушуєв, В.Д. Гогунський, К.В. Кошкін // Управління розвитком складних систем. — 2012. — Вип. 12. — С. 5 — 7.
3. Advancing project and portfolio management research: Applying strategic management theories / C.P. Killen, K. Jugdev, N. Drouin, Y. Petit // International Journal of Project Management. — 2012. — Vol. 30, Issue 5. — PP. 525 — 538.
4. Вайсман, В.О. Моделі, методи та механізми створення і функціонування проектно-керованої організації: монографія / В.О. Вайсман; Укр. асоц. упр. проектами. — К.: Науковий світ, 2009. — 146 с.
5. Bushuyev, S. Proactive program management for development national finance system in turbulence environment / S. Bushuyev, R. Jaroshenko // Procedia - Social and Behavioral Sciences. — 2013. — Vol. 74. — PP. 61 — 70.
6. Turner, J.R. The handbook of project-based management: leading strategic change in organizations / J.R. Turner. — 4th Ed. — New York: McGraw-Hill, 2014. — 356 p.
7. Фарионова, Т.А. Когнитивное моделирование в проектировании композиционных материалов и покрытий / Т.А. Фарионова, Ю.А. Казимиренко // Восточно-Европейский журнал передовых технологий. — 2011. — № 1/6 (49). —С. 36 — 38.
8. Колесникова, Е.В. Трансформация когнитивных карт в модели марковских процессов для проектов создания программного обеспечения / Е.В. Колесникова, А.А. Негри // Управління розвитком складних систем. — 2013. — Вип. 15. — С. 30 — 35.
9. Вайсман, В.О. Проектно-керовані організації: моделі і метод аналізу структурних схем управління процесами / В.О. Вайсман // Наук. записки Міжнар. гуманіт. ун-ту. Серія «Управління проектами та програмами». — 2009. — Вип. 14. — С. 4 — 12.
10. Vaysman, V.A.The planar graphs closed cycles determination method / V.A. Vaysman, E.V. Kolesnikova, D.V. Lukianov // Пр. Одес. політехн. ун-ту. — 2012. — Вип. 1(38). — С. 222 — 226.
11. Вентцель, Е.С. Исследование операций: задачи, принципы, методология / Е.С. Вентцель. — 3-е изд., стер. — М.: Дрофа, 2004. — 208 с.
12. Колесникова, Е.В. Моделирование слабо структурированных систем проектного управления / Е.В. Колесникова // Пр. Одес. політехн. ун-ту. — 2013. — Вип. 3(42). — С. 127 — 131.
13. ГОСТ Р 54869–2011. Проектный менеджмент. Требования к управлению проектом. — Введ. 2012-09-01. — М.: Стандартинформ, 2011. — 14 с.

References

1. Bushuyev, S.D. (2005). Development of systems of knowledge and technology project management. *Project and Program Management*, 2, 31–43.
2. Bushuyev, S.D., Gogunsky, V.D. & Koshkin, K.V. (2012). Directions dissertation research specialty "Project and Program Management". *Management of Development of Complex Systems*, 12, 5–7.
3. Killen, C.P., Jugdev, K., Drouin, N., & Petit, Y. (2012). Advancing project and portfolio management research: Applying strategic management theories. *International Journal of Project Management*, 30(5), 525–538. DOI:10.1016/j.ijproman.2011.12.004
4. Vaysman, V.O. (2009). *Models, Methods and Mechanisms of Creation and Functioning Project Managing Organization*. Kyiv: Naukovyi Svit.
5. Bushuyev, S., & Jaroshenko, R. (2013). Proactive program management for development national finance system in turbulence environment. *Procedia – Social and Behavioral Sciences*, 74, 61–70. DOI:10.1016/j.sbspro.2013.03.044
6. Turner, J.R. (2014). *The Handbook of Project-Based Management: Leading Strategic Change in Organizations* (4th Ed.). New York: McGraw-Hill.
7. Farionova, T.A., & Kazimirenko, Yu.A. (2011). Cognitive modeling at designing of composites and coverings. *Eastern-European Journal of Enterprise Technologies*, 1(6), 36–38.
8. Kolesnikova, E.V., & Negri, A.A. (2013). Transformation of cognitive maps in the model of Markov processes for projects creating software. *Management of Development of Complex Systems*, 15, 30–35.
9. Vaysman, V.O. (2009). Project-driven organizations: models and methods of analysis of structural schemes of project management. *Scientific Proceedings of International Humanitarian University: Program and Project Management*, 14, 4–12.

ISSN 2076-2429 (print)
ISSN 2223-3814 (online)

10. Vaysman, V.A., Kolesnikova, E.V., & Lukianov, D.V. (2012). The planar graphs closed cycles determination method. *Odes'kyi Politechnichnyi Universytet. Pratsi*, 1, 222–226.
11. Ventsel, E.S. (2004). *Operations Research: Problems, Principles, Methodology* (3rd Ed.). Moscow: Drofa.
12. Kolesnikova, K.V. (2013). Modeling of semistructured project management systems. *Odes'kyi Politechnichnyi Universytet. Pratsi*, 3, 127–131.
13. ANO "Center for Standardizing Project Management". (2012). *Project Management. Requirements for Project Management* (GOST R 54869-2011). Moscow: Standardinform.

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