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**ХАЛЫҚАРАЛЫҚ АҚПАРАТТЫҚ ЖӘНЕ
КОММУНИКАЦИЯЛЫҚ ТЕХНОЛОГИЯЛАР
ЖУРНАЛЫ**

**МЕЖДУНАРОДНЫЙ ЖУРНАЛ
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КОММУНИКАЦИОННЫХ ТЕХНОЛОГИЙ**

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ӘЛЕУМЕТТІК-ЭКОНОМИКАЛЫҚ ЖҮЙЕЛЕРДІ ДАМЫТУДАҒЫ ЦИФРЛЫҚ ТЕХНОЛОГИЯЛАР

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USING THE ENTROPY APPROACH IN THE ANALYSIS OF KNOWLEDGE SYSTEMS IN THE FIELD OF PROJECT MANAGEMENT BY THE EXAMPLE OF ICB 4.0 IPMA

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Abstract. The article proposes to consider examples of studying complex systems using entropy analysis. The interpretation of the adjacency matrix created when analyzing a system, such as a channel matrix, is considered. It is proposed that an example of applying such logic when calculating information entropy for studying such a system be regarded as a model of individual requirements for the competencies of project managers proposed by the International Project Management Association (ICB IPMA). The approaches previously developed by the authors to the analysis of systems of factors through visualization in the form of a “system landscape” that arises when analyzing a Markov model, as well as through simulation modeling of transient processes in a discrete Markov system, are proposed to be supplemented with the logic of quantitative assessment of the properties of such systems as “information” systems, using the concept of “entropy” as a measure of the efficiency (organization) of internal information in the analyzed systems. An interpretation of the obtained data is proposed when applying the entropy approach, using the example of the ICB IPMA system under consideration. The presented results are proposed to be considered along with other options (models) of analysis from the point of view of one of the possible options for implementing the concept of “systems engineering based on modeling” when analyzing knowledge systems in various fields of professional activity. It seems likely to use the proposed approach, including comparing different knowledge systems existing in the same line of work, particularly in professional project management, where a whole family of competing knowledge systems, competency models, and certification systems has existed for a long time.

Keywords: model-based system engineering, Markov models, graph theory, information system, modeling, entropy, competences, project management

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ІСВ 4.0 IPMA МЫСАЛЫ БОЙЫНША ЖОБАНЫ БАСҚАРУ САЛАСЫНДАҒЫ БІЛІМ ЖҮЙЕЛЕРІН ТАЛДАУДА ЭНТРОПИЯ ТӘСІЛДІ ПАЙДАЛАНУ

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Аннотация. Мақалада энтропиялық талдауды қолдану арқылы күрделі жүйелерді зерттеу мысалдарын қарастыру ұсынылады. Арна матрицасы сияқты жүйені талдау кезінде құрылған іргелес матрицаның интерпретациясы қарастырылады. Жобаларды басқарудың халықаралық қауымдастығы (ICB IPMA) ұсынған жоба менеджерлерінің құзыреттеріне жеке талаптардың үлгісі ретінде мұндай жүйені талдау үшін ақпараттық энтропияны есептеу кезінде мұндай логиканы қолданудың мысалын қарастыру ұсынылады. Марков моделін талдау кезінде пайда болатын «жүйелік ландшафт» түріндегі визуализация арқылы факторлар жүйесін талдауға, сондай-ақ дискретті Марков жүйесіндегі өтпелі процестерді модельдеу арқылы бұрын авторлар әзірлеген тәсілдер ұсынылған. талданатын жүйелердегі ішкі ақпараттың тиімділігінің (ұйымдастырылуының) өлшемі ретінде «энтропия» түсінігін пайдалана отырып, «ақпараттық» жүйелер сияқты жүйелердің қасиеттерін сандық бағалау логикасымен толықтыру. Алынған деректердің интерпретациясы қарастырылып отырған ICB IPMA жүйесінің мысалын пайдалана отырып, энтропия тәсілін қолдану кезінде ұсынылады. Ұсынылған нәтижелерді кәсіби қызметтің әртүрлі салаларындағы білім жүйесін талдау кезінде «модельдеуге негізделген жүйелік инженерия» тұжырымдамасын жүзеге асырудың ықтимал нұсқаларының бірі тұрғысынан талдаудың басқа нұсқаларымен (үлгілерімен) қатар қарастыру ұсынылады. Ұсынылған тәсілді пайдалану мүмкін сияқты, соның ішінде. және бір жұмыс жолында бар әртүрлі білім жүйелерін салыстыру, атап айтқанда, бәсекелес білім жүйелерінің, құзыреттілік үлгілерінің және сертификаттау жүйелерінің тұтас отбасы ұзақ уақыт бойы бар кәсіби жобаларды басқару саласында.

Түйін сөздер: модельдеуге негізделген жүйелер инженериясы, Марков модельдері, графиктер теориясы, ақпараттық жүйе, модельдеу, энтропия, құзыреттер, жобаны басқару

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ИСПОЛЬЗОВАНИЕ ЭНТРОПИЙНОГО ПОДХОДА В АНАЛИЗЕ СИСТЕМ ЗНАНИЙ В СФЕРЕ УПРАВЛЕНИЯ ПРОЕКТАМИ НА ПРИМЕРЕ ICB 4.0 IPMA

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Аннотация. В статье предлагается рассмотреть примеры исследования сложных систем используя энтропийный анализ. Рассматривается интерпретация матрицы смежности, создаваемой при анализе такой системы, как канальной матрицы. Предлагается рассмотреть пример применения подобной логики при расчете информационной энтропии для анализа такой системы как модель индивидуальных требований к компетенциям проектных менеджеров, предлагаемых Международной ассоциацией управления проектами (ICB IPMA). Разработанные ранее авторами подходы к анализу систем факторов через визуализацию в виде «системного ландшафта», возникающую при анализе марковской модели, а также через имитационное моделирование переходных процессов в дискретной марковской системе предлагается дополнить логикой количественной оценки свойств такого рода систем как «информационных» систем, используя понятие «энтропия» как меры эффективности (организованности) внутренней информации в анализируемых системах. Предлагается интерпретация полученных данных при применении энтропийного подхода на примере рассматриваемой системы ICB IPMA. Представленные результаты предлагается рассматривать наряду с другими вариантами (моделями) анализа с точки зрения одного из возможных вариантов реализации концепции «системного инжиниринга на основе моделирования» при анализе систем знаний в различных сферах профессиональной деятельности. Представляется возможным использование предлагаемого подхода в т.ч. и для сравнения различных систем знаний, существующих в одном и том же направлении деятельности, в частности, в сфере профессионального управления проектами, где существует целое семейство конкурирующих систем знаний, моделей компетенций и систем сертификаций на протяжении длительного времени.

Ключевые слова: системный инжиниринг на основе моделирования, марковские модели, теория графов, информационная система, моделирование, энтропия, компетенции, управление проектами

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Introduction

The authors' works widely use the tools of graph theory and Markov methods in analyzing various complex technical and socio-economic systems. Based on it, a universal calculation template was developed using Microsoft Excel software (microsoft.com/en-us/microsoft-365/excel, 2024) and guidelines for its use (Methodology for carrying out analysis using the Markov model for ergodic systems, 2024). This approach was applied in several research (Kolesnikova et al., 2019: 455–460; Gogunskii et al., 2017: 60–65; Lukianov et al., 2019: 506–512; Pitera et al., 2018: 30–39), which made it possible to identify the corresponding mathematical apparatus and its application areas as an "information system." During this time, the authors developed a relatively large number of models, which made it possible to put forward specific hypotheses regarding predicting the behavior of the systems they modeled. To test some of these hypotheses, particularly regarding the properties of structural connections of modern knowledge systems in professional project management, the authors took alternative methods to obtain the properties they studied. This approach is increasingly used in the world; on its basis, such a direction as "simulation-based systems engineering" has been formed (What is MBSE, 2024), which offers not just methods for analyzing a particular model describing a specific system but also proposes the creation of many models for the analysis of the same system. This inevitably led the authors to the need to evaluate information connections and the information itself in the system models they considered. The proposed work presents an experience for analyzing the model of individual competencies of project managers — Individual Competence Baseline (ICB), proposed by the International Project Management Association (IPMA) (ICB IPMA Individual Competence Baseline 4th Version. ICB4, 2015).

Problem

The development of approaches to project management occurs at different speeds in different fields of activity. This inevitably leads to their differences, attempts to transfer approaches tested in some conditions to other situations, and, finally, to competition. This applies to both "formal" knowledge systems and recognition of the qualifications of specialists in this field, including those of the relevant professional certification systems. This can also lead to uncertainty or a situation of conflict in choosing one or another approach to managing a specific project - directly among project team members who make particular decisions regarding the choice of approach to managing projects in which they are involved as actors. This, ultimately, also inevitably leads to the intersection and mixing of different approaches. In project management, there is a corresponding well-established term for this type of situation - "Blended project management frameworks" (Bushuev, 2020: 187–207). Accordingly, all kinds of analytical materials appear to compare different approaches, carrying out the so-called "mapping," which is mutual "mapping" or "comparison" of such approaches proposed by various standards (Caupin et al., 2004; Yao, 2016: 1677; Crawford, 2013: 1–9; Ghosh, 2012: 1–77). However, what is quite strange is that despite the abundance of this kind of analytics, it does not present such a type of analysis (and, accordingly, a comparison of its results for different models) as "entropy analysis". Moreover, there is no such data for comparing different approaches (standards) or versions of the same standard.

Material and methods

To solve the structuring problem, it is proposed to analyze the relevant sections of the following elements of the mathematical apparatus, as well as the applied tools used by the authors, including:

1. Competency model of specialists in the field of project management ICB 4.0 IPMA (ICB IPMA Individual Competence Baseline 4th Version. ICB4, 2015).



2. Graph theory (Tutt, 1988)
3. Markov methods (Dynkin, 1960: 1–21)
4. Entropy analysis
5. Microsoft Excel software (microsoft.com/en-us/microsoft-365/excel, 2024)

When constructing their models, the authors use the principle "everything is connected to everything" (Barry Commoner's first law (Kramarenko)). Guided by this law, the constructed models always have the form of a square adjacency matrix, translated into a matrix of transition probabilities according to Laplace's principle to determine probabilities under conditions of uncertainty (or according to B. Commoner's third law, "Nature knows best"). On the other hand, based on the logic of B. Commoner's second law ("Everything must go somewhere"), they also introduce a "measure" of interaction between the elements of the simulated systems in the form of a "system landscape," taking into account the number of connections between the components of the system based on the calculation of the matrix adjacency of order n such that the corresponding matrix no longer contains "empty" (equal to zero) elements. In this regard, such several connections (increasing like an avalanche with an increase in the degree of the adjacency matrix) can be considered close to E. Schrödinger's interpretation of the concept of entropy, who thought it as a measure of disorganization of a system of any nature (Commoner, 1974: 280), which, accordingly, can be considered as a measure of the organization of the system of any nature, which, according to the authors, is their interpretation of the "system model" as a Markov chain.

It is important to note that "entropy is qualitatively different from other thermodynamic quantities, such as pressure, volume or internal energy, because it is not a property of the system, but of how we consider this system" (Kaziev, 2024). This is well illustrated by the well-known model of "Maxwell's Demon" (Entropy? It's simple, 2024). About the "observation point," the following analogy can be drawn - someone who is not in the "industry," for example, in the field of professional project management, may have a rather vague idea (mainly due to lack of information) about what specific competencies are required project participants for successful project management. Anyone who has a different "observation point" may well "divide" possible knowledge, skills, and abilities into, at a minimum, "relevant" and "inappropriate" acting, for example, as a project manager. At the same time, the task of "distributing" responsibilities, solved by the project manager, in this case, can be considered as an analog of the work of that same Maxwellian "demon." The implementation of this kind of system at the physical level has proven to be very interesting from the point of view of the potential use of such a mechanism (Cunning, calculating and unreal: who is Maxwell's demon, 2024); on the other hand, efforts to reduce entropy in project management systems may be of no less interest and practical significance. The qualifications of such a project manager, in turn, may need to depend on a kind of block of "supra-system" competencies, including an understanding of the very logic of the work of project teams and elements of assessing the competencies of project team members. At the same time, one should not at all expect the emergence of some "simple" system, which at the same time can be "good enough" for use in any case, which, unfortunately, can be seen in attempts to "prescribe" some methodology, set of methods or principles as the "only correct" one".

To assess the effectiveness of an information system, it is proposed to use entropy methods, which are widely used in the study of complex systems (Fifth stage: 22). As noted in (What Is the Markov Decision Process), the use of entropy methods in constructing a theory of self-organization processes is especially effective.

When using entropy methods, a distinction is made between thermodynamic entropy S and informational entropy H (Wilson, 1978: 246). Let us briefly consider the



methods of thermodynamic entropy in the study of evolutionary processes and the dynamics of hierarchical systems (Pereverzev, 2024).

As is known, the change in thermodynamic entropy dS is defined as

$$dS = \frac{\Delta Q}{T} \quad (1)$$

where

ΔQ is the change in heat during the process;

T – absolute temperature.

In the general case, the entropy increment dS can be represented as the sum of two terms

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

where

dS_e – change in entropy due to exchange with the environment;

dS_i is the increase in entropy caused by irreversible changes within the system.

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

Let's consider the use of the proposed tools by analyzing the system of individual competencies of project managers ICB 4.0 IPMA.

As a starting point, we'll consider the adjacency matrix between elements. This matrix is built on the basis of an analysis of the text of the standard [ICB 4.0 IPMA], which provides data on the presence of such connections (Fig. 1).

Based on the logic of K. Shannon, it is necessary to operate with the probabilities of transitions from one state to any of those achievable from this state, where the fundamental achievability (possibility) of such a transition is designated as "1", and the absence of direct influence ("transfer of information") of one element to another represented as "0". The amount of information presented by any source or transmitted over a specific time through any channel is measured by the logarithm of the total number (n) of different possible equally probable information options that could be presented by a given source or transmitted over a given time (including discrete-time as a specific time interval).

As is known, information binary entropy, in the absence of information losses, is calculated using Hartley's formula (3).

$$i = \log_2 N \quad (3)$$

where

N is the power of the alphabet,

i is the amount of information in each message symbol.

For independent random events x with n possible states distributed with probabilities

p_i ($i = 1, 2, \dots, n$), Hartley's formula transforms into Shannon's formula (4)

$$H(x) = - \sum_{i=1}^n p_i \log_2 p_i \quad (4)$$

| Factor name | Elements that are affected (columns) | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---------------------------------------|--------------------------------------|---|---|---|---|---|---|---|---|---|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|---|---|
| | FI0 | 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 | | |
| Influencing Elements (Rows) | FI0 | 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 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | | |
| Compliance, standards and regulations | 3 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | |
| Power and interests | 4 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 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 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 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 | 1 | 0 | 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 | 1 | 0 | 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 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 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 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 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 | 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 | 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 | 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 | 0 | 0 | 1 | 1 | 0 | 0 |
| Negotiation | 14 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 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 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 |
| Project design | 16 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 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 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Scope | 18 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 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 | 1 | 1 | 1 | 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 | 1 | 1 | 1 | 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 | 1 | 1 | 1 | 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 | 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 | 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 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Plan and control | 25 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Risk and opportunities | 26 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 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 | 1 | 1 | 1 | 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 | 1 | 1 | 1 |

Figure 1- “First order adjacency matrix ICB 4.0 IPMA”

This quantity is also called the average entropy of a message.

C. Shannon also suggested that the gain in information is equal to the loss of uncertainty and set requirements for its measurement:

1. The measure must be continuous; that is, a change in the value of the probability value by a small amount should cause a small resulting change in the function (from this point of view, regarding project management, all project management activities can be reduced to the activities of managing project risks, reducing the likelihood of undesirable events and their consequences, and on the contrary, increasing the probability of events favorable for the development of the project);

2. In the case when all options (elements of competencies in the example with ICB IPMA) are equally probable, an increase in the number of options (elements of competencies) should always increase the value of the function describing the rise in information;

3. It should be possible to make a choice (in the example under consideration, elements of competencies) in two steps, in which the value of the final result function should be the sum of the tasks of intermediate results (which, from our point of view, indicates the potential for further decomposition of the ICB IPMA model to the level "finite elements" inherent only to the corresponding block of the model).

As can be seen further in the examples, particularly in the tables (numbers), all these rules are fulfilled when analyzing the IPMA ICB model.



To use Shannon's formula, it is necessary to convert the adjacency matrix into a matrix of transition probabilities. To do this, in the case of an actual situation of uncertainty, you can use logic similar to the logic of the Laplace criterion when calculating the Laplace criterion in game theory - consider the probabilities equal, but in our case, we will make some change - we will consider the probabilities equal not for all columns of the "payment matrix," and for each row we define 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 that the sum of the elements in each of the rows of such a matrix of transition probabilities is equal to 1. It is possible to determine such values expertly or based on historical data. In that case, this can also be done, and 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. 2).

| Factor name | Influencing (Rewards / Wins) | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---------------------------------------|------------------------------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| | 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 | 0.00 | 0.35 | 0.30 | 0.30 | 0.30 | 0.00 | 0.00 | 0.00 | 0.00 | 0.30 | 0.00 | 0.00 | 0.00 | 0.00 | 0.30 | 0.30 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Governance, structure and processes | 0.35 | 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 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Compliance, standards and regulations | 0.30 | 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 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Power and interests | 0.30 | 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 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Culture and values | 0.30 | 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 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Self-reflection and self-management | 0.30 | 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 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Personal integrity and reliability | 0.30 | 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 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Personal communication | 0.30 | 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 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Relations and engagement | 0.30 | 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 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Leadership | 0.30 | 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 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Teamwork | 0.30 | 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 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Conflict and risks | 0.30 | 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 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Responsiveness | 0.30 | 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 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Negotiation | 0.30 | 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 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Results orientation | 0.30 | 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 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Project design | 0.30 | 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 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Requirements and objectives | 0.30 | 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 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Scope | 0.30 | 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 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Time | 0.30 | 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 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Organization and information | 0.30 | 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 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Quality | 0.30 | 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 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Finance | 0.30 | 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 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Resources | 0.30 | 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 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Procurement | 0.30 | 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 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Plan and control | 0.30 | 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 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Risk and opportunities | 0.30 | 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 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Stakeholder | 0.30 | 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 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Risk and opportunities | 0.30 | 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 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Change and transformation | 0.30 | 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 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

Figure 2 - "Transition probability matrix for the first-order adjacency matrix of ICB 4.0 elements based on the modified Laplace criterion"

This representation encapsulates all the necessary data for calculating the information entropy for the presented system, as per K. Shannon's theory. Imagine each element represented by the corresponding row of the transition probability matrix as an element 'influencing' all other elements of the system. Rows are 'sources' and columns are 'sinks' of information. All lines are elements, i.e. elementary subsystems of the system under consideration. The entropy of the entire system is the sum of the entropies for each of the available states of the system. To do this, you need to understand the distribution of the random variable 'X' that describes the 'system' for each of the finite number of values of the potential system states'. This practical approach to information entropy can be directly applied to project management, making it a valuable tool in your professional toolkit.

At the same time, it is worth introducing a particular assumption that the "project" itself as an object of management can be defined in terms, concepts, and states of the system that manages it. This is not entirely obvious logic, but it is the same argument when discussing the possibility of defining "mass" in terms of the "force" required to move it. In our case, this "mass" is the project, and the "force" is the set of competencies necessary to "move" the project to the desired state. It is assumed that the random variable "X" as a kind of "total force" at a particular moment can only be in one of the possible states. Suppose this "power" is in the "head" of a specific project manager. In that case, we will accept that at any given moment, the bearer of this "power" can be in one or only one of the states associated with using the corresponding element of competence. This approach is consistent with determining entropy using one's information (4).



Using a similar logical approach, it's also possible to calculate entropy changes for any nth step based on the calculation of the corresponding transition probabilities. The entropy of the initial state of the system will be equal to 0, due to the values of transition probabilities at the start of the simulation. For all except the 'start' one, these values are equal to '1', indicating no uncertainty, and therefore the entropy is equal to zero. This straightforward process of calculating entropy changes can be easily understood and applied in your project management practices. The simulation data, as shown in Fig. 3, further illustrates this.

Figure 3 - “Information modeling data for a discrete model of the dynamics of transitions between states for the transition probability matrix ICB 4.0 IPMA”

Accordingly, knowing the set of final states and the probability of the system being in them, it is possible to calculate the entropy values for each of the steps (Fig. 4).

Figure 4 - “Data on the calculation of entropy based on information modeling data for a discrete model of the dynamics of transitions between states for the transition probability matrix ICB 4.0 IPMA”

As can be seen from the model (shown on Fig. 4), starting from step (4), the value of information entropy becomes constant. We can obtain similar results by calculating the entropy values for adjacency matrices of orders two and higher. The elements of these matrices represent the total number of connections between elements, including both direct and intermediate connections through "post stations."

On the other hand, one can approach the calculation of the entropy of a system also based on its entropy, but no longer calculate it as the probability of the state of the “entire system,” but consider its calculation based on the entropy values of each specific transition to a particular state available at the corresponding moment in the system. To do this, one can calculate the conditional entropy and consider the first-order adjacency matrix as a channel matrix.

As is known, conditional entropy of the first order (similarly for the Markov model of the first order) is the entropy for the alphabet, where the probabilities of the appearance of one letter after another are known (that is, the probabilities of two-letter combinations). In our case, the “alphabet” is the ICB 4.0 IPMA model, and the “letters” of such an “alphabet” are the elements of this model. Accordingly, you can use the formula if you have an adjacency matrix.

$$H_1(S) = - \sum p_i \sum p_i(j) \log_2 p_i(j), \tag{5}$$

To calculate the conditional entropy, we need to use the previous symbol and the probability of the current symbol given the previous one. We can form a matrix of conditional entropy values based on the transition probabilities between states. The row of the matrix corresponds to the current state, and the column corresponds to the next state. We can calculate the probabilities of getting into a specific state using information modeling data. With this information, we can calculate the conditional entropy for any step n.



It is known that information losses during data transmission in a channel with noise are thoroughly described through the partial and general conditional entropies. So-called channel matrices are used for this purpose. To explain the losses on the source side (that is, the sent signal is known), the conditional probability $p(b_j | a_i)$ of receiving the symbol b_j by the receiver, provided that the symbol a_i was sent, is considered. In this case, the channel matrix has the following form (Fig.5)

Figure 5 - "Channel matrix"

| | | | | | | |
|-------|----------------|----------------|-----|----------------|-----|----------------|
| | b_1 | b_2 | ... | b_j | ... | b_m |
| a_1 | $p(b_1 a_1)$ | $p(b_2 a_1)$ | ... | $p(b_j a_1)$ | ... | $p(b_m a_1)$ |
| a_2 | $p(b_1 a_2)$ | $p(b_2 a_2)$ | ... | $p(b_j a_2)$ | ... | $p(b_m a_2)$ |
| ... | ... | ... | ... | ... | ... | ... |
| a_i | $p(b_1 a_i)$ | $p(b_2 a_i)$ | ... | $p(b_j a_i)$ | ... | $p(b_m a_i)$ |
| ... | ... | ... | ... | ... | ... | ... |
| a_m | $p(b_1 a_m)$ | $p(b_2 a_m)$ | ... | $p(b_j a_m)$ | ... | $p(b_m a_m)$ |

The sum of all elements of any row gives 1 (in the case of considering systems with absorbing states, it is evident that the diagonal values will have to differ from 0). The losses per transmitted signal a_i are described through the partial conditional entropy (6).

$$H(B | a_i) = - \sum_{j=1}^m p(b_j | a_i) \log_2 p(b_j | a_i). \tag{6}$$

To calculate the transmission losses of all signals, the general conditional entropy is used (7).

$$H(B | A) = \sum_i p(a_i) H(B | a_i). \tag{7}$$

where

$H(B | A)$ means the entropy on the source side,

$H(A | B)$ is the entropy on the receiver side, and by summing the elements of the line, we can get $p(a_i)$, and the diagonal elements mean the probability that precisely the one was sent the symbol that is received, that is, the probability of correct transmission. In our case, A and B are the same elements (states) of the ICB 4.0 IPMA system.

The matrix of transition states for the first-degree adjacency matrix of our system fully corresponds to the logic of constructing a channel matrix, with the only difference being that the diagonal elements, in this case, are taken equal to zero. Based on it, it is possible to carry out a line-by-line calculation of the information entropy values (Fig. 6).

Figure 6 - "Calculation of Shannon entropy based on the channel matrix as a matrix of transition probabilities ICB 4.0 IPMA"



Significantly, the entropy value for element 10 (“Leadership”) with the calculation method presented in Fig. 6 corresponds to the entropy value of the system at the first step, when at the zero steps (initial state), it was chosen to start from element 10. Of course, for situations with other elements of competencies, it would be an ideal management decision to know precisely at what point and at what step to “turn on” this or that element with its tools and methods. In this regard, the PMBOK PMI process model looks more advantageous, offering a precise sequence of actions from forming the Project Charter to summing up the completed project. However, this is precisely why such a prescriptive model will work well under a highly predictive task. For example, consider ICB model versions 2, 3 and 4, for which we calculate the “amount of information” based on (James Glick, 2024). Accordingly, the following values can be taken for the models under consideration (Table 1).

Conclusion

In our case, if we use the definition of entropy, based on E. Schrödinger's interpretation of the concept of entropy as a measure of system disorganization, for information systems, we can accept the following definition: “Entropy is how much information is not known about the system” (Entropy? It's simple, 2024), then a reasonable question will arise about how to measure it (entropy). Here, we can build the following chain of reasoning based on what is considered “known” and “unknown.” In the author's approach, the system reaches a complete understanding at a certain level of its development, known as the “Markov process step” n . At this stage, other aspects of the system influence every element in the system (represented by the corresponding degree's adjacency matrix). In other words, no single component of the system does not affect different aspects of the entire system.

Accordingly, it is possible to calculate the number of missing connections in the system (in particular, the authors do this based on constructing a reachability matrix). The models developed by the authors are aimed primarily at use during the decision-making process as a process of identifying problems, searching for alternative opportunities and their formalization in a form suitable for analysis for, in fact, making subsequent decisions related to eliminating problems and realizing opportunities (Brazhnikov et al., 2012: 107).

Table 1- “Amount of information that can be transferred from elements of ICB IPMA competency models”

| Version of ICB | Number of competency elements | Amount of information, bits |
|----------------|-------------------------------|-----------------------------|
| ICB | 2.060 | 5,907 |
| ICB | 3.046 | 5,524 |
| ICB | 4.028 (29) | 4,807 (4,858) |

According to the technological management cycle, making a management decision is a critical aspect, and it involves a sequence of selection procedures that culminate in a system of management decisions. In this regard, a proposal has been made for an “information system” that can act as a “system” of management decision support in an area where such a toolkit has not been proposed. According to the authors, this proposal has at least the potential for practical application.

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