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# Entropy analysis of organizations' knowledge systems on the example of project management standards

**Viktor D. Gogunskii[1)]**
ORCID: https://orcid.org/0000-0002-9115-2346; vgog@i.ua. Scopus Author ID: 57194244349
**Kateryna V. Kolesnikova[2)]**
ORCID: http://orcid.org/0000-0002-9160-59823; amberk4@gmail.com. Scopus Author ID: 57188623059
**Dmytro V. Lukianov[3)]**
ORCID: http://orcid.org/ /0000-0001-8305-2217 ; dlukiano@gmail.com. Scopus Author ID: 57192572835
[1)] Odessa National Polytechnic University, 1, Shevchenko Ave. Odessa, 65044, Ukraine
[2)] International IT University, 34/1 Manas St. Almaty, 050040, Kazakhstan
[3)] GIGACloud, Pr. Bortnikova, 499A, Kiev, 03212, Ukraine

## ABSTRACT

The problems of managing complex project management systems are associated with numerous parameters that characterize their state. Most modern methods of forecasting project activity are based on the use of statistical modeling of individual processes and tools, for example, a work schedule, which requires both the justification of the adopted laws for the distribution of random work durations and the planning of a certain organizational and technological sequence of work. The collection and processing of data on all parameters is a complex and expensive procedure, and a complete justification of all project characteristics can lead to the information complexity of the system under consideration. However, it is impossible to refuse this due to the need to obtain relevant and reliable data for the adoption and implementation of management decisions. Thus, it is necessary to look for ways and means to reduce the number of controlled parameters, create algorithms that allow predicting the presence of undesirable processes in a controlled system, and develop recommendations for a more detailed analysis of individual project management subsystems. To overcome the informational complexity of predictive models, it is proposed to use a phenomenological approach that is associated with the definition of entropy, which allows using a minimum of information about the planned and updated course of the project. The concept of entropy is one of the key concepts of thermodynamics and information theory, and also finds its application in a number of other sciences, the subject of research and study of which are complex stochastic systems. The possibilities of using entropy and entropy modeling are currently being actively explored in the theory of project management. The paper considers an entropy approach to modeling project management systems, in which, on the basis of mathematical procedures arising from K. Shannon's information theory, information phenomenological models are created. The IPMA ICB 4.0 standard is considered as an example. The developed tool creates the prerequisites for the effective use of the entropy approach to assessing complex economic and social systems.

**Keywords**: Entropy; knowledge systems; project management; K. Shannon's information theory; phenomenological models

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## INTRODUCTION

Today, in theory, significant experience has been accumulated in the systematic consideration of project management processes and a serious scientific groundwork has been created in this direction. In project and program management, much attention is paid to the consideration of processes from the standpoint of a systematic approach. Books, articles and standards are devoted to this problem (D. Milosevic, G. Kertsner, V. Voropaev, S. Bushuev, N. Bushueva, P2M, etc.). In recent years, due to the acceleration of innovation processes and the implementation of large-scale changes in various fields of activity (international relations and economic relations, finance, law, technology, etc.), the processes of radical changes in business, education and public administration have intensified. Projects are implemented in any sphere of human activity. Projects can be implemented within the framework of one organization, and they can also be of an international nature. However, regardless of the scale of projects, there are always external and internal factors that affect the implementation of the project. The more such factors, the greater the number of stakeholders, the more difficult it is to find a compromise among the requirements and wishes of the participants for the successful completion of the project.

Today, most companies use project management tools and implement most of their activities through projects. However, despite the positive trends, many approaches remain unchanged, such as decision-making at the national level, the mentality of society, as well as the desire to implement a Western level of management, without adapting to national characteristics. Therefore, there are often some kind of “gaps” in understanding between the participants and stakeholders of the project. This may entail the occurrence of risky activities, which means damage and the threat of its successful completion.

When managing a project, a manager must operate effective project management tools, conduct various kinds of assessments, forecasting and measurements, as well as be able to hear and establish communication channels between project stakeholders, while reducing the level of uncertainty. Such management tools include the Monte Carlo method, the earned value method, etc.

When implementing any project, its result is always in the nature of uncertainty. However, in the process of project implementation, it is possible to significantly reduce the level of uncertainty through control at certain stages of project implementation. One of the tools that can be used to do this is entropy.

## THE PURPOSE OF THE ARTICLE

The aim of the research is to consider the possibility of using the entropy approach to monitoring project management systems. On the basis of mathematical procedures arising from the information theory of K. Shannon, develop information phenomenological models and check their adequacy using the analysis of the IPMA ICB (ver. 4.0) standard as an example.

## MAIN PART

By definition [1], entropy (from the Greek – rotation, transformation) – in control theory – is a measure of the uncertainty of the state or behavior of the system under given conditions. The term is widely used in other areas of knowledge, and is also relevant for any system.

When using entropy methods, a distinction is made between thermodynamic entropy S and informational entropy H [1]. Let us briefly consider the methods of thermodynamic entropy in the study of evolutionary processes and the dynamics of hierarchical systems [2].

The change in thermodynamic entropy $dS$ is defined as:

$$dS=\Delta Q/T, \qquad (1)$$

where $\Delta Q$ is the change in heat in the process; $T$ is the absolute temperature.

In the general case, the entropy increment $dS$ can be represented as the sum of two terms [3]:

$$dS= dS_e + dS_i, \qquad (2)$$

where $dS_e$ is the change in entropy due to the exchange with the environment; $dS_i$ increment of entropy caused by irreversible changes within the system.

In accordance with the laws of thermodynamics, $dS_e$ can take both positive and negative values. The increment, $dS_i$ in accordance with the second law of thermodynamics, can only be positive. For an isolated system $dS_e = 0$, and in such a system the entropy can only increase.

The quantity $\Theta = dS_e/dt$ is called the entropy production. This value characterizes the rate of accumulation of irreversible changes.

In the thermodynamics of irreversible processes, it is assumed [4] that

$$\Theta=\Sigma X_i J_i. \qquad (3)$$

As a simple example, in the logic of knowledge management systems, as shown by E. Deming [5], the source of knowledge is always outside the system, and becomes “requested” (or “invited”) only when the system needs the knowledge which it does not possess, which, obviously, occurs when resources are exhausted (“realization” of the accumulated “ignorance” as informational entropy) for solving a particular problem [6]. Taking the definition of entropy for information systems as “Entropy is how much information about the system is unknown” [7], we apply this definition to create an entropy model.

Suppose that in the logic of information entropy:

$dH_e$ – the change in entropy (“ignorance”), due to the exchange with the environment;

$dH_i$ – increment of entropy (“ignorance”), caused by irreversible changes within the system, respectively,

$$dH = dH_e + dH_i\,. \qquad (4)$$

Obviously, when the “internal resources” are exhausted, the “production” of entropy has reached a certain critical (positive) value, there is a conscious need to attract an “external resource” that can solve the problem (minimize the entropy of the system), and in this case, a negative value of “ignorance” is needed (which would correspond to “knowledge”).

Such logic can be illustrated in the form of a 2x2 matrix, if it is considered as a “coordinate system” as shown in Fig. 1.

In this case, we proceed from the fact that the system is no longer closed, i.e. a situation is possible when it is not necessary, $dH_e = 0$, but there may be a “delivery of knowledge from the outside” ($dH_e < 0$).

| internal knowledge | | |
|---|---|---|
| surplus | No, the need to attract external source, you can become a source of knowledge for external systems | There is opportunity for improvement based on comprehensive benchmarking |
| deficit | There is need to attract external knowledge in conditions lack internal knowledge, but no capabilities attract knowledge | No, the need to create internal source, you can use knowledge from external systems |
| | deficit | surplus |
| | | external knowledge |

*Fig. 1.* **Matrix of relations to an external source of knowledge in the system**

***Source: compiled by the authors***

This two-dimensional matrix can be transformed into a “cube of need” for knowledge by adding another dimension - awareness of the presence of “knowledge / ignorance” in the system. In this interpretation, the model can be a set of the following eight states, through which, in particular, it can be proposed to understand such a phenomenon as “technological maturity in management” (including in project management).

Table 1 is illustrating the insufficiency of the existence of knowledge as such – it is necessary to understand its sufficiency (or even “surplus”) or lack (“deficit”) to solve specific problems facing a particular system (be it an individual or an organization). It is important not only to understand the “balance of knowledge”, but also to understand how the process of working with knowledge can be launched in the organization, ensuring the creation and maintenance of at least a minimum sufficient level for the functioning of the system (organization).

In the conditions of even the constancy of the external and internal environment of the “non – VUCA world”, it is necessary to ensure the maintenance of a stable meaning for the expression $dH = dH_e + dH_i = 0$, from which follows $dH_e = -dH_i$, which corresponds to compensation "from the outside" of those losses of knowledge (information) that will inevitably occur “inside” the system. An example is the procedure for maintaining the qualifications of personnel in process-oriented organizations. Professional development must be carried out with certain regularity, and updated. Assuming, as an initial condition, the presence of changes in the external environment, it is necessary to ensure the growth of “external knowledge” to compensate for losses due to the inevitable increase in such “organizational entropy”. In this logic, one can also consider the activity of creating and further updating standards in any of the areas of human activity, including project management. At the same time, some approaches may be replaced by others, thanks to the analysis of best practices from related disciplines or related knowledge systems. This is what can now be observed in the field of professional project management in the form of “harmonization” of the approaches of Agile and Waterfall.

To understand the logic of knowledge management processes in an organization, it is necessary

*Table 1.* **Extended model of attitude to knowledge in the organization**

| External knowledge | Internal knowledge | Understanding states | Description situations |
|---|---|---|---|
| 1 | 1 | 1 | Readiness for development based on benchmarking. High level technological maturity in the issue / technology |
| 1 | 1 | 0 | State “as is” for many organizations with some “latent” level maturity, allowing to receive acceptable results of activities, also leading to low efficiency use key competencies due to them unconsciousness |
| 1 | 0 | 1 | Situation an express “request” to receive external knowledge (including understanding the “location” of such a “source”) |
| 1 | 0 | 0 | Situation an express “request” to receive external knowledge (including understanding the “location” of such a “source”) |
| 0 | 1 | 1 | The situation of “conscious leadership”, creating prerequisites for the “export of knowledge”. Also, situation maybe to be considered how prerequisite for expansion species activities within existing competencies (individual and/ or organizational) |
| 0 | 1 | 0 | The situation of “unconscious leadership”. It creates the prerequisites for “loss of knowledge” or the risk of replacing existing methods and work tools with worse, but more common or already known ones. The situation can lead to low efficiency in the use of key competencies (unconsciousness). |
| 0 | 0 | 1 | Conscious condition abandonment of the project / activity (may become the starting point for processes related to research and development) |
| 0 | 0 | 0 | “Nirvana” as the absence of the need for any knowledge |

***Source:*** **compiled by the authors**

to consider not only the dynamics of changing the state of "sufficiency" of existing knowledge, but also the processes of technology development, on the one hand, as well as the logic of external and internal use of products and services based on the use of appropriate technologies, as shown in Fig. 2 [7, 8].

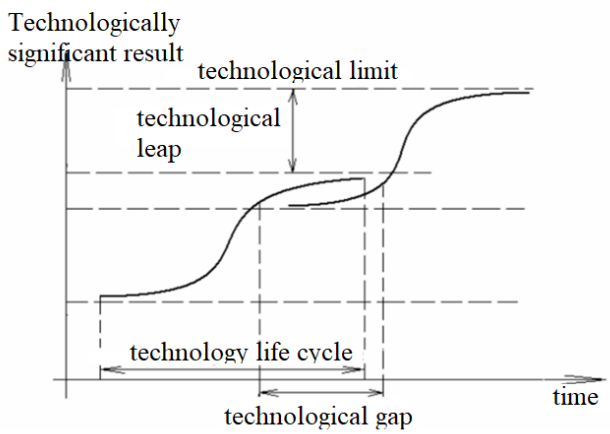


*Fig. 2.* **The logic of technological leaps and gaps in the development of technologies**
***Source:*** **compiled by the [7]**

In this case, it makes sense to define the entropy $dH = dH_e + dH_i$ like the difference between technologies (in the case of $t_x$ development), where the index *i* refers to the "established" version, and *e* – to the "new" version.

As you can see, four states can be clearly distinguished and correlated in the model presented in Fig. 2. In particular, in logic of coexistence, for example, in the construction industries, where various technologies for the development of design estimate coexist. Moreover, in such a scheme, technologies can not only reach their technological limit, but also degrade.

As noted in [8], when studying the dynamics of many complex systems, by analogy with the production of entropy, one can introduce the rate of change in information entropy. In the general case, it is necessary to take into account both the change in thermodynamic and informational entropy.

In this case, when solving variational problems, the function *F*, which is to be studied for an extremum, is written as follows:

$$F = S + BH, \quad (5)$$

or

$$F = H + bS. \quad (6)$$

$B*b = 1$ must be satisfied between the coefficients *B* and *b*.

In self-organizing processes, the rate *dH/dt* takes on negative values, which corresponds to the "increment of knowledge".

It is known that the entropy *H* can be determined by the formula,

$$H = lnW, \quad (7)$$

where *W* is the number of microstates by which the given macrostate can be realized.

Hence, we can assume the number of microstates W, through which it is possible to realize a macrostate with a given value H :

$$W = exp(H) \quad . \quad (8)$$

It is also correct to insert here a remark about the choice of the base of the logarithm, but we can also consider the classical formula:

$$H = log_2 W, \quad (9)$$

if you choose "bit" as the unit of measure.

And to present the amount of information that can be transferred from the elements of the ICB IPMA competency models.

In this case, it would be logical to see new versions of standards as knowledge systems, those that allow solving problems in the relevant subject areas using updated information. The calculation of such indicators can be illustrated by the example of the analysis of the system of individual competencies of project managers ICB 4.0 IPMA [9]. As an initial model, consider the adjacency matrix between elements, built on the basis of the text analysis of the ICB4.0 IPMA standard, which shows data on the presence of such relationships (Fig. 3).

Based on the logic of K. Shannon, it is necessary to operate with the probabilities of transitions from one state to any of those reachable from this state, where the fundamental possibility of such a transition is indicated as 1, and the absence of a direct influence of one element on another is represented as 0. We suggest using the formula of K. Shannon to calculate the entropy obtained by him based on the use of the Nyquist and Hartley formula

$$H = n*\log S, \quad (10)$$

which Shannon K. used to measure information as a function of probabilities. This is the logarithm of the "improbability" of the message, in fact, a measure of the "surprise" of the appearance of one or another "information influence":

$$H = \Sigma p_k \log_2(1/p_k) \, , \quad (11)$$

where $p_k$ is the probability of each message.


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| Factor name | Elements that are affected (columns) | Strategy | Governance, structure and processes | Compliance, standards and regulations | Power and interests | Culture and values | Self-reflection and self-management | Personal integrity and reliability | Personal communication | Relations and engagement | Leadership | Teamwork | Conflict and crisis | Resourcefulness | Negotiation | Results orientation | Project design | Requirements and objectives | Scope | Time | Organisation and information | Quality | Finance | Resources | Procurement | Plan and control | Risk and opportunities | Stakeholder | Change and transformation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Influencing Elements (Rows) | FID | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 |
| Strategy | 1 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 |
| Governance, structure and processes | 2 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 1 |
| Compliance, standards and regulations | 3 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| Power and interests | 4 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 |
| Culture and values | 5 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Self-reflection and self-management | 6 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Personal integrity and reliability | 7 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Personal communication | 8 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| Relations and engagement | 9 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| Leadership | 10 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Teamwork | 11 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 |
| Conflict and crisis | 12 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 0 |
| Resourcefulness | 13 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 |
| Negotiation | 14 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 |
| Results orientation | 15 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 0 |
| Project design | 16 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Requirements and objectives | 17 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Scope | 18 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Time | 19 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Organisation and information | 20 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Quality | 21 | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Finance | 22 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 |
| Resources | 23 | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 |
| Procurement | 24 | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 |
| Plan and control | 25 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 |
| Risk and opportunities | 26 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 |
| Stakeholder | 27 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 |
| Change and transformation | 28 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |

*Fig. 3.* **First order adjacency matrix for ICB 4.0**

***Source: compiled by the authors***

*H* is commonly referred to as “message entropy”, “Shannon entropy”, or simply “information”. The resulting value is measured in the measure of information proposed by Shannon K. – “bits” [10].

Shannon K. suggested that the information gain is equal to the lost uncertainty, and set the requirements for its measurement:

– the measure must be continuous; that is, a change in the value of the probability value by a small amount should cause a small net change in the function;

– when all options (competency elements in the ICB example IPMA) are equally probable, an increase in the number of options (elements of competence) should always increase the value of the function that describes the increase in information;

– it should be possible to make a choice (in the example under consideration – competency elements) in two steps, in which the value of the final result function should be the sum of the functions of intermediate results

All these rules are satisfied when analyzing the IPMA model ICB.

In order to use the formula, it is necessary to convert the considered matrix into a matrix of transition probabilities. To do this, in the case of a real situation of uncertainty, you can use logic similar to the logic of the Laplace criterion when calculating the Laplace criterion in game theory. We will consider the probabilities equal, but in our case we will make some changes – we will consider the probabilities equal not for all columns of the "payoff matrix", but for each row we will determine the values of transition probabilities in the form of equal values, based on the number of non-zero values in the adjacency matrix, but in such a way so that the sum of the elements in each of the rows of such a matrix of transition probabilities is equal to 1. In the case when it is possible to determine such values in an expert way or on the basis of statistical data, then such logic in the "line by line" application will correspond to the logic of determining the Bayes criterion. The proposed version presents the logic of such a modified Laplace criterion (Fig. 4).

As you can see, in this representation, there is already all the necessary data for calculating the information entropy for the presented system. Based on the logic that each element that represents the corresponding line of the matrix of transition probabilities is "influencing" all other elements of the system, i.e. rows are "sources" and columns are "receivers" of information, and, in turn, all rows are elements, i.e. "elementary subsystems" of the system under consideration, the entropy of the entire system will be equal to the sum of the entropies for each of the elements.

Thus, it is also possible to calculate the entropy changes for any *n – th* step based on the calculation of the corresponding transition probabilities, while the entropy of the initial state of the system will be equal to 0 (due to the values of the transition probabilities at the start of the simulation, which for all, except for the "starting", equal to 1, will be equal to 0). The data of such modeling are presented in Fig.5. As can be seen from the presented model, starting from step (4), the value of information entropy becomes constant. A similar result will be obtained if we calculate the values of information entropy for adjacency matrices of orders 2 and higher, the values of the elements of which will correspond to the total number of links between the elements ("reached information"), both directly due to "direct links" (the presence of arcs between vertices in the corresponding mapping in the form of a directed graph), and thanks to the "messages" that reached through the intermediate "post stations" (through a chain of other vertices). As an example, we present the values of information entropy for each of the elements and in total for the entire system in the form of a table for the first five degrees of the original adjacency matrix, which was calculated using the following logic for determining the values of transition probabilities (Fig. 6).

| Factor name | Elements that are affected (columns) | Strategy | Governance, structure and processes | Compliance, standards and regulations | Power and interests | Culture and values | Self-reflection and self-management | Personal integrity and reliability | Personal communication | Relations and engagement | Leadership | Teamwork | Conflict and crisis | Resourcefulness | Negotiation | Results orientation | Project design | Requirements and objectives | Scope | Time | Organisation and information | Quality | Finance | Resources | Procurement | Plan and control | Risk and opportunities | Stakeholder | Change and transformation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Influencing Elements (Rows) | FID | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 |
| Strategy | 1 | 0,00 | 0,10 | 0,10 | 0,10 | 0,10 | 0,00 | 0,00 | 0,00 | 0,00 | 0,10 | 0,00 | 0,00 | 0,00 | 0,10 | 0,10 | 0,10 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,10 | 0,10 | 0,00 |
| Governance, structure and processes | 2 | 0,09 | 0,00 | 0,09 | 0,09 | 0,09 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,09 | 0,00 | 0,00 | 0,00 | 0,09 | 0,00 | 0,09 | 0,09 | 0,09 | 0,09 | 0,00 | 0,00 | 0,09 |
| Compliance, standards and regulations | 3 | 0,09 | 0,09 | 0,00 | 0,09 | 0,09 | 0,00 | 0,00 | 0,00 | 0,00 | 0,09 | 0,00 | 0,00 | 0,00 | 0,09 | 0,00 | 0,09 | 0,09 | 0,00 | 0,00 | 0,09 | 0,09 | 0,00 | 0,00 | 0,00 | 0,00 | 0,09 | 0,00 | 0,00 |
| Power and interests | 4 | 0,09 | 0,09 | 0,09 | 0,00 | 0,09 | 0,00 | 0,09 | 0,09 | 0,09 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,09 | 0,00 | 0,00 | 0,00 | 0,09 | 0,00 | 0,00 | 0,00 | 0,09 | 0,00 | 0,00 | 0,09 | 0,00 |
| Culture and values | 5 | 0,11 | 0,11 | 0,11 | 0,11 | 0,00 | 0,00 | 0,11 | 0,11 | 0,11 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,11 | 0,00 | 0,00 | 0,00 | 0,00 | 0,11 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 |
| Self-reflection and self-management | 6 | 0,00 | 0,00 | 0,00 | 0,09 | 0,09 | 0,00 | 0,09 | 0,09 | 0,09 | 0,09 | 0,09 | 0,09 | 0,09 | 0,09 | 0,09 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 |
| Personal integrity and reliability | 7 | 0,00 | 0,00 | 0,08 | 0,08 | 0,08 | 0,08 | 0,00 | 0,08 | 0,08 | 0,08 | 0,08 | 0,08 | 0,08 | 0,08 | 0,08 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 |
| Personal communication | 8 | 0,00 | 0,00 | 0,00 | 0,08 | 0,08 | 0,08 | 0,08 | 0,00 | 0,08 | 0,08 | 0,08 | 0,08 | 0,08 | 0,08 | 0,08 | 0,00 | 0,00 | 0,00 | 0,00 | 0,08 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,08 | 0,00 |
| Relations and engagement | 9 | 0,00 | 0,00 | 0,00 | 0,08 | 0,08 | 0,08 | 0,08 | 0,08 | 0,00 | 0,08 | 0,08 | 0,08 | 0,08 | 0,08 | 0,08 | 0,00 | 0,00 | 0,00 | 0,00 | 0,08 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,08 | 0,00 |
| Leadership | 10 | 0,00 | 0,00 | 0,00 | 0,04 | 0,04 | 0,04 | 0,04 | 0,04 | 0,04 | 0,00 | 0,04 | 0,04 | 0,04 | 0,04 | 0,04 | 0,04 | 0,04 | 0,04 | 0,04 | 0,04 | 0,04 | 0,04 | 0,04 | 0,04 | 0,04 | 0,04 | 0,04 | 0,04 |
| Teamwork | 11 | 0,00 | 0,00 | 0,00 | 0,07 | 0,07 | 0,07 | 0,07 | 0,07 | 0,07 | 0,07 | 0,00 | 0,07 | 0,07 | 0,07 | 0,07 | 0,00 | 0,00 | 0,00 | 0,00 | 0,07 | 0,00 | 0,00 | 0,07 | 0,00 | 0,07 | 0,00 | 0,00 | 0,00 |
| Conflict and crisis | 12 | 0,00 | 0,00 | 0,00 | 0,07 | 0,07 | 0,07 | 0,07 | 0,07 | 0,07 | 0,07 | 0,07 | 0,00 | 0,07 | 0,07 | 0,07 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,07 | 0,00 | 0,07 | 0,07 | 0,00 | 0,00 |
| Resourcefulness | 13 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,08 | 0,08 | 0,08 | 0,08 | 0,08 | 0,08 | 0,08 | 0,00 | 0,08 | 0,08 | 0,08 | 0,08 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,08 | 0,08 | 0,00 | 0,00 |
| Negotiation | 14 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,08 | 0,08 | 0,08 | 0,08 | 0,08 | 0,08 | 0,08 | 0,08 | 0,00 | 0,08 | 0,08 | 0,08 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,08 | 0,08 | 0,00 | 0,00 | 0,00 |
| Results orientation | 15 | 0,06 | 0,00 | 0,00 | 0,00 | 0,00 | 0,06 | 0,06 | 0,06 | 0,06 | 0,06 | 0,06 | 0,06 | 0,06 | 0,06 | 0,00 | 0,06 | 0,06 | 0,00 | 0,00 | 0,00 | 0,06 | 0,00 | 0,00 | 0,00 | 0,06 | 0,06 | 0,06 | 0,00 |
| Project design | 16 | 0,05 | 0,05 | 0,05 | 0,05 | 0,05 | 0,00 | 0,00 | 0,00 | 0,00 | 0,05 | 0,00 | 0,00 | 0,05 | 0,05 | 0,05 | 0,00 | 0,05 | 0,05 | 0,05 | 0,05 | 0,05 | 0,05 | 0,05 | 0,05 | 0,05 | 0,05 | 0,05 | 0,05 |
| Requirements and objectives | 17 | 0,05 | 0,05 | 0,05 | 0,00 | 0,00 | 0,00 | 0,00 | 0,05 | 0,00 | 0,05 | 0,00 | 0,00 | 0,05 | 0,05 | 0,00 | 0,05 | 0,00 | 0,05 | 0,05 | 0,05 | 0,05 | 0,05 | 0,05 | 0,05 | 0,05 | 0,05 | 0,05 | 0,05 |
| Scope | 18 | 0,05 | 0,05 | 0,05 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,05 | 0,00 | 0,00 | 0,05 | 0,05 | 0,05 | 0,05 | 0,05 | 0,00 | 0,05 | 0,05 | 0,05 | 0,05 | 0,05 | 0,05 | 0,05 | 0,05 | 0,05 | 0,05 |
| Time | 19 | 0,00 | 0,06 | 0,06 | 0,00 | 0,00 | 0,00 | 0,00 | 0,06 | 0,00 | 0,06 | 0,00 | 0,00 | 0,06 | 0,06 | 0,00 | 0,06 | 0,06 | 0,06 | 0,00 | 0,06 | 0,06 | 0,06 | 0,06 | 0,06 | 0,06 | 0,06 | 0,06 | 0,06 |
| Organisation and information | 20 | 0,00 | 0,05 | 0,05 | 0,00 | 0,00 | 0,00 | 0,00 | 0,05 | 0,00 | 0,05 | 0,05 | 0,00 | 0,05 | 0,05 | 0,00 | 0,05 | 0,05 | 0,05 | 0,05 | 0,00 | 0,05 | 0,05 | 0,05 | 0,05 | 0,05 | 0,05 | 0,05 | 0,05 |
| Quality | 21 | 0,00 | 0,06 | 0,06 | 0,00 | 0,06 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,06 | 0,00 | 0,06 | 0,00 | 0,06 | 0,06 | 0,06 | 0,06 | 0,06 | 0,06 | 0,00 | 0,06 | 0,06 | 0,06 | 0,06 | 0,06 | 0,06 | 0,06 |
| Finance | 22 | 0,00 | 0,06 | 0,06 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,06 | 0,00 | 0,00 | 0,06 | 0,06 | 0,06 | 0,06 | 0,06 | 0,06 | 0,06 | 0,06 | 0,06 | 0,00 | 0,06 | 0,06 | 0,06 | 0,06 | 0,06 | 0,06 |
| Resources | 23 | 0,00 | 0,05 | 0,05 | 0,00 | 0,05 | 0,00 | 0,00 | 0,00 | 0,00 | 0,05 | 0,05 | 0,00 | 0,05 | 0,05 | 0,00 | 0,05 | 0,05 | 0,05 | 0,05 | 0,05 | 0,05 | 0,05 | 0,00 | 0,05 | 0,05 | 0,05 | 0,05 | 0,05 |
| Procurement | 24 | 0,00 | 0,05 | 0,05 | 0,00 | 0,05 | 0,00 | 0,00 | 0,00 | 0,05 | 0,05 | 0,00 | 0,00 | 0,05 | 0,05 | 0,00 | 0,05 | 0,05 | 0,05 | 0,05 | 0,05 | 0,05 | 0,05 | 0,05 | 0,00 | 0,05 | 0,05 | 0,05 | 0,05 |
| Plan and control | 25 | 0,05 | 0,05 | 0,05 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,05 | 0,00 | 0,05 | 0,05 | 0,05 | 0,00 | 0,05 | 0,05 | 0,05 | 0,05 | 0,05 | 0,05 | 0,05 | 0,05 | 0,05 | 0,00 | 0,05 | 0,05 | 0,05 |
| Risk and opportunities | 26 | 0,05 | 0,05 | 0,05 | 0,05 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,05 | 0,00 | 0,05 | 0,05 | 0,00 | 0,00 | 0,05 | 0,05 | 0,05 | 0,05 | 0,05 | 0,05 | 0,05 | 0,05 | 0,05 | 0,05 | 0,00 | 0,05 | 0,05 |
| Stakeholder | 27 | 0,05 | 0,05 | 0,05 | 0,05 | 0,05 | 0,00 | 0,00 | 0,05 | 0,05 | 0,05 | 0,00 | 0,00 | 0,05 | 0,00 | 0,00 | 0,05 | 0,05 | 0,05 | 0,05 | 0,05 | 0,05 | 0,05 | 0,05 | 0,05 | 0,05 | 0,05 | 0,00 | 0,05 |
| Change and transformation | 28 | 0,05 | 0,05 | 0,00 | 0,05 | 0,05 | 0,00 | 0,00 | 0,05 | 0,00 | 0,05 | 0,00 | 0,00 | 0,05 | 0,00 | 0,00 | 0,05 | 0,05 | 0,05 | 0,05 | 0,05 | 0,05 | 0,05 | 0,05 | 0,05 | 0,05 | 0,05 | 0,05 | 0,00 |

*Fig. 4.* **Transition probability matrix for the first order adjacency matrix of ICB 4.0 elements based on the modified Laplace criterion**
***Source:* compiled by the authors**

| Вероятность перехода в состояние | Strategy | Governance, structure and processes | Compliance, standards and regulations | Power and interests | Culture and values | Self-reflection and self-management | Personal integrity and reliability | Personal communication | Relations and engagement | Leadership | Teamwork | Conflict and crisis | Resourcefulness | Negotiation | Results orientation | Project design | Requirements and objectives | Scope | Time | Organisation and information | Quality | Finance | Resources | Procurement | Plan and control | Risk and opportunities | Stakeholder | Change and transformation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | p1 | p2 | p3 | p4 | p5 | p6 | p7 | p8 | p9 | p10 | p11 | p12 | p13 | p14 | p15 | p16 | p17 | p18 | p19 | p20 | p21 | p22 | p23 | p24 | p25 | p26 | p27 | p28 |
| 0 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 1,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 |
| 1 | 0,00 | 0,00 | 0,00 | 0,04 | 0,04 | 0,04 | 0,04 | 0,04 | 0,04 | 0,00 | 0,04 | 0,04 | 0,04 | 0,04 | 0,04 | 0,04 | 0,04 | 0,04 | 0,04 | 0,04 | 0,04 | 0,04 | 0,04 | 0,04 | 0,04 | 0,04 | 0,04 | 0,04 |
| 2 | 0,03 | 0,04 | 0,04 | 0,03 | 0,04 | 0,02 | 0,03 | 0,04 | 0,04 | 0,05 | 0,03 | 0,03 | 0,05 | 0,05 | 0,03 | 0,04 | 0,04 | 0,03 | 0,03 | 0,04 | 0,03 | 0,03 | 0,03 | 0,03 | 0,04 | 0,04 | 0,04 | 0,03 |
| 3 | 0,03 | 0,04 | 0,04 | 0,04 | 0,04 | 0,03 | 0,03 | 0,04 | 0,04 | 0,05 | 0,03 | 0,03 | 0,05 | 0,05 | 0,04 | 0,05 | 0,04 | 0,02 | 0,02 | 0,04 | 0,03 | 0,03 | 0,03 | 0,03 | 0,04 | 0,04 | 0,04 | 0,03 |
| 4 | 0,03 | 0,04 | 0,04 | 0,04 | 0,04 | 0,02 | 0,03 | 0,04 | 0,04 | 0,05 | 0,03 | 0,03 | 0,05 | 0,05 | 0,03 | 0,05 | 0,04 | 0,02 | 0,02 | 0,04 | 0,03 | 0,03 | 0,03 | 0,03 | 0,04 | 0,04 | 0,04 | 0,03 |
| 5 | 0,03 | 0,04 | 0,04 | 0,04 | 0,04 | 0,02 | 0,03 | 0,04 | 0,04 | 0,05 | 0,03 | 0,03 | 0,05 | 0,05 | 0,03 | 0,05 | 0,04 | 0,02 | 0,02 | 0,04 | 0,03 | 0,03 | 0,03 | 0,03 | 0,04 | 0,04 | 0,04 | 0,03 |
| 6 | 0,03 | 0,04 | 0,04 | 0,04 | 0,04 | 0,02 | 0,03 | 0,04 | 0,04 | 0,05 | 0,03 | 0,03 | 0,05 | 0,05 | 0,03 | 0,05 | 0,04 | 0,02 | 0,02 | 0,04 | 0,03 | 0,03 | 0,03 | 0,03 | 0,04 | 0,04 | 0,04 | 0,03 |
| 7 | 0,03 | 0,04 | 0,04 | 0,04 | 0,04 | 0,02 | 0,03 | 0,04 | 0,04 | 0,05 | 0,03 | 0,03 | 0,05 | 0,05 | 0,03 | 0,05 | 0,04 | 0,02 | 0,02 | 0,04 | 0,03 | 0,03 | 0,03 | 0,03 | 0,04 | 0,04 | 0,04 | 0,03 |
| 8 | 0,03 | 0,04 | 0,04 | 0,04 | 0,04 | 0,02 | 0,03 | 0,04 | 0,04 | 0,05 | 0,03 | 0,03 | 0,05 | 0,05 | 0,03 | 0,05 | 0,04 | 0,02 | 0,02 | 0,04 | 0,03 | 0,03 | 0,03 | 0,03 | 0,04 | 0,04 | 0,04 | 0,03 |
| 9 | 0,03 | 0,04 | 0,04 | 0,04 | 0,04 | 0,02 | 0,03 | 0,04 | 0,04 | 0,05 | 0,03 | 0,03 | 0,05 | 0,05 | 0,03 | 0,05 | 0,04 | 0,02 | 0,02 | 0,04 | 0,03 | 0,03 | 0,03 | 0,03 | 0,04 | 0,04 | 0,04 | 0,03 |
| 10 | 0,03 | 0,04 | 0,04 | 0,04 | 0,04 | 0,02 | 0,03 | 0,04 | 0,04 | 0,05 | 0,03 | 0,03 | 0,05 | 0,05 | 0,03 | 0,05 | 0,04 | 0,02 | 0,02 | 0,04 | 0,03 | 0,03 | 0,03 | 0,03 | 0,04 | 0,04 | 0,04 | 0,03 |

*Fig. 5.* **Information modeling data for discrete state transition dynamics model for ICB 4.0 IPMA transition probability matrix**

***Source*: compiled by the authors**

| Elements that are affected (columns) | Strategy | Governance, structure and processes | Compliance, standards and regulations | Power and interests | Culture and values | Self-reflection and self-management | Personal integrity and reliability | Personal communication | Relations and engagement | Leadership | Teamwork | Conflict and crisis | Resourcefulness | Negotiation | Results orientation | Project design | Requirements and objectives | Scope | Time | Organisation and information | Quality | Finance | Resources | Procurement | Plan and control | Risk and opportunities | Stakeholder | Change and transformation | Shannon entropy |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| step | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | |
| 0 | 0,0000 | 0,0000 | 0,0000 | 0,0000 | 0,0000 | 0,0000 | 0,0000 | 0,0000 | 0,0000 | 0,0000 | 0,0000 | 0,0000 | 0,0000 | 0,0000 | 0,0000 | 0,0000 | 0,0000 | 0,0000 | 0,0000 | 0,0000 | 0,0000 | 0,0000 | 0,0000 | 0,0000 | 0,0000 | 0,0000 | 0,0000 | 0,0000 | 0,00000 |
| 1 | 0,0000 | 0,0000 | 0,0000 | 0,1910 | 0,1910 | 0,1910 | 0,1910 | 0,1910 | 0,1910 | 0,0000 | 0,1910 | 0,1910 | 0,1910 | 0,1910 | 0,1910 | 0,1910 | 0,1910 | 0,1910 | 0,1910 | 0,1910 | 0,1910 | 0,1910 | 0,1910 | 0,1910 | 0,1910 | 0,1910 | 0,1910 | 0,1910 | 4,58496 |
| 2 | 0,1367 | 0,1756 | 0,1798 | 0,1610 | 0,1736 | 0,1325 | 0,1644 | 0,2005 | 0,1794 | 0,2295 | 0,1602 | 0,1519 | 0,2271 | 0,2019 | 0,1687 | 0,1980 | 0,1702 | 0,1379 | 0,1374 | 0,1839 | 0,1637 | 0,1374 | 0,1597 | 0,1633 | 0,1897 | 0,1694 | 0,1834 | 0,1379 | 4,77488 |
| 3 | 0,1466 | 0,1724 | 0,1768 | 0,1819 | 0,1895 | 0,1358 | 0,1595 | 0,1862 | 0,1715 | 0,2240 | 0,1563 | 0,1512 | 0,2064 | 0,2058 | 0,1698 | 0,2140 | 0,1746 | 0,1283 | 0,1280 | 0,1907 | 0,1623 | 0,1409 | 0,1563 | 0,1631 | 0,1877 | 0,1788 | 0,1773 | 0,1412 | 4,77678 |
| 4 | 0,1511 | 0,1774 | 0,1812 | 0,1827 | 0,1897 | 0,1309 | 0,1596 | 0,1871 | 0,1715 | 0,2220 | 0,1525 | 0,1473 | 0,2052 | 0,2029 | 0,1671 | 0,2159 | 0,1730 | 0,1293 | 0,1290 | 0,1900 | 0,1645 | 0,1409 | 0,1563 | 0,1656 | 0,1862 | 0,1775 | 0,1790 | 0,1412 | 4,77681 |
| 5 | 0,1520 | 0,1786 | 0,1824 | 0,1832 | 0,1905 | 0,1296 | 0,1582 | 0,1858 | 0,1704 | 0,2217 | 0,1513 | 0,1458 | 0,2042 | 0,2026 | 0,1665 | 0,2167 | 0,1732 | 0,1294 | 0,1292 | 0,1909 | 0,1649 | 0,1416 | 0,1565 | 0,1659 | 0,1859 | 0,1780 | 0,1795 | 0,1419 | 4,77655 |
| 6 | 0,1524 | 0,1792 | 0,1828 | 0,1831 | 0,1904 | 0,1289 | 0,1577 | 0,1855 | 0,1699 | 0,2215 | 0,1507 | 0,1452 | 0,2039 | 0,2023 | 0,1660 | 0,2171 | 0,1734 | 0,1297 | 0,1295 | 0,1911 | 0,1653 | 0,1420 | 0,1567 | 0,1663 | 0,1860 | 0,1782 | 0,1796 | 0,1422 | 4,77653 |
| 7 | 0,1526 | 0,1794 | 0,1830 | 0,1830 | 0,1904 | 0,1286 | 0,1574 | 0,1852 | 0,1696 | 0,2214 | 0,1504 | 0,1448 | 0,2038 | 0,2022 | 0,1658 | 0,2172 | 0,1735 | 0,1299 | 0,1296 | 0,1913 | 0,1654 | 0,1422 | 0,1568 | 0,1664 | 0,1860 | 0,1784 | 0,1797 | 0,1425 | 4,77653 |
| 8 | 0,1526 | 0,1795 | 0,1831 | 0,1830 | 0,1903 | 0,1284 | 0,1572 | 0,1851 | 0,1695 | 0,2214 | 0,1503 | 0,1447 | 0,2037 | 0,2022 | 0,1657 | 0,2173 | 0,1736 | 0,1300 | 0,1297 | 0,1913 | 0,1655 | 0,1423 | 0,1569 | 0,1665 | 0,1861 | 0,1784 | 0,1798 | 0,1426 | 4,77653 |
| 9 | 0,1527 | 0,1796 | 0,1831 | 0,1830 | 0,1903 | 0,1283 | 0,1571 | 0,1850 | 0,1694 | 0,2213 | 0,1502 | 0,1446 | 0,2037 | 0,2021 | 0,1657 | 0,2174 | 0,1736 | 0,1300 | 0,1298 | 0,1913 | 0,1655 | 0,1424 | 0,1569 | 0,1666 | 0,1861 | 0,1785 | 0,1798 | 0,1426 | 4,77653 |
| 10 | 0,1527 | 0,1796 | 0,1831 | 0,1829 | 0,1903 | 0,1283 | 0,1571 | 0,1850 | 0,1694 | 0,2213 | 0,1502 | 0,1446 | 0,2037 | 0,2021 | 0,1656 | 0,2174 | 0,1736 | 0,1301 | 0,1298 | 0,1913 | 0,1656 | 0,1424 | 0,1569 | 0,1666 | 0,1861 | 0,1785 | 0,1798 | 0,1427 | 4,77654 |

*Fig. 6.* **Calculation of the entropy for a discrete model of the dynamics of transitions between states for the matrix of transition probabilities ICB 4.0 IPMA**

***Source:* compiled by the authors**

We investigate how the dependence of the elements of the system affects the change in entropy. Consider a system whose state is described by a multidimensional normal vector u. Information entropy in this case is calculated by the formula [11]:

$$H=\log[(2\pi e)^n|K|]^{1/2} \quad , \qquad (12)$$

where n is the dimension of the vector;

|K| is the determinant of the correlation matrix.

For convenience, consider a system in which all components have the same $\sigma^2$ variances.

Then

$$|K| = \sigma^{2n}\Delta \quad , \qquad (13)$$

where $\Delta$ is the determinant of the normalized correlation matrix.

How noted in [12], "Physically, it is impossible to realize systems with all component correlation coefficients equal to unity. It is of interest to determine the values of the correlation coefficients at which the entropy reaches zero", and also gives the calculation of these coefficients.

For a situation with the same competency elements as in the example above, it would be an ideal solution to know exactly at what point at which step to "turn on" this or that element with its own tools and methods. In this regard, the PMBOK process model looks more advantageous. PMI, which offers a clear sequence of actions from the formation of the Charter of the project to summing up the results of the completed project.

In general, it is possible to put forward a hypothesis about the project's striving , in case of its success, to be able to describe the complete model of its implementation, which allows repeating the project in similar conditions (which is fundamentally difficult to achieve, in particular, for really complex systems, based on the logic of "attributes" complex systems according to the L. Rasstrigin), while hoping to get a similar result – to transfer the project to the category of "typical", the implementation of which can be clearly described as a sequence of repetitive actions, include with all the attributes inherent in the Waterfall model.

With regard to project management, it can be conditionally assumed that the entropy of the project during each “planning and reporting” period changes from the minimum to the maximum and vice versa - ideas about the work plan for the corresponding future period under the assumptions and assumptions about its possible implementation, including h, backed up by the obligations of the performers who are ready to give them, again, based on their set of assumptions and assumptions related to the information they received from their suppliers and subcontractors (a typical situation for the implementation of a project in the construction industry), which corresponds to the minimum entropy. After that, starting to implement directly in the course of work, “requests for changes” inevitably arise, which corresponds to an increase in the level of entropy to the maximum, and during the next communication event (“planning meeting”), issues related to requests for information are resolved, the situation “as is”, plans are adjusted “as will be” and the cycle repeats.

At the same time, it seems possible to calculate the entropy for the project management model based on the PMBOK recommendations. The text of this standard also contains a description of the “inputs” and “outputs” of each of the 46 project management sub-processes described, grouped into 10 knowledge areas. This allows you to form the following first-order adjacency matrix (Fig.7):

As can be seen from the data presented in Fig. 7 and Fig. 8, such an interpretation of the text of the standard, with all the desire, will not allow to “assemble” the correct model, because it contains 5 elements, each of which, in the logic of “inputs” and “outputs”, does not contain informational “outputs”, and, in such logic, they can simply be excluded from the model. Although this remark refers rather to the extent to which these elements were correctly included in the standard at one time.

And, most importantly, in [12] it is shown that for systems with dependent elements, an increase in the complexity of the system leads to a decrease in entropy. It follows from the above that in order to reduce the entropy of real systems, it is necessary to find constructive methods for increasing the dependence between constituent elements, and for systems with dependent elements, methods for increasing their complexity by increasing the number of elements.

| Factor name | On what impact (columns) | 4.1. Development of the project charter | 4.2. Development of a project management plan | 4.3. Management of project work | 4.4. Project Knowledge Management | 4.5. Monitoring and control of project work | 4.6. Integrated Change Control | 4.7. Closing a project or phase | 5.1. Content management planning | 5.2. Gathering Requirements | 5.3. Definition of content | 5.4. Creation of the WBS | 5.5. Content Confirmation | 5.6. Content control | 6.1. Schedule Management Planning | 6.2. Defining Operations | 6.3. Determining the sequence of operations | 6.4. Activity duration estimation | 6.5. Schedule Development | 6.6. Schedule control | 7.1. Cost Management Planning | 7.2. Cost estimate | 7.3. Determination of the budget | 7.4. Cost control | 8.1. Quality management planning | 8.2. Quality control | 8.3. Quality control | 9.1. Resource management planning | 9.2. Activity Resource Estimation | 9.3. Acquisition of resources | 9.4. Team development | 9.5. Управление командой | 9.6. Resource control |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| From what influence (strings) | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 |
| 4.1. Development of the project charter | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| 4.2. Development of a project management plan | 2 | 0 | 0 | 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 |
| 4.3. Management of project work | 3 | 1 | 1 | 0 | 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 |
| 4.4. Project Knowledge Management | 4 | 1 | 1 | 1 | 0 | 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 |
| 4.5. Monitoring and control of project work | 5 | 0 | 0 | 1 | 1 | 0 | 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 |
| 4.6. Integrated Change Control | 6 | 0 | 0 | 1 | 1 | 1 | 0 | 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 |
| 4.7. Closing a project or phase | 7 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 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 |
| 5.1. Content management planning | 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5.2. Gathering Requirements | 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5.3. Definition of content | 10 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 5.4. Creation of the WBS | 11 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 5.5. Content Confirmation | 12 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 5.6. Content control | 13 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 6.1. Schedule Management Planning | 14 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 6.2. Defining Operations | 15 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 6.3. Determining the sequence of operations | 16 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 6.4. Activity duration estimation | 17 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 6.5. Schedule Development | 18 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 6.6. Schedule control | 19 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 7.1. Cost Management Planning | 20 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 7.2. Cost estimate | 21 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 7.3. Determination of the budget | 22 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 7.4. Cost control | 23 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 8.1. Quality management planning | 24 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 8.2. Quality control | 25 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 8.3. Quality control | 26 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 |
| 9.1. Resource management planning | 27 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 |
| 9.2. Activity Resource Estimation | 28 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 |
| 9.3. Acquisition of resources | 29 | 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 | 0 | 1 | 1 | 1 |

*Fig. 7.* **First-order adjacency matrix fragment built for project management processes in accordance with the recommendations of the PMBOK**

***Source:*** **compiled by the authors**

| Factor name | On what impact (columns) | 4.1. Development of the project charter | 4.2. Development of a project managem | 4.3. Management of project work | 4.4. Project Knowledge Management | 4.5. Monitoring and control of project w | 4.6. Integrated Change Control | 4.7. Closing a project or phase | 5.1. Content management planning | 5.2. Gathering Requirements | 5.3. Definition of content | 5.4. Creation of the WBS | 5.5. Content Confirmation | 5.6. Content control | 6.1. Schedule Management Planning | 6.2. Defining Operations | 6.3. Determining the sequence of opera | 6.4. Activity duration estimation | 6.5. Schedule Development | 6.6. Schedule control | 7.1. Cost Management Planning | 7.2. Cost estimate | 7.3. Determination of the budget | 7.4. Cost control | 8.1. Quality management planning | 8.2. Quality control | 8.3. Quality control | 9.1. Resource management planning | 9.2. Activity Resource Estimation | 9.3. Acquisition of resources | 9.4. Team development |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| From what influence (strings) | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 |
| 4.1. Development of the project charter | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 |
| 4.2. Development of a project management | 2 | 0 | 0 | 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 |
| 4.3. Management of project work | 3 | 1 | 1 | 0 | 4 | 4 | 4 | 3 | 2 | 3 | 3 | 2 | 3 | 4 | 2 | 2 | 3 | 3 | 3 | 4 | 2 | 3 | 3 | 4 | 3 | 3 | 5 | 3 | 3 | 3 | 3 |
| 4.4. Project Knowledge Management | 4 | 1 | 1 | 2 | 0 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| 4.5. Monitoring and control of project work | 5 | 0 | 0 | 2 | 2 | 0 | 4 | 2 | 1 | 2 | 2 | 2 | 2 | 2 | 1 | 1 | 2 | 2 | 2 | 2 | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| 4.6. Integrated Change Control | 6 | 0 | 0 | 3 | 2 | 2 | 0 | 2 | 1 | 2 | 2 | 2 | 2 | 2 | 1 | 1 | 2 | 2 | 2 | 2 | 1 | 2 | 2 | 2 | 2 | 2 | 3 | 2 | 2 | 2 | 2 |
| 4.7. Closing a project or phase | 7 | 1 | 1 | 2 | 2 | 2 | 2 | 0 | 1 | 2 | 2 | 2 | 1 | 2 | 1 | 1 | 2 | 2 | 2 | 2 | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| 5.1. Content management planning | 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5.2. Gathering Requirements | 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5.3. Definition of content | 10 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 5.4. Creation of the WBS | 11 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 5.5. Content Confirmation | 12 | 0 | 0 | 1 | 1 | 2 | 2 | 2 | 0 | 1 | 1 | 1 | 0 | 2 | 0 | 0 | 1 | 1 | 1 | 2 | 0 | 1 | 1 | 2 | 1 | 1 | 2 | 1 | 1 | 1 | 1 |
| 5.6. Content control | 13 | 0 | 0 | 2 | 2 | 3 | 3 | 2 | 1 | 2 | 2 | 2 | 3 | 0 | 1 | 1 | 2 | 2 | 2 | 3 | 1 | 2 | 2 | 3 | 2 | 2 | 3 | 2 | 2 | 2 | 2 |
| 6.1. Schedule Management Planning | 14 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 6.2. Defining Operations | 15 | 0 | 0 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 6.3. Determining the sequence of operation | 16 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 6.4. Activity duration estimation | 17 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 6.5. Schedule Development | 18 | 0 | 0 | 2 | 2 | 2 | 3 | 2 | 1 | 2 | 2 | 2 | 2 | 2 | 1 | 1 | 2 | 2 | 0 | 2 | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| 6.6. Schedule control | 19 | 0 | 0 | 2 | 2 | 3 | 3 | 2 | 1 | 2 | 2 | 2 | 3 | 3 | 1 | 1 | 2 | 2 | 2 | 0 | 1 | 2 | 2 | 3 | 2 | 2 | 3 | 2 | 2 | 2 | 2 |
| 7.1. Cost Management Planning | 20 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 7.2. Cost estimate | 21 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 7.3. Determination of the budget | 22 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 7.4. Cost control | 23 | 0 | 0 | 2 | 2 | 3 | 3 | 2 | 1 | 2 | 2 | 2 | 3 | 3 | 1 | 1 | 2 | 2 | 2 | 3 | 1 | 2 | 2 | 0 | 2 | 2 | 3 | 2 | 2 | 2 | 2 |
| 8.1. Quality management planning | 24 | 0 | 0 | 2 | 2 | 2 | 2 | 2 | 1 | 2 | 2 | 2 | 2 | 2 | 1 | 1 | 2 | 2 | 2 | 2 | 1 | 2 | 2 | 2 | 0 | 2 | 2 | 2 | 2 | 2 | 2 |
| 8.2. Quality control | 25 | 0 | 0 | 2 | 2 | 2 | 3 | 2 | 1 | 2 | 2 | 2 | 2 | 2 | 1 | 1 | 2 | 2 | 2 | 2 | 1 | 2 | 2 | 2 | 2 | 0 | 2 | 2 | 2 | 2 | 2 |
| 8.3. Quality control | 26 | 0 | 0 | 2 | 2 | 3 | 4 | 2 | 1 | 2 | 2 | 2 | 3 | 3 | 1 | 1 | 2 | 2 | 2 | 3 | 1 | 2 | 2 | 3 | 2 | 2 | 0 | 2 | 2 | 2 | 2 |
| 9.1. Resource management planning | 27 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 |
| 9.2. Activity Resource Estimation | 28 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 |
| 9.3. Acquisition of resources | 29 | 1 | 1 | 3 | 3 | 3 | 4 | 3 | 2 | 3 | 3 | 3 | 2 | 3 | 2 | 2 | 3 | 3 | 3 | 3 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 0 | 3 |
| 9.4. Team development | 30 | 2 | 2 | 4 | 4 | 4 | 5 | 3 | 3 | 4 | 4 | 4 | 2 | 3 | 3 | 3 | 4 | 4 | 3 | 3 | 4 | 4 | 3 | 3 | 3 | 3 | 4 | 5 | 4 | 4 | 0 |

*Fig. 8.* **A fragment of the matrix which shows the number of links between elements, built for project management processes in accordance with the recommendations of the PMBOK (ver. 6.0)**
***Source:* compiled by the authors**

As an example, we can cite the data of similar calculations, only performed for the previous version of IPMA ICB 3.0. In this version, the number of elements was much larger – 46 elements. At the same time, the structure of links between, in fact, the same structural blocks, looks much more complex compared to ICB 4.0.

Also of interest for such a comparison is the comparison of IPMA ICB 3.0 with the presented calculations for PMI PMBOK version 6 due to the close number of elements in the considered structure.

To ensure the correct application of these conclusions, we need to make sure that we are really dealing with a "self-organizing system".

Based on the classification of systems on "Well organized" (deterministic), "Poorly organized" (probabilistic) and "Self-organizing" (evolving or complex), given in [13], as well as "corrections" for the role and place of the "human" factor in complex systems, then any socio-economic and other systems involving a person or taking into account any other manifestation of the actions of the human psyche can hardly be considered as "deterministic", and completely "stochastic" (although the probabilistic factor, of course, will be present). In this case, to such systems, incl. models of competencies, communications, knowledge, etc. built by the authors. in relation to project activity, it is possible to approach rather as to "Self-organizing systems".

Also important is such an extensive remark, given in the [13]: "With the accumulation of experience in the study and transformation of systems with similar properties, their main feature was realized – the fundamental limitation of a formalized description of developing, self-organizing systems". This feature, the need to combine formal methods and methods of qualitative analysis, and is the basis of most models and methods of system analysis. When forming such models, the usual idea of models, which is characteristic of mathematical modeling and applied mathematics, changes. The idea of proving the adequacy of such models also changes.

The adequacy of the model is proved, as it were, sequentially (as it is formed) by evaluating the correctness of the reflection in each subsequent model of the components and relationships necessary to achieve the goals. In other words, such modeling becomes, as it were, a kind of mechanism for the development of the system.

The practical implementation of such a "mechanism" is associated with the need to develop a language for modeling the decision-making process. Such a language can be based on one of the systems modeling methods: for example, set-theoretic representations, mathematical logic, mathematical linguistics, simulation dynamic modeling, information approach, etc. As the model develops, the methods may change.

The representation of an object in the form of a self-organizing system is used to solve the most complex problems inherent in decentralized systems with large initial uncertainty and unpredictability of the behavior of agents of economic relations. At the same time, the systemic mechanism of development (self-organization) can be implemented in the form of an appropriate approach using various methods to implement its stages [13].

As the most general conditions necessary for the self-organization processes to begin in the system, the following are:

– least one of the above with the environment);

– it must be far from the point of thermodynamic equilibrium, since at the point of thermodynamic equilibrium, it is in a state of maximum disorganization and is incapable of organization;

– it is necessary that fluctuations arise and intensify in the system, which undermine the old order in it and can lead to a new order;

– the emergence of self-organization is based on positive feedback (changes caused by the environment in the system are accumulated and amplified by the system itself);

– self-organization can begin only in a system that has a sufficient (critical) number of interacting elements;

– self-organization processes are accompanied by a violation of time symmetry (irreversibility of time) during the transition from one structure to another.

The factors noted above can also be considered as a kind of "checklist" to determine the "interest" in the consideration (and modeling) of certain systems in terms of predicting the behavior of such systems in the future (including projects of organizational changes, etc.), as well as to take into account item 2, the neglect of which from this point of view fully explains the failure of a huge number of "anti-crisis" projects.

For example, consider the ICB 4.0, for which we calculate the "amount of information", based on [14, 15]. The amount of information provided by any source or transmitted in a given time through any channel is measured by the logarithm of the total number ($n$) of different possible equally probable information that could be presented by a given source or transmitted in a given time.

In this case, the information binary entropy, in the absence of information loss, is calculated using the well-known Hartley formula: $i = \log_2 N$, where $N$ is the power of the alphabet; $i$ is the amount of information in each symbol of the message.

The logarithmic measure is taken based on the conditions for ensuring proportionality between the amount of information that can be transmitted over any period of time and the value of this segment and between the amount of information that can be stored in any system and the number of physical elements (for example, relays) needed to build this system. The choice of the base of the logarithms is determined by the choice of the unit of measure for the amount of information. With a base equal to two, the simplest, elementary message about the result of choosing one of two equiprobable possibilities yes» or «no» is taken as a unit of the amount of information. To designate this unit of quantity information, a special name "bid" was introduced (from the initial letters of the term "binary digit").

On the other hand, in general terms, it can look like

$$I = \log_a n. \quad (14)$$

The simplest particular case of determining the amount of information is the case when the individual possible variants of the message have the same probability. Accordingly, for the models under consideration, the following values can be taken (Table 2).

Such a comparison will be an interesting addition to the usual formats of comparative analyzes between existing knowledge systems in project management [16].

As noted in [17], in the general case, individual data variants have different probabilities, and the amount of information in messages depends on the distribution of these probabilities.

The mathematical definition of the concept of the amount of information is obtained as follows. In probability theory, a complete system of events is such a group of events $A_1$, $A_2$ ..., $A_n$, in which one and only one of these events necessarily occurs during each test. The final scheme is the complete system of events $A_1, A_2, \ldots, A_n$, given together with their probabilities: $P_1, P_2, \ldots, P_n$.

Any finite scheme is characterized by some uncertainty, that is, only the probabilities of possible events are known, but which event will actually occur is uncertain. It is this logic that is used in the simulation models of transient processes built by the author based on the analysis of the structure of possible connections between the elements of the studied competency models.

*Table 2.* **The amount of information that can be transferred from the elements of the ICB competency models IPMA**

| ICB IPMA version | Quantity elements competencies | Quantity information, bit |
|---|---|---|
| ICB 1.0 | n/a | n/a |
| ICB 2.0 | 60 | 5.907 |
| ICB 3.0 | 46 | 5.524 |
| ICB 4.0 | 28 (29) | 4.807 (4.858) |

***Source:*** **compiled by the authors**


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Information theory introduces the following characteristic to assess the degree of uncertainty of any finite pattern of events:

$$H(P_1, P_2 \dots, P_n) = - \sum n_{k-1} P_k * \log P_k, \quad (15)$$

where – the logarithms can be taken for an arbitrary but always the same base, and where for $P_{k0} = P_k * logP_k = 0$ is assumed.

The quantity $H$ is called the entropy of a given finite scheme of events [15, 16]. It has the following properties:

1. The quantity $H(P_1, P_2, \dots, P_n)$ is continuous with respect to $P_k$.

2. The value $H(P_1, P_2, \dots, P_n) = 0$ if one of the numbers $P_1, P_2, \dots, P_n$ is equal to 1, and the rest are equal to 0, that is, the entropy is equal to 0 when there is no – or uncertainty in the final scheme.

3. The value of $H(P_1, P_2, \dots, P_n)$ has a maximum value when all $P_k$ are equal to each other, that is, when the final scheme has the greatest uncertainty.

Entropy has the property of additivity, i.e. the entropy of two independent finite circuits is equal to the sum of the entropies of these finite circuits.

Thus, it can be seen that the chosen entropy expression quite conveniently and fully characterizes the degree of uncertainty of one or another final scheme of events.

In information theory, it is proved that the only form that satisfies the three specified properties is the accepted form for expressing entropy

$$H = - \sum n_{k-1} P_k * \log_a P_k \quad . \quad (16)$$

Data on the results of the test, the possible outcomes of which were determined by the given final scheme, are some information that removes the uncertainty that existed before the test. Moreover, the greater the uncertainty of the final scheme, the more information we receive as a result of testing and removing this uncertainty. Since the characteristic of the degree of uncertainty of any finite scheme is the entropy of this finite scheme, it is advisable to measure the amount of information given by the test by the same value.

The specified moment is very important in terms of understanding the importance of "information stream" which generate design activity and ability of the "center of acceptance of solutions" let him pass through himself. How the more difficult the project, the more essential to his success is creation of relevant systems capable of modern such flow information "digest" (compared to projects "limited difficulties").

Thus, in the general case, the amount of information of any system that has different probabilities of possible outcomes is determined by the entropy of the final scheme that characterizes the behavior of this system. Since the simplest and unified type of information, namely, the message about the result of a choice between two equally probable options, is taken as a unit of the amount of information, the base of the logarithms in the expression for entropy is taken equal to two.

Based on this conclusion from the point of view of information theory, the entropy of the "final scheme" characterizing the project management system should determine a certain "threshold value" of information that such a system is able to perceive and make appropriate management decisions. If the amount of information of the "project" conflicts with the "capacity" of the control system, this indicates the risk of project failure if such a control system is chosen.

Information theory provides a very general method for assessing the quality of information, its reliability. Any information is considered as the result of the impact of two processes: a regular process designed to transmit the required information, and a random process caused by interference. Information theory studies the relationship between quantity and quality of information; explores methods for converting information in order to ensure maximum efficiency of various information processing systems and to find out the optimal principles for constructing such systems.

## CONCLUSIONS

To ensure maximum reliability of systems acceptance solutions in project management, of course, we would have to deal with the most predictable conditions implementation project while confidence in correctness developed at the initial stage of project plans like this is suggesting classic "waterfall" approach. At the same time logical assume that as you move along the implementation project uncertainty also must decrease, simply because part of events, where such uncertainty was present, are already in the past. Ideally, according to definitions proposed by K. Shannon, uncertainties should not be, respectively, there is no information in it understanding. Information is the loss of uncertainty, which can be measured by counting the number of possible messages. If only one message is possible, there is no uncertainty. There is no information either.

If information appears, it means that something went wrong in the project as planned. After all, if everything goes according to plan, there is nothing unexpected, as K. Shannon interprets it.

Information is a measure of surprise. If the letter *t* is followed by an *h*, then not much information is transmitted, because the probability of an *h* appearing after *t* is high.

And finally, the most interesting interpretation of the information given by K. Shannon: “Information is entropy. It was the strangest and most powerful definition of all. For a physicist, entropy is a measure of the uncertainty of the state of a physical system – one of those states in which a system can be. For an information theorist, entropy is a measure of the uncertainty of a message – one message that might appear. This is not just a coincidence: nature gives the same answers to the same questions”. Continuing this logic, for a project manager, entropy is a measure of risk in a project.

K. Shannon first used the phrase “information theory”. Several definitions could be given, and all of them seemed paradoxical at first glance. Information is uncertainty, surprise, difficulty and entropy.

It is worth noting an important point – to calculate the “design entropy”, as we have already seen in the example above, it is necessary to determine the values of the matrix of transition probabilities, which can be done in various ways. The simplest is to use the Laplace logic, when all non-zero probabilities in the primary matrix are assigned equal numerical values $1/n$ based on the total number of first-order «working connections» (direct influences). On the other hand, it is possible to estimate in another way – taking into account the emergence of influences by “influence through influence” – estimating for each step $n$ the total number of connections, both “direct” and indirect (for each element, taking into account the “accumulation” of connections through $n-1$, $n-2$, ..., $n-m$; where $m$, $n$ belong to $Z>0$, $m<n$ of the directed graph for the system under consideration – the competency model). Thus, a series of values of the “project entropy” parameter for 1, 2,… , $n$,.., $k$ steps will also be obtained , and starting from a certain step $k$, one should expect the stabilization of the value of this parameter.

Carrying out this kind of analysis gives a systemic understanding of the informational nature of such knowledge systems in general. And the chosen object of study – the ICB 4.0 IPMA model has the property of “triple interdependence” – as a system consisting of three blocks, which consist of a total of 28 different elements (29 for programs and project portfolios). Such an interpretation and evaluation of any approach (through the “information entropy” parameter) will allow one to be more critical of the recommendations, despite the degree of authority of the organization or the team of authors proposing new standards and documents.

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# Ентропійний аналіз систем знань організацій на прикладі стандартів з управління проектами

**Гогунський Віктор Дмитрович**[1)]
ORCID: https://orcid.org/0000-0002-9115-2346; vgog@i.ua. Scopus Author ID: 57194244349
**Колеснікова Катерина Вікторівна**[2)]
ORCID: http://orcid.org/0000-0002-9160-59823; amberk4@gmail.com. Scopus Author ID: 57188623059
**Лук’янов Дмитро Володимирович**[3)]
ORCID: http://orcid.org/ /0000-0001-8305-2217; dlukiano@gmail.com. Scopus Author ID: 57192572835
[1)] Одеський національний політехнічний університет, пр. Шевченка, 1. Одеса, 65044, Україна
[2)] АТ «Міжнародний університет інформаційних технологій», вул. Манаса, 34/1. Алмати, Казахстан
[3)] ТОВ “GIGACloud”, пр-т Бортнікова, 499А. Київ, 03212, Україна

## АНОТАЦІЯ

Проблеми управління складними системами проектного управління пов'язані з великою кількістю параметрів, що характеризують їхній стан. Більшість сучасних методик прогнозування проектної діяльності базується на використанні статистичного моделювання окремих процесів та інструментів, наприклад, календарного плану робіт, що вимагає як обґрунтування прийнятих законів розподілу випадкових тривалостей робіт, так і планування певної організаційно-технологічної послідовності виконання робіт. Збір та обробка даних про всі параметри є складною та дорогою процедурою, а повне обґрунтування всіх характеристик проекту може призвести до інформаційної складності аналізованої системи. Однак відмовитися від цього неможливо через необхідність отримання актуальних та достовірних даних для прийняття та реалізації управлінських рішень. Таким чином, необхідно шукати способи та шляхи скорочення числа контрольованих параметрів, створювати алгоритми, що дозволяють прогнозувати наявність небажаних процесів у контрольованій системі, виробити рекомендації для детальнішого аналізу окремих підсистем проектного управління. Для подолання інформаційної складності прогнозних моделей пропонується використовувати феноменологічний підхід, який пов'язаний з визначенням ентропії, що дозволяє використовувати мінімум інформації про планову та актуалізовану течію проекту. Поняття ентропії є одним із ключових понять термодинаміки та теорії інформації, а також знаходить своє застосування в ряді інших наук, предметом дослідження та вивчення яких є складні стохастичні системи. Можливості використання ентропії та ентропійного моделювання сьогодні активно досліджуються в теорії управління проектами. У роботі розглянуто ентропійний підхід до моделювання систем проектного управління, в якому на основі математичних процедур, що випливають з теорії інформації Шеннона, К. створюються інформаційні феноменологічні моделі. Як приклад розглядається стандарт IPMA ICB 4.0. Розроблені інструменти створюють передумови для ефективного використання ентропійного підходу до оцінки складних економіко-соціальних систем.

**Ключові слова:** ентропія; системи знань; управління проектами; теорія інформації К. Шеннона; феноменологічні моделі

## ABOUT THE AUTHORS

**Viktor D. Gogunskii -** D.Sc (Eng), Professor, Head of the Department of Life Safety Systems Management. Odessa National Polytechnic University, 1, Shevchenko Ave. Odessa, 65044, Ukraine
ORCID: https://orcid.org/0000-0002-9115-2346; vgog@i.ua. Scopus Author ID: 57194244349
***Research field*:** Project management; computer science; modeling of complex objects and systems

**Гогунський Віктор Дмитрович -** доктор технічних наук, професор, завідувач кафедри Управління системами безпеки життєдіяльності. Одеський національний політехнічний університет, пр. Шевченка, 1. Одеса, 65044, Україна

**Kateryna V. Kolesnikova –** D.Sc (Eng), Professor, Head of the Department of Scientific Personnel Training. International IT University, 34/1, Manas Str. Almaty, 050040 Kazakhstan
ORCID: http://orcid.org/0000-0002-9160-59823; amberk4@gmail.com. Scopus Author ID: 57188623059
***Research field*:** Project management; knowledge management; computer science; modeling of complex objects and systems

**Колеснікова Катерина Вікторівна -** доктор технічних наук, професор. Директор департаменту з підготовки наукових кадрів. АТ «Міжнародний університет інформаційних технологій», вул. Манаса, 34/1. Алмати, Казахстан

**Dmytro V. Lukianov –** D.Sc (Eng), CIO, "GUGACloud", 499A, Pr. Bortnikova. Kiev, 03212, Ukraine
ORCID: http://orcid.org/ /0000-0001-8305-2217 ; dlukiano@gmail.com. Scopus Author ID: 57192572835
**Research field:** Project management; systems engineering; project team management

**Лук'янов Дмитро Володимирович -** доктор технічних наук. CIO "GUGACloud", пр-т Бортнікова, 499А. Київ, 03212, Україна


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