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DEVELOPMENT OF A METHOD FOR ASSESSING THE QUALITY OF PROJECT MANAGEMENT PROCESSES BASED ON THE ENTROPY APPROACH

The object of this research is to assess the quality of project management processes. The conducted research is aimed at developing a method for assessing the quality of project management processes in accordance with modern requirements for management and its results. The study is based on the entropy concept of management, and entropy is considered as an integral indicator for assessing the quality of management processes, characterizing the «controllability» of the project and «confidence» in certain results of the project.

It is proposed to use information entropy as an indicator of management quality, which is understood as the ability to assess and minimize, through preventive or adaptive measures, uncertainty or negative impact from outside and inside on the project, that is, to ensure the success of the project.

The main factors influencing the level of entropy of the project are determined. It is substantiated that the role of management is to counteract entropy and create such conditions for the implementation of the project, under which its level tends to be acceptable. Only under this condition can the quality of management be defined as «high level» or «sufficiently high level». A scale for assessing the entropy level of a project is proposed, which is substantiated by experimental studies of the entropy level of various projects.

The concept of «entropy index» of the project is introduced into consideration, as a relative indicator of the level of entropy of the project. The proposed approach is illustrated on the example of a specific project, which substantiated the adequacy of the results of applying the approach to the logic and experience of project implementation, and also demonstrated the practical applicability of the approach for assessing the level of project entropy and management quality.

The results obtained make it possible to assess the quality of management processes at each stage of the project life cycle in order to identify problems early; and also form a theoretical basis for the further development of tools to ensure and improve the quality of project management processes.

Keywords: *entropy management concept, quality of management processes, project management, project success, network model.*

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1. Introduction

Quality management is one of the areas of expertise in project management. According to international project management standards [1], project quality implies two components – *the quality of the product (project product) and the quality of management processes.* In modern literature, considerable attention is paid to the first component – *the quality of the project product.* This is explained by the fact that this direction is connected both ideologically and instrumentally with quality management, ISO standards, for which relevant studies of both theoretical and practical nature have been conducted for quite some time. Examples of such studies can be [2–4], in which attention is paid to those procedures and tools from quality management that are used in project management, taking into account the recommendations of the standards. At the same time, special attention is paid to business processes as the basis for managing the quality of the project product (for example, [5–7]).

The quality of project management processes is of a different nature and, according to [8], affects not only and not so much on the quality of the product, but on *the effectiveness of the project.* In particular, in [8] a conceptual model for measuring the quality of the project management process is presented, but these results set the direction of research to a greater extent than give specific quality assessment tools or outline the way to obtain them.

Thus, *the quality of project management processes* is a certain property of the project management system, the presence of which ensures the achievement of the project goal and its effectiveness. Naturally, this property should have a certain assessment, which, given the lack of such in modern literature, determines the relevance of this direction.

Therefore, *the object of this research* is to assess the quality of project management processes. *The aim of research* is to develop a method for assessing the quality of project management processes in accordance with modern requirements for management and its results. This will make it possible, firstly, to assess the quality of management processes at each stage of the project life cycle, in order to identify problems early; secondly, it will form the basis for the further development of tools for ensuring and improving the quality of project management processes.

2. Research methodology

Entropy is one of the universal categories of modern science, successfully used not only to assess the state of physical systems, but also enterprises, organizations, and human communities. The universality of entropy as a thermodynamic category was substantiated in [9], after which some authors used this entropy in relation to socio-economic systems [10]. At the same time, many researchers used information entropy (Shannon entropy) as a measure of uncertainty in the activities of enterprises, including as a measure of uncertainty and risks in project management [11–13].

In [14], at the theoretical level, the relationship between entropy (in the energy aspect) and informational entropy (Shannon entropy) for systems of various natures was substantiated.

Thus, informational entropy «stepped» beyond the limits of information theory, and in parallel, entropy as a thermodynamic category also went beyond the limits of thermodynamics. All this formed the prerequisites for the formation of the entropy management concept [15–17], which considers entropy as a universal and integral category for assessing the state of individual projects and organizations as a whole. Studies [18–20] present the main provisions and tools of this new theory.

According to the entropy concept of management, entropy reflects the state of the object of management, in this case, the project, from the standpoint of the influence of a system of factors on it, including internal ones, such as management.

The information entropy H reflects the degree of uncertainty of the results of the project implementation, and, in particular, in [20] it is proposed to use the *Shannon formula* to assess it:

$$H = -\sum_{k=1}^{K} p(A_k)\cdot \ln\left(p(A_k)\right), \quad (1)$$

where A_k – options for the results of the project; $p(A_k)$ – probabilities of these results; K – total number of options. At the content level, A_k is a set of values, for example, the value (income) and costs of the project, that is, the event A_k consists in the fact that the income (value) and costs of the project have taken specific values.

This approach to assessing the entropy of the project is the basis for developing a method for assessing *the quality of project management processes.*

3. Research results and discussion

Naturally, the higher the value of H in (1), the more uncertain are the results of the project, which can serve as a kind of assessment of *not only the risk, but also the quality of the project at the planning stage.* The latter is true if *the quality of management processes* as a component of *project quality* is assessed *from the point of view of the ability of the management (control) system to provide* the required result for the project.

Thus, the information entropy of the project characterizes the «confidence» of management in the results of the project, which can serve as both a risk assessment and an assessment of the quality of management. Let's note that, unlike traditional methods for assessing project risks, which are based on the probabilistic nature of market factors, the entropy H is *an integral value. This value* reflects not only the uncertainty of market factors, but also *the ability of the management system* to cope with this uncertainty.

As it is known, possible risks are present in almost any project. But *the biggest threat to the project*, as well as *the biggest strength of the project*, is *the project management system.* It is on it that an adequate assessment of risks depends, the possibility of minimizing them through either preventive and/or adaptive measures. Thus, project risks, as well as its *information entropy*, have *a common system of factors*, but it is not the very fact of the existence or occurrence of risks that determines the success or failure of the project, but the ability of the management system to cope with them, which is ensured by *a certain level of quality of management processes.* Moreover, even under favorable conditions for the implementation of the project, the management system itself can serve as a source of project failures (for example, the incompetence of managers in making certain decisions).

So, for two similar projects implemented in the same environmental conditions, that is, with the same risk factors, the information entropy may be different depending on the competence of management and the quality of management processes. Thus, the quality of project management processes *should be eassessed from the standpoint of the ability of the management system to adequately assess and minimize the information entropy of the project.*

Thus, the quality of the project, which consists of the quality of the product and the quality of the management processes, directly affects the success of the project (the required product, of a certain quality on time, budget and with a set result). At the same time, it is natural that the quality of the product and the success of the project as a whole is influenced by a whole set of factors that can be *partially controlled and managed by the project management system.* In particular, in [18], one of the postulates of the entropy concept of management is expressed, according to which, through *partial control over the external environment*, the entropy of the project (the organization as a whole) is reduced. Therefore, the quality of management processes, which is determined solely by the project management system itself, underlies the ability to reduce the information entropy of the project and influence its success.

Let's take the information entropy H as a*n indicator of the quality of project management processes,* and expression (1) as the basis for its formalization. Let's note that from the point of view of management processes, *the time of project implementation* is also important. Indeed, according to the definitions of *project success* [21], a project is successful if it is implemented on time within the established budget and achieves the planned results. Thus, only providing cost limits as well as income or other value indicators for, for example, non-commercial projects does not reflect the quality of project management processes. Thus, the necessary indicators achieved, but with a significant delay in time, indicate the unsatisfactory quality of management processes.

Thus, the performance indicators characterizing the quality of management processes and underlying information entropy, as the main indicator of the quality of these processes, is the set «time-budget (expenses) – result (value)»:

$$A_k = \langle T_k, R_k, V_k \rangle, k = \overline{1,K}, \quad (2)$$

where T_k – project implementation time; R_k – budget (expenses) of the project; V_k – result (value) of the project. So, the essence of the event is adjusted taking into account the above.

So, let's analyze how the entropy of the project is formed. The basic formalized description of the project is *a network schedule (a network model* that demonstrates the sequence of work). The model is given by a directed graph G, reflecting the logical sequence of work W_i, $i=\overline{1,n}$. Each work W_i, $i=\overline{1,n}$ of the network model is characterized, first of all, by the duration T_i and the costs of various resources R_i, expressed in monetary terms:

$$\langle T_i, R_i \rangle, i = \overline{1,n}. \quad (3)$$

The resulting indicators for the project (2) are formed taking into account the characteristics of each work included in the network model. So, the project implementation time (the time of receiving the project product) is the critical path of the network model – the path with the maximum duration of work:

$$T = \sum_{i \in \Omega_{Kr}} T_i, \quad (4)$$

where Ω_{Kr} – set of works on the critical path of the network model.

Accordingly, the cost of the project R is the sum of the cost of all work on the project:

$$R = \sum_{i=1}^{n} R_i. \quad (5)$$

Let's note that in modern studies, for example, in [22, 23], methods for optimizing the time and resources of projects based on a network diagram are proposed. Therefore, let's take into account the fact that (4) and (5) were formed after the process of optimizing the progress of work by using the methods proposed in the indicated sources. Thus, given the cost and duration of the project is the best option considering the leveling of resources.

Naturally, in practice, the characteristics of many project activities are random variables – for example, the duration of some activities may depend on weather conditions. In addition, there is always a «human factor» – illnesses, mistakes, for example, disruptions in the supply of raw materials or equipment for the project, etc. can also be included here. The larger and longer the project, the more likely it is to deviate from the planned characteristics of the project work.

The cost of project work may also increase, for example, under the influence of force majeure circumstances: in the course of a construction or infrastructure project, additional impact factors may be identified that require additional resources or additional work. The intervention of natural and climatic factors in the course of the project can also lead to an increase in costs. Termination of the contract with suppliers due to various circumstances and attraction of resources at higher prices are also examples of reasons for the possible increase in the cost of project work. As a rule, planned characteristics and resulting indicators are based on the most probable estimates (mathematical expectation) [24].

Such circumstances should be considered as part of the project risk analysis, which results in estimates of the possible increase in time and costs for each activity. These estimates can be obtained in various ways (which is not the subject of this study) – expert estimates, analysis of the distribution law, for example. In the latter case, options for changing the characteristics for different probabilities can be considered (for example, as in [21]). In any case, regardless of the method, a set can be set for each work W_i, $i=\overline{1,n}$:

$$\left\{ \left(T_i^j; p_i^j\right), \left(R_i^m; q_i^m\right) \right\}, \; i=\overline{1,n}, \; j=\overline{1,K_J}, \; m=\overline{1,K_M}, \quad (6)$$

where p_i^j and q_i^m are, respectively, the probabilities that the options for the duration and cost of the work W_i, $i=\overline{1,n}$ are T_i^j and R_i^m. Naturally, the number of time and cost options may be different, in this study they are taken as – K_J, K_M.

Let's note that $\left(T_i^j; p_i^j\right)$, $i=\overline{1,n}$, $k=\overline{1,K_J}$ and $\left(R_i^m; q_i^m\right)$, $i=\overline{1,n}$, $m=\overline{1,K_M}$ form complete groups of events, therefore:

$$\sum_{j=1}^{K_J} p_i^j = 1, \; i=\overline{1,n}, \; \sum_{m=1}^{K_M} q_i^m = 1, \; i=\overline{1,n}. \quad (7)$$

Based on the network model, taking into account the options for the characteristics of work (6), options for the sets of resulting indicators with the corresponding probabilities can be obtained. These sets can be obtained, for example, by sorting through possible combinations of time and expenses with an estimate of the final probability of this combination. This is the first way. The second, which generates fewer options, can be based on considering a single principle for forming combinations, for example, the «worst» option with the maximum possible increase in cost and time for all works, then the option with moderate risk, etc.

LET's note that the «project value» can be expressed in different ways, but, in any case, as a rule (especially for commercial projects), it depends on both the project costs and the project implementation time (the latter is characterized and studied on a mathematical model in [21]). Therefore, they are determined on the basis of combinations of characteristics of time and costs, as well as the specific characteristics of those works from the set W_i, $i=\overline{1,n}$ that are associated with obtaining «value» (for example, income from the sale of a project product).

Thus, as a result of this stage of the analysis of the network model, the desired combinations are formed with the corresponding probabilities:

$$A_k = \langle T_k, R_k, V_k \rangle,$$
$$P(T = T_k \wedge R = R_k \wedge V = V_k) = p_k,\ k = \overline{1,K}. \quad (8)$$

It should be noted that the condition of the complete group for A_k, $k = \overline{1,K}$ and, accordingly, the execution of $\sum_{k=1}^{K} p_k = 1$. If, when forming possible combinations of results A_k, $k = \overline{1,K}$, not all combinations of options for the characteristics of work were used, then it should be artificially formed from A_k, $k = \overline{1,K}$ a complete group by transforming their probabilities. At the same time, the same principle should be followed in further processes of studying the dynamics of the informational entropy of the project.

Naturally, just the value of the informational entropy of the project at the initial moment of time does not give a clear understanding of «good-bad». The use of this or that indicator for analysis requires a certain scale that allows to determine the «degree of confidence» of management in the results and the «quality of project management» at the stage of its preparation.

As it is known, the ideal variant, that is, full confidence in one specific variant of the project implementation, corresponds to an entropy equal to $H = 0$. Therefore, the closer the value of the project entropy to 0, the more «confident in the results» is the management. On the other hand, the level of information entropy is proposed as a basis for comparison in the worst case, namely, in a situation where the available scenarios, variants of results have an equal probability. That is, the management system is not able to provide conditions for the more likely implementation of a certain option or cannot adequately assess possible situations in the process of project implementation. Such a «worst situation» is characterized by the following level of entropy:

$$H^w = -\sum_{k=1}^{K} \frac{1}{K} \cdot \ln\left(\frac{1}{K}\right), \quad (9)$$

where $P(A_k) = p_k = 1/K$, and K – the number of considered options for the implementation of the project, which is fair taking into account the full group of events consisting in obtaining results A_k, $k = \overline{1,K}$.

Thus, the actual value of the entropy of the project at the initial stage of its consideration (implementation) lies within:

$$0 \le H \le H^w. \quad (10)$$

As a variant of the scale for assessing the entropy of the project and identifying the quality of project management at the initial stage, the following is proposed (Table 1), which was substantiated by experimental studies.

Table 1

Project entropy level identification scale

Project entropy ranges	Characteristics of the project and the management quality
$0 \le H \le 0.4 \cdot H^w$	– project with practically certain results; – level of risk is low; – management quality is assessed as «high level»
$0.4 \cdot H^w < H \le 0.6 \cdot H^w$	– project with sufficiently defined results; – level of risk is moderate; – management quality is assessed as «a fairly high level»
$0.6 \cdot H^w < H \le 0.8 \cdot H^w$	– project with rather uncertain results; – level of risk is high; – management quality is «not fully satisfactory»
$0.8 \cdot H^w < H \le H^w$	– high-risk project with practically uncertain results; – justifications are not carried out at the proper level; – management quality is «unsatisfactory»

Let's define the relative value $I^H = H/H^w$ as the «entropy index of the project», its use is more convenient from the point of view of the visibility of the entropy level of the project.

As an illustrative example, let's take the network model of the project shown in Fig. 1, where critical activities and, accordingly, the critical path of this graph are highlighted. Actually, the duration of these works determines the duration of the project.

For this project, let's consider the following time and cost options (Tables 2, 3).

On the basis of these data, many sets of project results were formed (Table 4). Let's note that the calculation of the value was carried out as follows:

$$V_k = 2000 - R_k - 1 \cdot (T_k - 251). \quad (11)$$

Thus, the value is formed as the difference between a certain income value of 2,000 thousand USD, costs R_k, taking into account fines, of 1 dollar for each day of project delay compared to the base case of 251 days.

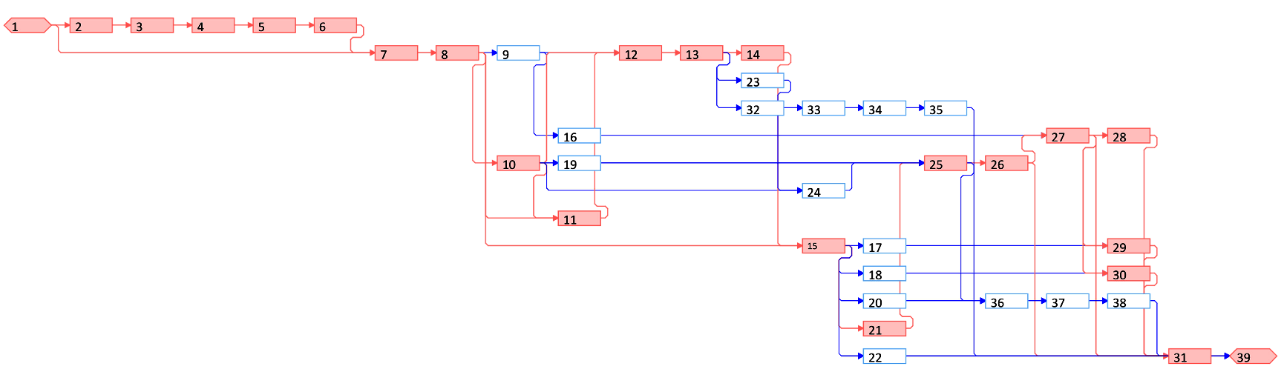

Fig. 1. Network diagram of an illustrative example

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Table 2

Project duration options

Basic option	Increase in the duration of work by 10 %	Increase in the duration of work by 10–20 %	Increase in the duration of work by 20 %
Probability			
0.65	0.1	0.2	0.05
Project duration (*T*), days			
251	275	287	301

Table 3

Project cost options

Basic option	Increase in the cost of work by 5–10 %	Increase in the cost of work by 10 %	Increase in the cost of work by 150 %
Probability			
0.85	0.05	0.05	0.05
Project cost (*R*), thousand USD			
1280	1370	1408	1472

Table 4

Project result set options

Cost, R_k	Duration, T_k	Value, V_k	Probability, p_k
1280	251	720	0.5525
1280	275	696	0.085
1280	287	684	0.17
1280	301	670	0.0425
1370	251	630	0.0325
1370	275	606	0.005
1370	287	594	0.01
1370	301	580	0.0025
1408	251	592	0.0325
1408	275	568	0.005
1408	287	556	0.01
1408	301	542	0.0025
1472	251	528	0.0325
1472	275	504	0.005
1472	287	492	0.01
1472	301	478	0.0025

The entropy of such a variant of the project result sets according to (1) is estimated as: $H=1.569$. According to the proposed approach $H^w=2.95$ (at $K=16$), the entropy index is $I^H=1.569/2.95=0.53$, which, according to Table 1 allows to characterize the project as moderately risky, and the quality of management is characterized as «a fairly high level».

Note that when the probabilities of individual resulting indicators (Table 5) are changed to more «confident», the entropy of the project naturally decreases gradually to 1.015.

At $H=1.015$, the entropy level of the project is $I^H=0.34$, which corresponds to the high quality of management and the low risk of the project.

Table 5

Changed options for project duration probabilities

Version number	Basic option	Increase in the duration of work by 10 %	Increase in the duration of work by 10–20 %	Increase in the duration of work by 20 %	Entropy
0	Probability				
	0.65	0.1	0.2	0.05	1.569
1	Probability				
	0.85	0.02	0.1	0.03	1.139
2	Probability				
	0.9	0.02	0.05	0.03	1.015

This example illustrated the practical aspects of assessing the information entropy of a project, its applicability as an additional assessment of project risks, as well as a basic assessment of the quality of project management. So, at the stage of planning and justifying the project, high entropy indicates a low level of «confidence» of managers in certain project results. The lower the entropy at this stage, the better the management «prepared» the conditions for the project, and, accordingly, vice versa. As in this example, with the probability of the project's base case time $p=0.65$ (which is not high enough), the entropy is accordingly «highly noticeable» and the entropy index of the project is 0.53. With an increase in the probability of the base case to $p=0.85$ and then to $p=0.9$, the entropy decreased to 1.015, respectively, the entropy index to 0.34.

The proposed method for assessing the quality of project management processes at the initial stage of its life cycle is widely used regardless of the specifics of the project. But for its practical use, information is needed on the possible outcomes of the project with their probabilistic assessment, which is performed by the project team. At the same time, the assessment of the quality of management processes should be carried out by top project managers or independent experts, based on the assessments of the team. Here, obviously, a conflict of interests is possible and procedures should be developed that allow an objective assessment of the quality of management processes. This is a direction for further research. In addition, the quality of project management processes is subject to monitoring throughout the life cycle of the project. This also requires special attention in future studies of the problems of assessing the quality of project management processes.

4. Conclusions

This research is based on the *entropy concept of management*, and the results obtained develop it in terms of specific methods for using entropy in project management processes. In this case, it is proposed to use entropy in project quality management, namely, its component – *the quality of project management processes.*

In this research, entropy is considered as an integral indicator for assessing the quality of management processes (in the framework of this study, at the initial stage of the project life cycle), characterizing the «controllability» of the project and «confidence» in certain results of the project. This is a new approach to the use of information entropy, which does not contradict existing theories and approaches, but complements and develops them.

Thus, it is proposed to use information entropy as an indicator of *management quality,* which is understood as *the ability to assess and minimize, through preventive or adaptive measures, uncertainty or negative impact from outside and inside on the project*, that is, to ensure the success of the project.

The main factors influencing the level of entropy of the project are determined. It is substantiated that the role of management is to counteract entropy and create such conditions for the implementation of the project, under which its level tends to be acceptable. Only under this condition can the quality of management be defined as «high level» or «sufficiently high level». A scale for assessing the entropy level of a project is proposed, which is substantiated by experimental studies of the entropy level of various projects.

The concept of «entropy index» of the project is introduced into consideration, as a relative indicator of the level of entropy of the project.

The proposed approach is illustrated on the example of a specific project, which substantiated the adequacy of the results of applying the approach to the logic and experience of project implementation, and also demonstrated the practical applicability of the approach for assessing the level of project entropy and management quality.

The results obtained make it possible to assess the quality of management processes at each stage of the project life cycle in order to identify problems early; and also form a theoretical basis for the further development of tools to ensure and improve the quality of project management processes.

In particular, for the project, on the example of which the quality of management processes was assessed, it was found that the entropy of the initial version was 1.569. This made it possible to characterize the project as moderately risky, and the quality of management as «a fairly high level». It has been shown that with a better design of the project and an increase in the probability of one of the outcome options, the entropy decreased to 1.015. This makes it possible to assess the quality of management processes as «high», and the project as «moderately risky».

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