DOI: 10.15276/aait.03.2020.7
UDC 005.8

ELABORATION OF A MARKOV MODEL OF PROJECT SUCCESS

Heorhii S. Olekh,
Odessa National Polytechnic University, Odesa, Ukraine
ORCID: https://orcid.org/0000-0002-7033-8504
Ihor V. Prokopovych
Odessa National Polytechnic University, Odesa, Ukraine
ORCID: https://orcid.org/0000-0002-8059-6507
Tetiana M. Olekh
Odessa National Polytechnic University, Odesa, Ukraine
ORCID: http://orcid.org/0000-0002-9187-1885
Kateryna V. Kolesnikova
Taras Shevchenko National University of Kyiv, Kyiv, Ukraine
ORCID: http://orcid.org/0000-0002-9160-5982

ABSTRACT

The development of software and the creation on its basis of models that reflect the main features of project management systems is an important task of project management. Despite the significant differences between the types of projects and the variety of conditions for their implementation, assessments of the effectiveness / success of projects should be carried out in a certain way uniformly, on the basis of common justified principles. This article discusses the construction of a matrix of "strong connectivity" for the methodological principles of assessing the effectiveness / success of projects based on a directed graph. Methodological, the most general principles that ensure, when applied, the rational behavior of stakeholders regardless of the nature and objectives of the project. All of the above principles for evaluating the effectiveness / success of projects are interconnected. In order to show the topology and directions of the interconnections of methodological principles, it is necessary to draw up a matrix diagram. With its help, it can determine the relationship between methodological principles. The matrix diagram often called the matrix of connections, shows the degree of dependence of the criteria of one on another, how strong are the connections between them. The resulting matrix illustrates the relationship between all methodological principles and indicates that relying on only one of the methodological principles for evaluating the effectiveness / success of projects, we can conclude that the mission / project is effective / successful. Presentation of modeling data based on the analysis of the structure of relations between elements allows also to determine the areas of greatest attention from the project manager. In particular, we can make an assumption, by analogy with the Pareto rule, that the maximum managerial effect can be expected from the control of some factors. The developed model allows to evaluate the effectiveness of project activities on the basis of only one from all indicators of the methodological principles of project evaluation.

Keywords: project; project management; methodological principles; evaluation of the effectiveness / success of projects; matrix diagram; oriented graph; Markov models; system landscape

For citation: **Olekh H. S, Prokopovych I. V., Olekh T. M., Kolesnikova K. V. Elaboration of a markov model of project success. *Applied Aspects of Information Technology.* 2020; Vol.3 No.3: 191–202. DOI: 10.15276/aait.03.2020.7**

INTRODUCTION

Sustainable development of the Ukrainian economy is impossible without the implementation of various projects in the real sector of entrepreneurship and economy. At the same time, all partners involved in the project (project, financing organizations, customers, and government institutions) are tasked with choosing the most optimal management solutions.

In addition, investors and other stakeholders want to assess the results of the project as fully and accurately as possible and relate them to their goals and interests. For this purpose, the so-called "efficiency calculations" of projects are carried out. The initial principles of such calculations are quite simple, but adequate consideration of the influence of individual factors often leads to serious methodological problems. The term "project" has various definitions. In a number of industries (for example in construction) a project is understood as a document (technical and economic grounding) of a certain composition and content. But then it makes no sense to talk about scenarios or options for the feasibility and effectiveness of such a project. Therefore, in P2M [1] it is determined that a project is a set of planned actions and management decisions aimed at achieving certain goals. Documents containing a description of these actions, their rationale and ways to achieve goals, assessments of various implementation options are called project scope, and the persons who participate in the project and are interested in it are called stakeholders or the project team.

Despite the significant differences between the types of projects and the variety of conditions for their implementation, assessments of the effectiveness of projects and their examination should be carried out in a certain sense uniformly, on the basis of common justified principles.

These principles can be divided into three groups [2–3] (*Table 1*):

– methodological, the most general, ensuring their rational behavior of customers, contractors, (stakeholders) regardless of the nature and purpose of the project;

– methodological, providing economic feasibility assessments of the effectiveness of projects and decisions made on their basis;

– operating rooms, compliance with which will facilitate and simplify the process of evaluating the effectiveness of projects and ensure the necessary accuracy of evaluations.

Table 1. **Principles for evaluating the effectiveness of projects**

Methodological	***Methodical***	***Operating***
1. Measurability 2. Additivity 3. Profitability 4. Consistency 5. Paid resources 6. Non-negativity and maximum effect 7. Systematic 8. Complexity 9. Irrefutable methods	1. Comparison of situations “with the project” and “without the project” 2. Uniqueness 3. Suboptimi-zation 4. The uncontrol-lability of the past 5. Dynamic 6. The temporary value of money 7. Incomple-teness of information 8. Capital structure 9. Multicurrency	1. The relationship of the parameters 2. Modeling 3. Project implementation mechanism 4. Multi-stage evaluation 5. Information and methodological consistency 6. Simplification

LITERATURE REVIEW

When assessing the effectiveness of a project, its “physical” content is insignificant, and the project is formalized, i.e. is replaced by its economic and mathematical model – some mathematical object. Therefore, we usually identify the project itself and its model, speaking about the “project”, and not about the “project model” [3–6].

The implementation of real projects can take decades, which makes it necessary to take into account the heterogeneous aspects of the influence of the time factor (dynamics of prices, exchange rates, technical and economic indicators of objects, the difference in the time difference of costs and profits, physical and moral deterioration of fixed assets, gaps in time between the production of products and their payment, etc.). For this purpose, the scenario or variant of the project implementation is modeled [7].

In continuous models (usually used for analytical purposes), the process of implementing costs and obtaining results is considered in continuous time. Discrete models have become more widespread. Here the period of the project is divided into a finite number of steps (you can choose certain time intervals), and it is assumed that the costs and results of each step are carried out at one point in time [8]. Discrete models do not take into account the distribution of results and costs within the time interval, but they allow you to present a scenario or a variant of the project implementation and calculations of its effectiveness in a visual tabular form.

Analysis of world experience has shown the feasibility of using a minimum number of parameters to assess the effectiveness of projects. This allows to most effectively to solve the problems of the successful implementation of projects in conditions of limited time, financial, human, and other types of resources [9–11].

The project approach, as the basis for change management, orients any activity towards the proactive (with prejudice) foundations of managing the system “project – project team – environment” through the use of models that reflect the essential properties of the system, including methods for measuring project parameters and assessing their effectiveness [12].

In the case of assessing the success of projects of complex systems, a set of probabilities of certain states of the system is chosen as the objective function. This set reflects the level of perfection of the system in the sense of meeting certain criteria [13]. Such a system can be changed and improved through management. This is possible due to various impacts on resources, technologies, communications or structural changes in the system [14–15].

THE GOAL OF THE ARTICLE

The article continues the research presented in papers [3–17]. In these works, the use of the mathematical apparatus of Markov chains for modeling the control processes of project-driven or project-oriented organizational and technical systems is considered.The purpose of the research is to confirm the fact that the methodological principles for assessing the effectiveness of projects are tightly coupled factors, and that based on one of them,
it is possible to assess the success of the entire project as a whole.

ISSN 2617-4316 (Print)
ISSN 2663-7723 (Online)

MAIN PART

There are also other principles or rules that are not included in this classification, in accordance with which individual stages of evaluation are carried out or individual conditions specific to a particular project are taken into account. Such rules, sometimes based on practical experience, sometimes specifying general principles in relation to a specific situation, are, if necessary, set forth in the description of the corresponding stages of the project [18].

Methodological principles:

1. Measurability (M_1). The effectiveness of the project is characterized by indicators expressed in a qualitative scale, i.e. by numbers. This means that all the main characteristics of the project that determine its effectiveness should also be measured quantitatively. At the same time, for other purposes, the necessary characteristics of objects can be measured on a nominal or ordinal scale.

2. Additivity (M_2). Any two projects *A1* and *A2* are comparable, i.e. there is always one and only one of the following three cases:

– project A_1 is more efficient (better, preferable) A_2, or that the same project A_2 is less effective than A_1;

– project A_2 is more effective than A_1 (project A_1 is less effective than A_2);

– both projects are equally effective (equally preferred).

3. Profitability (M_3). A project is considered effective if its implementation is beneficial to its participants. This means that the costs associated with the implementation of the project are estimated no higher than the results obtained. Thus, the assessment of project effectiveness is based on estimates of the costs and results of the project, presented in quantitative (numerical) terms.

4. Consistency of interests of participants (M_4). In the general case, the implementation of the project requires coordinated actions of various participants, and their goals and interests do not coincide, and they can evaluate the project from different points of view using different methods and dissimilar performance indicators. Thus, the implementation of the project will be possible only if the project is beneficial for each participant.

However, increasing the effectiveness of a project for one participant is not necessarily associated with a decrease in efficiency for another participant (the interests of the participants are not necessarily opposite).

5. Paid resources (M_5). When evaluating the effectiveness of projects, the limited nature of all types of reproducible and non-reproducible resources (economic benefits), and the unlimited need for them should be taken into account. This means that each resource required for the implementation of the project, in principle, can be used in another way, for example in another project.

Therefore, the tasks of the most efficient use of resources and the selection of appropriate projects are so important. Restrictions on the total amount of resources and the directions of their alternative use are important characteristics of the economic environment (i.e., the conditions in which the project participant operates) and are manifested in the paidness of resources (this applies equally to both single and multiple use resources, monetary, tangible and intangible).

Thus, in the calculations of efficiency, the resources expended and the results obtained, expressed in physical or arbitrary units (volumes of products or harmful emissions, scientific and technical results, etc.), should be evaluated in terms of value based on their estimates determined by the economic environment and party preferences. At the same time, the cost estimate of the resource spent or used in the project should also reflect the benefit lost due to the inability to use it elsewhere and for other purposes [19].

The loss of profit from the alternative use of a resource is called its alternative cost (opportunity cost).

6. Non-negativity and maximum effect (M_6). It follows from the principle of comparability that any projects should be compared according to a single criterion, despite the fact that in the general case projects are characterized by a system of key performance indicators (KPI). Such a criterion – the integral effect – reflects the difference between the estimates of the total results and costs of the project for the entire period of its implementation.

The effect of project *X* will be denoted by $\mathcal{E}(X)$. The principle linking the structure of the criterion with the task of evaluating the effectiveness of projects is called the principle of non-negativity and maximum effect.

Definition Project *X* is effective if $\mathcal{E}(X) > 0$ and inefficient if $\mathcal{E}(X) < 0$. Of several alternative projects, the one with the greatest effect is more effective. Projects with the same effect will be called equally effective.

7. Systematic (M_7). The project is implemented in a specific (economic, social, environmental, political) environment. Therefore, the effectiveness of the project for any of its participants largely depends on how this participant is distinguished from their general system and how he interacts with it. The participant's interaction with the "environment" includes such an important aspect as the rational use of funds from the project.

On the other hand, such interaction can lead to external effects, i.e., to positive or negative consequences for economic entities that are not participants in the project. Such consequences can take place not only during the project implementation period but also before and after its commencement.

External (systemic, synergistic) effects can occur during the joint implementation of programs or a portfolio of projects. Such projects are considered as mutually affecting. Projects in the joint implementation of which additional external effects do not arise are considered independent.

8. Complexity (M_8). An integrated approach to assessing project effectiveness includes:

1) taking into account the structure and characteristics of the designed object;

2) taking into account all the most significant consequences of the project. When the project is evolving, all the consequences of its implementation must be taken into account, both directly economic and non-economic (external effect or externality), public goods, social effect, environmental situation). It is desirable that any such consequences be quantified (even better if they are evaluated in terms of value, at least expertly). This principle involves a one-time accounting of the consequences of the project and, therefore, does not allow re-calculation of the same costs or results of the project;

3) consideration of the entire project life cycle.

This means that the effectiveness of the project should be determined by the costs and results throughout its entire life cycle, and not only achieved at any one point in time (for example, at the end of the project).

This also applies to the consequences arising from the liquidation of facilities or enterprises under construction, and, if necessary, to more distant ones. At the same time, the initial position of the economic entities and the external environment at the beginning of the life cycle of the project (settlement period) affect the effectiveness of the project.

9. Irrefutability of methods (M_9). It is unacceptable to use methods and indicators in the presence of examples showing that they, under the conditions considered in the draft, contradict the rules of rational economic behavior.

For example, it is unacceptable to evaluate the effectiveness of a project with indicators whose values may deteriorate with a clear improvement in all project parameters.

At the same time, statements or assessment methods, the inadmissibility of which is confirmed by examples, may be admissible if the scope of their application is properly limited.

One of the most vulnerable characteristics of the methodological principles of assessment is the quantitative measurability of indicators. Using quantitative measurements and statistical methods, it is difficult enough to evaluate all the proposed criteria. In this case, you can use the qualitative assessment. Therefore, it is better to use a multilateral approach using qualitative and quantitative methods [19–21].

All of the listed principles of assessment are interconnected. In order to show the topology and directions of interconnections, it is necessary to draw up a matrix diagram, with which you can determine the relationships between the indicators [22].

A matrix diagram is a tool for identifying the importance of various relationships. A matrix diagram is used for such an organization and presentation of a large amount of data (elements) in order to graphically illustrate the logical connections between different elements while reflecting the importance (strength) of these connections.

The purpose of the matrix diagram is a tabular presentation of logical relationships and the relative importance of these relationships between a large number of verbal (verbal) descriptions related to the following: quality tasks (problems); causes of quality problems; requirements of the established and anticipated needs of consumers; product characteristics and functions; process characteristics and functions; characteristics and functions of production operations and equipment [23–26].

The matrix diagram, often called the matrix of relationships, shows the degree (strength) of the dependence of the criteria on each other, how strong are the relationships between them. In the matrix diagram, the presence of a connection between the indicators is indicated by "1", and the absence – by "0".

The following notation can be introduced:

M_1 – measurability;

M_2 – additivity;

M_3 – profitability;

M_4 – reconciling the interests of stakeholders;

M_5 – paid resources;

M_6 – non-negativity and maximum effect;

M_7 – systematic;

M_8 – complexity;

M_9 – non-repudiation methods.

Almost all system parameters affect the indicator A_1 directly or through intermediate factors. Four indicators affect the effectiveness of E_1. Efficiency is better, the higher the efficiency, added value, environmental friendliness, and reliability [27]. And for acceptability A_2 – efficiency and environmental friendliness. The ethics of E_4 is directly related to performance and reliability.

ISSN 2617-4316 (Print)
ISSN 2663-7723 (Online)

Taking into account all the factors influencing each other, the methodological principles of evaluation it will make a matrix diagram (*Table 2*).

Based on the matrix diagram presented in *Table 1*, it can record the relationship between the various indicators in the form of a directed graph. (*Fig. 1*).

Summarizing the relationships between the individual indicators, it can present the general assessment model in the form of a directed graph *G = (V, H)*, where *V* is a finite set of vertices (nodes, points) of the graph (in this case n = 9), and *H* is a certain set of pairs tops, that is, a subset of the set *V* × *V* or a binary relation on *V*. Elements *H* are called edges or constraints. For an edge $h = (u, v) \in H$, the top *u* is called the beginning of *h*, and the top *v* is called the end of *h*; it is said that the edge *h* leads from *u* to *v*.

Table 2. **The matrix diagram of the methodological principles of assessment M$_1$-M$_9$**

	M$_1$	***M$_2$***	***M$_3$***	***M$_4$***	***M$_5$***	***M$_6$***	***M$_7$***	***M$_8$***	***M$_9$***
M$_1$	***	1	1	0	1	1	0	1	1
M$_2$	0	***	0	1	1	1	1	0	0
M$_3$	1	1	***	1	1	1	0	0	1
M$_4$	0	1	1	***	0	1	1	0	0
M$_5$	0	0	1	1	***	0	0	1	0
M$_6$	1	0	0	1	0	***	1	1	1
M$_7$	1	0	0	0	1	0	***	1	0
M$_8$	1	1	0	0	0	1	1	***	1
M$_9$	1	1	1	1	1	1	0	0	***

The strongly connected matrix of an oriented graph is a binary matrix containing information about all strongly connected vertices in an oriented graph. The strongly connected matrix is symmetric. In a strongly connected graph, such a matrix is filled with “1”.

The connected matrix of the graph *G* is the square matrix *S(G)* = [s_{ij}] of order *n* whose elements are equal:

$$s_{ij} = \begin{cases} 1, \text{ if } \exists \text{ route that combines } v_j \text{ and } v_i \\ 0, \text{ otherwise} \end{cases}. \quad (1)$$

The strongly connected matrix of the directed graph *G** is the square matrix *S(G*)* = [s_{ij}] of order *n* whose elements are equal:

$$s_{ij} = \begin{cases} 1, \text{ if } v_j \text{ available to } v_i \text{ and } v_i \text{ available to } v_j \\ 0, \text{ otherwise} \end{cases}, \quad (2)$$

$$S(G^*) = \tilde{A}^8 * \tilde{A}^{8^T}, \quad (3)$$

where $\tilde{A}^{8^T}$ transposed matrix; * – binary elementwise matrix multiplication.

Consider a method for constructing a strongly connected matrix for a graph *G** based on the use of the adjacency matrix *AG* of a graph *G* and Boolean operations.

Based on the directed graph *G = (V, H)* (*Fig. 1*), the adjacency matrix was composed.

The adjacency matrix of the directed graph *G = (V, H)* with *n* tops $V = \{v_1, K, v_n\}$ is the Boolean matrix *AG* of $n \times n$ size with elements

$$s_{ij} = \begin{cases} 1, \text{ if } (v_j, v_i) \in E \\ 0, \text{ otherwise} \end{cases}. \quad (4)$$

Let the top set be *V = {v$_1$, ..., v$_9$}*. Then the matrix *AG* is a 9 × 9 Boolean matrix.

To preserve the similarities with ordinary operations on matrices, we will use “arithmetic” notation for Boolean operations: by “+” the disjunction ∨ is denoted, and by “*” the conjunction ∧ is denoted.

Denote by In the identity matrix of size n × n, I_9 has a size 9 × 9.

Put $\tilde{A} = A_G + I_n$. Let $\tilde{A} = I_n$, $\tilde{A}_1 = \tilde{A}, \ldots, \tilde{A}_{k+1} = \tilde{A}_k * \tilde{A}$.

The procedure for constructing *G** is based on a simple statement: $\tilde{A}_k = \left(a_{ij}^{(k)}\right)$, where:

$$a_{ij}^{(k)} = \begin{cases} 1, \text{ if } G \text{ from } v_i \text{ to } v_j \text{ there is a path length } \le k \\ 0, \text{ otherwise} \end{cases}$$

The element $a_{ij}^{(k)}$ of the matrix $\tilde{A}_k$ of the directed graph *G = (V, H)* is equal to the number of all paths (routes) of length *k* from v_i to v_j.

In the case under consideration, a 9×9 matrix *AG* was obtained (5).

This view makes it easy to check for edges or links between given pairs of vertices. To search for all neighbors in the leading edges from the vertex v_i, it is necessary to revise the corresponding *i-th* row of the matrix *AG*, and to find the vertices from which the edges go to v_i, it is necessary to revise its *i-th* column [13].

$$A_G = \begin{pmatrix} 0 & 1 & 1 & 0 & 1 & 1 & 0 & 1 & 1 \\ 0 & 0 & 0 & 1 & 1 & 1 & 1 & 0 & 0 \\ 1 & 1 & 0 & 1 & 1 & 1 & 0 & 0 & 1 \\ 0 & 1 & 1 & 0 & 0 & 1 & 1 & 0 & 0 \\ 0 & 0 & 1 & 1 & 0 & 1 & 1 & 0 & 0 \\ 1 & 0 & 0 & 1 & 0 & 0 & 1 & 1 & 1 \\ 1 & 0 & 0 & 0 & 1 & 0 & 0 & 1 & 0 \\ 1 & 1 & 0 & 0 & 0 & 1 & 1 & 0 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 0 & 0 & 0 \end{pmatrix}. \quad (5)$$

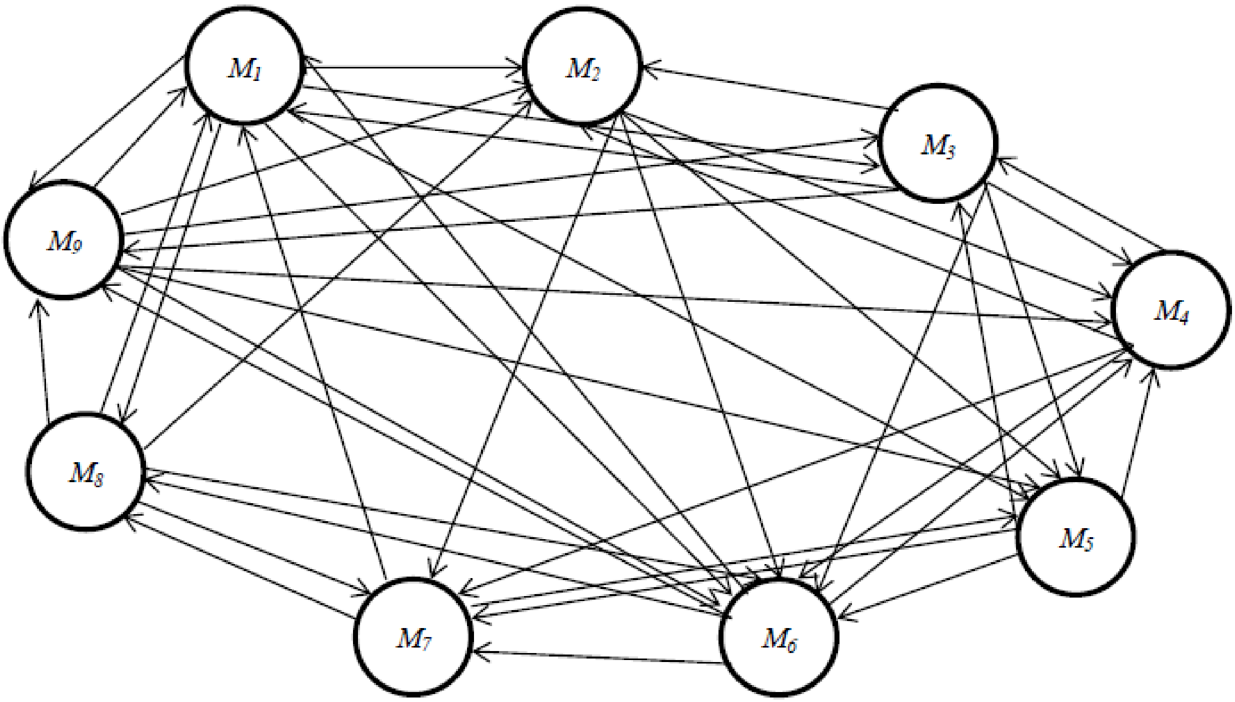

Fig. 1. **Directed graph based on a matrix diagram (*Table 2*)**

The reach graph $G^*=(V,E^*)$ for G has the same set of vertices V and the following set of edges $E^*=\{(u, v)|$ in the graph G, the vertex v is reachable from the vertex $u\}$.

For each vertex of the graph G, the set of vertices reachable from it can be determined by sequentially adding vertices to it that can be reached from it by edges and lengths 0, 1, 2, etc.

$$\tilde{A} = A_G + E_9 = \begin{pmatrix} 1 & 1 & 1 & 0 & 1 & 1 & 0 & 1 & 1 \\ 0 & 1 & 0 & 1 & 1 & 1 & 1 & 0 & 0 \\ 1 & 1 & 1 & 1 & 1 & 1 & 0 & 0 & 1 \\ 0 & 1 & 1 & 1 & 0 & 1 & 1 & 0 & 0 \\ 0 & 0 & 1 & 1 & 1 & 1 & 1 & 0 & 0 \\ 1 & 0 & 0 & 1 & 0 & 1 & 1 & 1 & 1 \\ 1 & 0 & 0 & 0 & 1 & 1 & 1 & 1 & 0 \\ 1 & 1 & 0 & 0 & 0 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 0 & 0 & 1 \end{pmatrix}. \quad (6)$$

If $G = (V, E)$ is a directed graph with n tops, and G^* is its reach graph, then $A\{G^*\} = \tilde{A}_{n-1}$. Thus, the procedure for constructing the adjacency matrix AG^* of the reach graph for G^* reduces to raising the matrix $\tilde{A}$ to the degree n-1.

Since G contains 9 tops, then $A_{G^*} = \tilde{A}^8$. This matrix is calculated:

$$\tilde{A}^2 = \begin{pmatrix} 1 & 1 & 1 & 1 & 1 & 1 & 0 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 0 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 0 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 0 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 0 & 0 \\ 1 & 1 & 1 & 1 & 0 & 1 & 1 & 1 & 1 \\ 1 & 0 & 1 & 1 & 1 & 0 & 1 & 1 & 0 \\ 1 & 1 & 1 & 0 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 0 & 1 & 1 \end{pmatrix}. \quad (7)$$

$$\tilde{A}^6 = \tilde{A}^8 = \begin{pmatrix} 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \end{pmatrix}. \quad (8)$$

The resulting strongly connected matrix of the directed graph is a binary matrix, symmetric, filled with “1”.

ISSN 2617-4316 (Print)
ISSN 2663-7723 (Online)

RESULTS AND DISCUSSION

Indicators of the methodological principles of evaluation objectively reflect the effectiveness of projects, since each indicator can be used as the main one for a certain type of project/program/portfolio. The resulting strongly connected matrix contains all the connections from vertex *i* to vertex *j*. As the degree of adjacency matrices increases, the elements of the matrix of strongly connected are filled with units. The square matrix filled with units shows that all the vertices of the graph are interconnected. And this is a description of all the possible paths in a directed graph. The strong connectivity matrix, which reaches unit values at a certain stage of the iteration, illustrates the direct relationship between all indicators.

The results obtained allow us to consider this set of factors M_1-M_9 as a system. In the context of this, further analysis by Markov methods is of interest, which has already been done in a number of other works [22–24; 26–29], and to visualize the results obtained similarly to the “system landscape” proposed in [30], which clearly demonstrates how the most “influencing” factors considered system, and experiencing the greatest influence from the whole system as a whole. Below is a screenshot of the first order adjacency matrix for the graph shown in *Fig. 1*, made using Microsoft Excel software (*Fig. 2*):

When calculating adjacency matrices, even for a matrix of degree 3 there will not be a single element with a value equal to zero, as shown in (8), but, nevertheless, data on how many connections will pass in the system can be of additional interest through each of the vertices of the considered graph, as shown below in the screenshot of the corresponding adjacency matrix (*Fig.3*).

For greater clarity, the authors propose to present it in a recombined form in order to get an idea of the existing “system landscape” of the system in question, sorting the columns and rows in descending order. The result obtained is presented in the following *Figure* (*Fig. 4*).

Presentation of modeling data based on the analysis of the structure of relations between elements allows, from the point of view of the authors, also to determine the areas of greatest attention from the project manager. In particular, we can make an assumption, by analogy with the Pareto rule, that the maximum managerial effect can be expected from the control of factors M_1, M_3, M_9, M_6, and M_8.

The obtained representation will probably be a good complement, allowing one to better represent the nature of the interactions between the elements of the system under consideration in addition to the simulation model based on the transition probability matrix, which can be calculated for the “general case” using equally probable transition values between states of the graph (*Fig. 1*) as presented above (*Fig. 5*).

This indicates that considering any indicator of the methodological principles of project evaluation, it can be concluded that the project mission is successful.

Factor name	To	M1 - measurability	M2 - Additivity	M3 - Profitability	M4 - Reconciling the interests of stakeholders	M5 - Paid resources	M6 - Non-negativity and maximum effect	M7 - Systematic	M8 - Complexity	M9 - Non-repudiation methods
From		1	2	3	4	5	6	7	8	9
M1 - measurability	1	0	1	1	0	1	1	0	1	1
M2 - Additivity	2	0	0	0	1	1	1	1	0	0
M3 - Profitability	3	1	1	0	1	1	1	0	0	1
M4 - Reconciling the interests of stakeholders	4	0	1	1	0	0	1	1	0	0
M5 - Paid resources	5	0	0	1	1	0	0	0	1	0
M6 - Non-negativity and maximum effect	6	1	0	0	1	0	0	1	1	1
M7 - Systematic	7	1	0	0	0	1	0	0	1	0
M8 - Complexity	8	1	1	0	0	0	1	1	0	1
M9 - Non-repudiation methods	9	1	1	1	1	1	1	0	0	0

Fig. 2. **First-order adjacency matrix based on a matrix diagram (***Table 2***) created in MS Excel (screenshot fragment)**

Factor name	To	M1 - measurability	M2 - Additivity	M3 - Profitability	M4 - Reconciling the interests of stakeholders	M5 - Paid resources	M6 - Non-negativity and maximum effect	M7 - Systematic	M8 - Complexity	M9 - Non-repudiation methods
From		1	2	3	4	5	6	7	8	9
M1 - measurability	1	14	16	15	15	15	19	14	14	12
M2 - Additivity	2	9	10	6	6	8	11	7	6	8
M3 - Profitability	3	16	15	11	16	14	18	14	12	13
M4 - Reconciling the interests of stakeholders	4	8	10	11	8	8	11	8	10	7
M5 - Paid resources	5	8	6	6	10	10	9	7	8	6
M6 - Non-negativity and maximum effect	6	13	11	9	16	14	15	11	12	12
M7 - Systematic	7	9	8	5	9	8	10	7	5	7
M8 - Complexity	8	12	13	12	13	11	15	11	12	11
M9 - Non-repudiation methods	9	16	15	12	16	14	18	14	12	12

Fig. 3. **A third-order adjacency matrix based on a matrix diagram (***Table 2***), indicating the number of connections between elements, created in MS Excel (screenshot fragment)**

Factor name	To	M6 - Non-negativity and maximum effect	M4 - Reconciling the interests of stakeholders	M1 - measurability	M2 - Additivity	M5 - Paid resources	M7 - Systematic	M8 - Complexity	M9 - Non-repudiation methods	M3 - Profitability
From		6	4	1	2	5	7	8	9	3
M1 - measurability	1	19	15	14	16	15	14	14	12	15
M3 - Profitability	3	18	16	16	15	14	14	12	13	11
M9 - Non-repudiation methods	9	18	16	16	15	14	14	12	12	12
M6 - Non-negativity and maximum effect	6	15	16	13	11	14	11	12	12	9
M8 - Complexity	8	15	13	12	13	11	11	12	11	12
M4 - Reconciling the interests of stakeholders	4	11	8	8	10	8	8	10	7	11
M2 - Additivity	2	11	6	9	10	8	7	6	8	6
M5 - Paid resources	5	9	10	8	6	10	7	8	6	6
M7 - Systematic	7	10	9	9	8	8	7	5	7	5

Fig. 4. **Recombined third-order adjacency matrix based on a matrix (Fig.3), indicating the number of connections between elements, created in MS Excel (screenshot fragment)**

CONCLUSIONS

The hypothesis that the success of the project can be predicted based on the values of indicators of the methodological principles of their assessment is confirmed. Each individual indicator can be used to assess the specific state of the project. The resulting matrix filled with "1" shows that all indicators are interconnected.

A study was made of a system of indicators for management and balanced project assessment, which are considered in the context of developing the capabilities of existing project management systems.

The developed model allows you to evaluate the effectiveness of project activities on the basis of only one from all indicators of the methodological principles of project evaluation.

ISSN 2617-4316 (Print)
ISSN 2663-7723 (Online)

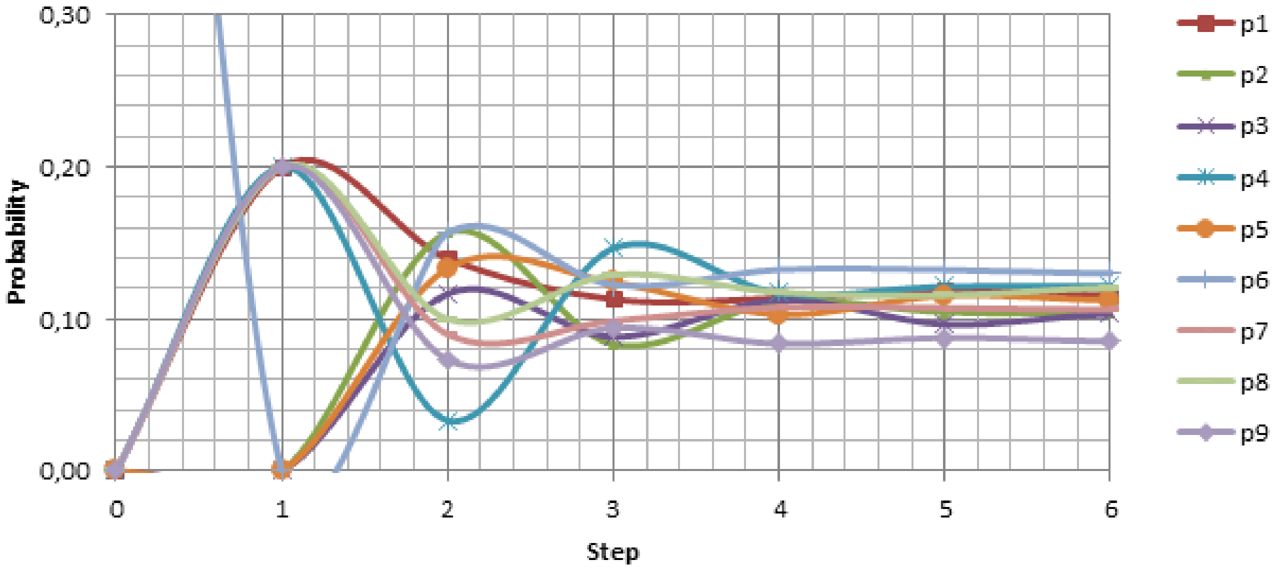

Fig. 4. **Transition state diagram M_1-M_9 for starting transients from the M_6 state – Non-negativity and maximum effect created in MS Excel (screenshot fragment)**

REFERENCES

1. The GPM®Global P5TM Standard for Sustainabilityin Project Management". Ver. 1.5. GPM Global. Available from: https://www.greenprojectmanagement. org/the-p5-standard. [Accessed 20th August 2020].

2. Rehacek , I. P. "Application and usage of the standards for project management and their comparison". *Journal of Engineering and Applied Sciences.* 2017; 12(4): 994–1002.

3. (2019) "Managing Successful Programmes". Available from: https://www.itgovernance.co.uk/shop/product/managing-successful-programmes-2011-edition. [Accessed 20th August 2020].

4. Kolesnikova, E. V. "Prikladnyie aspektyi primeneniya tsepey Markova dlya modelirovaniya slabo strukturirovannyih sistem proektnogo upravleniya". *Informatsiini tekhnolohii v osviti, nautsi ta vyrobnytstvi.* 2014; 4(5): 77–82 (in Russian)

5. Kolesnikov, A. E., Lukyanov, D. V. & Olekh, T. M. "Development of a model for the representation of competencies in training projects". *Electronic and Computer Systems.* 2016; 23: 201–209.

6. Kafarov, V. V., Perov, V. L. & Meshalkin, V. P. "Principles of mathematical modeling of chemical-technological systems". Chemistry. Moscow, Russian Federation: 1974. 344 p. (in Russian)

7. Morozov, V., Steshenko, G. & Kolomiiets, A. „Learning through practice in IT management projects master program implementation approach". *Proceedings of the 2017 IEEE 9th International Conference on Intelligent Data Acquisition and Advanced Computing Systems: Technology and Applications, IDAACS*. – Available from: https://ieeexplore.ieee.org/document/8095223.

8. Piterska, V., Lukianov, D., Gogunskii, V. & Kolesnikov O. "Development of the Markovian model for the life cycle of a project's benefits". *Eastern-European Journal of Enterprise Technologies*. 2018; 5 (4): 30–39.

9. Lukianov, D., Bespanskaya-Paulenka, K., Gogunskii, V., Kolesnikov, O., Moskaliuk, A. & Dmitrenko, K. "Development of the markov model of a project as a system of role communications in a team". *Eastern-European Journal щf Enterprise Technologies*. 2017; 3(3(87)): 21–28.

10. Yaroshenko, F. A., Bushuev, S. D. & Tanaka, Kh. "Management of innovative projects and programs. *"Sammit-Kniga"*. Kyiv, Ukraine: 2012. p. 272 (in Russian).

11. Qureshi, S. M. & Kang, C. "Analysing the organizational factors of project complexity using structural equation modelling". *International Journal of Project Management.* 2015; 33(1): 165–176. Doi: https:// doi.org/10.1016/j.ijproman.2014.04.006.

12. Kadykova, I. N, Larina, S. A. & Chumachenko, I. V. "Information technology of strategic management of a projectoriented organization". *Bulletin of the National Technical University "KhPI", Series: Strategic*

management, portfolio management, programs and projects. 2017; (3): 9–15. Available from: http://nbuv.gov.ua/UJRN/vntux_ctr_2017_3_4. [Accessed 15th May 2020]. (in Ukrainian).

13. Kadykova, I. M., Khvostichenko, V. V. & Khudiakov, I. O. "Application of convergent approach in strategic project management". *Herald of Advanced Information Technology*. *Publ. Nauka I Tekhnika*. Odessa, Ukraine: 2020; 3(2): 83–94.

14. Carlsson, B., Jacobsson, S., Holmén, M. & Rickne, A. "Innovation systems: analytical and methodological issues", Research policy. 2002; 31(2): 233–245 Available from: https://www.sciencedirect.com/science/article/pii/S0 04873330100138X. [Accessed 15th May 2020].

15. Stanovskiy, O., Prokopovich, I., Olekh, H., Kolesnikova, K. & Sorokina, L. „Procedure for impact assessing on the environment". *Proceedings of Odessa polytechnic university*. 2018; 1(54): 99–108. DOI: 10.15276/opu.1.54.2018.14.

16. Rudenko, S. V. & Gogunskiy, V. D. "Environmental safety assessment in projects". Monograph. *Fenix*. Odessa, Ukraine. 2006.

17. "Methodical instructions for carrying out the assessment of the impact of economic activity on the environment". Astana. Available from: online.zakon.kz. [Accessed 15th August 2020].

18. Dzh. Kemeni & Dzh. "SnellKonechnye tsepi Markova". *Publ. Nauka*. Moscow, Russian Federation: 1970. 129 p. (in Russian).

19. "PM2 project management methodology guide", Luxembourg. 2016. 147 p. Doi: http://doi.org/10.2799/957700.

20. Biloshchytskyi A., Myronov O., Reznik R., Kuchansky A., Andrashko Y., Paliy S. & Biloshchytska S.. "A method for the identification of scientists' research areas based on a cluster analysis of scientific publications". *Eastern-European Journal of Enterprise Technologies*. 2017; 5(2(89)): 4–11. Doi: https://doi.org/10.15587/1729-4061.2017.112323.

21. Wu, C. & Nikulshin, V. "Method of thermoeconomical optimization of energy intensive systems with linear structure on graphs". *International Journal of Energy Research.* 2000; 24(7): 615–623.

22. Kolesnikov, O., Gogunskii, V. & Lukianov, D. "Development of the model of interaction among the project, team of project and project environment in project system". *Eastern-European Journal of Enterprise Technologies.* 2016; 5((8)83): 20–26. Doi: https://doi.org/10.15587/1729-4061.2016.80769.

23. Gogunskii, V. "Developing a system for the initiation of projects using a Markov chain". *Eastern-European Journal of Enterprise Technologies*. 2017; 1(3(85): 25–32. Doi: https://doi.org/10.15587/1729-4061.2017.90971.

24. Kolesnikova, K. "Lifelong learning" is a new paradigm of personnel training in enterprises". *Eastern-European Journal of Enterprise Technologies.* 2016; 4(2(82)): 4–10. Doi: https://doi.org/ 10.15587/1729-4061.2016.74905.

25. Gogunskii, V. "Development of the Markov model of a project as a system of role communications in a team". *Eastern-European Journal of Enterprise Technologies.* 2017; 3(3(87)): 21–28. Doi: https://doi.org/10.15587/1729-4061.2017.103231.

26. Durand, G., Belacel, N. & LaPlante, F. "Graph theory based model for learning path recommendation". *Information Sciences.* 2013; 251: 10–21. Doi: https://doi.org/10.1016/j.ins.2013.04.017.

27. Kaiser, M. G., El Arbi, F. & Ahlemann, F. "Successful project portfolio management beyond project selection techniques: Understanding the role of structural alignment". *International Journal of Project Management*. 2015; 33(1): 126–139. Doi: https:// doi.org/10.1016/j.ijproman.2014.03.002.

28. Roland Kluge, Michael Stein, Gergely Varró. "A systematic approach to constructing incremental topology control algorithms using graph transformation". *Journal of Visual Languages & Computing.* 2017; 38:. 47–83. Doi: https://doi.org/ 10.1007/s10270-017-0587-8.

29. Ma, F., Rudenko, S. & Kolesnikova K. "Management of the Image of the Educational Institution". Monograph: Jinan. 2014. 84 p.

30. Kolesnikova, K. "Communication management in social networks for the actualization of publications in the world scientific community on the example of the network researchgate". *Eastern-European Journal of Enterprise Technologies.* 2017; 4(3(88)): 27–35. Doi:10.15587/1729-4061.2017.108589.

31. Lukianov, D., Mazhei, K. & Gogunskii V. "Transformation of the International Project Management Association Project Managers Individual Competencies Model". *IEEE International Conference on Advanced Trends in Information Theory (ATIT).* 2019. p. 506–512. Doi: 10.1109/ATIT49449.2019.903048.

 ISSN 2617-4316 (Print)
ISSN 2663-7723 (Online)

DOI: 10.15276/aait.03.2020.7
UDC 005.8

РОЗРОБКА МАРКОВСЬКОЇ МОДЕЛІ ЕФЕКТИВНОСТІ ПРОЄКТІВ

Георгій С. Олех
Одеський національний політехнічний університет, Одеса, Україна
ORCID: https://orcid.org/0000-0002-7033-8504
Ігор В. Прокопович
Одеський національний політехнічний університет, Одеса, Україна
ORCID: https://orcid.org/0000-0002-8059-6507
Тетяна М. Олех
Одеський національний політехнічний університет, Одеса, Україна
ORCID: http://orcid.org/0000-0002-9187-1885
Катерина В. Колеснікова
Київський національний університет імені Тараса Шевченка, Київ, Україна
ORCID: http://orcid.org/0000-0002-9160-5982

АНОТАЦІЯ

Незважаючи на істотні відмінності між типами проєктів і різноманітність умов їх реалізації, оцінки ефективності / успішності проєктів повинні проводитися певним чином одноманітно, на основі загальних обґрунтованих принципів. У даній статті розглядається побудова матриці «сильної пов'язаності» для методологічних принципів оцінки ефективності / успіху проєктів на основі орієнтованого графа. Розглядаються методологічні, найзагальніші принципи, щоб забезпечити раціональне поведінку зацікавлених сторін незалежно від характеру і цілей проєкту. Всі перераховані вище принципи оцінки ефективності / успішності проєктів взаємопов'язані. Щоб показати топологію і напрямки взаємозв'язку методологічних принципів, необхідно скласти матричну схему. З її допомогою можна визначити співвідношення між методологічними засадами. Матрична діаграма, часто звана матрицею зв'язків, показує ступінь залежності критеріїв одного від іншого, наскільки сильні зв'язки між ними. Отримана матриця ілюструє взаємозв'язок між усіма методологічними принципами і вказує на те, що, спираючись тільки на один з методологічних принципів оцінки результативності / успішності проєктів, ми можемо зробити висновок про успішність місії / проекту.

Ключові слова: проєкт; управління проєктами; методологічні принципи; оцінка ефективності / успішності проєктів; матрична діаграма; орієнтований граф; марковские моделі; системний ландшафт

DOI: 10.15276/aait.03.2020.7
UDC 005.8

РАЗРАБОТКА МАРКОВСКОЙ МОДЕЛИ ЭФФЕКТИВНОСТИ ПРОЕКТОВ

Георгий С. Олех
Одесский национальный политехнический университет, Одесса, Украина
ORCID: https://orcid.org/0000-0002-7033-8504
Игорь В. Прокопович
Одесский национальный политехнический университет, Одесса, Украина
ORCID: https://orcid.org/0000-0002-8059-6507
Татьяна М. Олех
Одесский национальный политехнический университет, Одесса, Украина
ORCID: http://orcid.org/0000-0002-9187-1885
Екатерина В. Колесникова
Киевский национальный университет имени Тараса Шевченко, Киев, Украина
ORCID: http://orcid.org/0000-0002-9160-5982

АННОТАЦИЯ

Несмотря на существенные различия между типами проектов и разнообразие условий их реализации, оценка эффективности / успешности проектов должны проводиться определенным образом, единообразно, на основе общих обоснованных принципов. В статье рассматривается построение матрицы «сильной связанности» для методологических принципов оценки эффективности / успешности проектов на основе ориентированного графа. Рассатриваются методологические, самые общие принципы, которые при применении обеспечивают рациональное поведение заинтересованных сторон независимо от характера и целей проекта. Все вышеперечисленные принципы оценки эффективности / успешности проектов взаимосвязаны.

Чтобы показать топологию и направления взаимосвязи методологических принципов, необходимо составить матричную схему. С его помощью можно определить соотношение между методологическими принципами. Матричная диаграмма, часто называемая матрицей связей, показывает степень зависимости критериев одного от другого,и то насколько сильны связи между ними. Полученная матрица иллюстрирует взаимосвязь между всеми методологическими принципами и указывает на то, что, опираясь только на один из методологических принципов оценки результативности / успешности проектов, можно сделать вывод,об успешности миссии / проекта.

Ключевые слова: проект; управление проектами; методологические принципы; оценка эффективности / успешности проектов; матричная диаграмма; ориентированный граф; марковские модели; системный ландшафт

Heorhii S. Olekh – Graduate student, Engineer of the department of organizational and technical support of the educational process, Odessa National Polytechnic University, Odessa, Ukraine
olekhta@gmail.com

Георгій С. Олех – аспірант, інженер відділу організаційно-технічного забезпечення освітнього процесу, Одеський національний політехнічний університет, Одеса, Україна

Георгий С. Олех – аспирант, инженер отдела организационно-технического обеспечения образовательного процесса, Одесский национальный политехнический университет, Одесса, Украина

Ihor V. Prokopovych – Doctor of Technical Sciences, Associate Professor of Information system and technology department, Odessa National Polytechnic University, Odessa, Ukraine
igor.prokopovich@gmail.com

Ігор В. Прокопович – доктор технічних наук, доцент, директор інституту медичної інженерії, Одеський національний політехнічний університет, Одеса, Україна

Игорь В. Прокопович – доктор технических наук, доцент, директор института медицинской инженерии, Одесский национальный политехнический университет, Одесса, Украина

Tatyana M. Olekh – PhD, Associate Professor of department Higher Mathematics and Systems Modeling, Odessa National Polytechnic University, Odessa, Ukraine
olekhta@gmail.com

Тетяна М. Олех – кандидат технічних наук, доцент кафедри вищої математики та моделювання систем, Одеський національний політехнічний університет, Одеса, Україна

Татьяна М. Олех – кандидат технических наук, доцент кафедры высшей математики и моделирования систем, Одесский национальный политехнический университет, Одесса, Украина

Kateryna V. Kolesnikova – Doctor of Technical Sciences, Professor, Professor of the Technology Management Department, Taras Shevchenko National University of Kyiv, Kyiv, Ukraine
amberk4@gmail.com

Катерина В. Колеснікова – доктор технических наук, профессор кафедры технологий управления, доктор технічних наук, професор кафедри технологій управління,
Київський національний університет імені Тараса Шевченка, Київ, Україна

Екатерина В. Колесникова – доктор технических наук, профессор кафедры технологий управления, Киевский национальный университет имени Тараса Шевченко, Киев, Украина

Received	15.08. 2020
Received after revision	10.09. 2020
Accepted	18.09. 2020