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ASSESSING THE QUALITY OF PROJECT MANAGEMENT IN INDUSTRIAL ENTERPRISES WITHIN THE FRAMEWORK OF INDUSTRY 4.0 BASED ON THE INTEGRAL ENTROPY INDEX

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ABSTRACT

The study aims at substantiating the entropy approach to assessing the quality of project management processes and developing an appropriate mathematical model. Within the framework of this article, entropy is considered an integral indicator for assessing the project management of Industry 4.0 enterprises, characterizing project controllability and confidence in its results. The quality of project management processes is understood as the ability to assess and minimize, through preventive or adaptive measures, uncertain or negative impacts from the inside and outside, i.e., to ensure a project's success. The authors determine the main factors influencing project entropy. It is substantiated that management is to counteract entropy and create such conditions for project implementation, under which its level is acceptable. A scale for assessing a project's entropy level is proposed, based on experiments. The obtained results allow the authors to assess the quality of management processes at each stage of the project life cycle and to form a theoretical basis for the further development of tools ensuring and improving quality.

Keywords: Industry 4.0, information entropy, project success, uncertainty, quality management, project management.

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AVALIAÇÃO DA QUALIDADE DA GESTÃO DE PROJETOS EM EMPRESAS INDUSTRIAIS NO ÂMBITO DA INDÚSTRIA 4.0 COM BASE NO ÍNDICE DE ENTROPIA INTEGRAL

RESUMO

O estudo visa fundamentar a abordagem da entropia para avaliar a qualidade dos processos de gerenciamento de projetos e desenvolver um modelo matemático apropriado. No âmbito deste artigo, a entropia é considerada um indicador integral para avaliar a gestão de projetos das empresas da Indústria 4.0, caracterizando a controlabilidade do projeto e a confiança nos seus resultados. A qualidade dos processos de gestão de projetos é entendida como a capacidade de avaliar e minimizar, através de medidas preventivas ou adaptativas, impactos incertos ou negativos de dentro e de fora, ou seja, garantir o sucesso de um projeto. Os autores determinam os principais fatores que influenciam a entropia do projeto. Está comprovado que a gestão deve neutralizar a entropia e criar condições para a implementação do projeto, sob as quais o seu nível seja aceitável. É proposta uma escala para avaliar o nível de entropia de um projeto, baseada em experimentos. Os resultados obtidos permitem aos autores avaliar a qualidade dos processos de gestão em cada fase do ciclo de vida do projeto e formar uma base teórica para o futuro desenvolvimento de ferramentas que garantam e melhorem a qualidade.

Palavras-chave: Indústria 4.0, entropia da informação, sucesso de projetos, incerteza, gestão da qualidade, gestão de projetos.

EVALUACIÓN DE LA CALIDAD DE LA GESTIÓN DE PROYECTOS EN EMPRESAS INDUSTRIALES EN EL MARCO DE LA INDUSTRIA 4.0 A PARTIR DEL ÍNDICE INTEGRAL DE ENTROPÍA

RESUMEN

El estudio tiene como objetivo fundamentar el enfoque de entropía para evaluar la calidad de los procesos de gestión de proyectos y desarrollar un modelo matemático apropiado. En el marco de este artículo, la entropía se considera un indicador integral para evaluar la gestión de proyectos de las empresas de Industria 4.0, caracterizando la controlabilidad del proyecto y la confianza en sus resultados. La calidad de los procesos de gestión de proyectos se entiende como la capacidad de evaluar y minimizar, mediante medidas preventivas o adaptativas, impactos inciertos o negativos desde el interior y el exterior, es decir, asegurar el éxito de un proyecto. Los autores determinan los principales factores que influyen en la entropía del proyecto. Se fundamenta que la gestión debe contrarrestar la entropía y crear condiciones para la implementación del proyecto en las que su nivel sea aceptable. Se propone una escala para evaluar el nivel de entropía de un proyecto, basada en experimentos. Los resultados obtenidos permiten a los autores evaluar la calidad de los procesos de gestión en cada etapa del ciclo de vida del proyecto y formar una base teórica para el desarrollo posterior de herramientas que garanticen y mejoren la calidad.

Palabras clave: Industria 4.0, entropía de la información, éxito de proyectos, incertidumbre, gestión de calidad, gestión de proyectos.

INTRODUCTION

Industry 4.0 is smart production with the massive use of digital technologies in automating production processes (Panasenko et al., 2023) and product sales, creating a cyber-physical space, and developing and using the industrial Internet (Gorodilov et al., 2022; Khoruzhy et al., 2022).

To summarize various studies, scholars identify the following revolutionary trends, which are also the main components of industrial development within Industry 4.0:

1. A revolution in the design and organization of production processes, i.e., modern industries are undergoing total technological and organizational reengineering based on the digitalization of production processes (Meissner et al., 2017; Tolkaneva et al., 2023; Zubritskaya, 2019).

2. A transition to new materials, i.e., their integration into automated design and production systems, combining the production of materials and components/products (Burmeister et al., 2016; Trachuk & Linder, 2017).

3. Smart environments, i.e., their mass introduction is expected in the near future; the struggle for the market of intelligent networks/infrastructures in the world has intensified; large-scale regional initiatives are being implemented (Zulu & Brown, 2004; Semenova et al., 2021).

The general understanding of these components can be formulated as the development of advanced production technologies which covers: 1) technological substitution leading to the improvement of existing products or the creation of fundamentally new products; 2) automated production that imposes new requirements on the qualifications of specialists; 3) customization of production as a flexible adaptation to the customer’s needs; 4) localization, i.e., cost reduction due to savings on logistics and geographical proximity to the consumer (customer); 5) economic efficiency associated either with a reduction in cost compared to mass production or with saving resources, increasing productivity labor, investment attractiveness, and competitiveness (Westerveld, 2003).

A problem in the project management of Industry 4.0 enterprises introducing advanced production technologies is the quality management of projects.

According to S. Zulu and A. Brown (2003), the quality of projects includes two components: the quality of products and the quality of management processes. In modern literature, much attention is paid to the first component (the quality of products) as this direction is connected both ideologically and methodologically with the quality management system and international quality standards. The quality of management processes is a property of the enterprise management system that reflects the ability to successfully implement a project (Kirillova et al., 2021). Thus, the quality of project management is a property of the project management system that ensures the achievement of the project goal and its effectiveness (Kiseleva et al., 2023).

Considering modern approaches to project management focus on the value (Baker, 2018) created by the project implementation (a broader category than efficiency), we can assume that the value is the result of such implementation. Since a project's success is the achievement of goals and planned results (primarily values on time within established budget constraints), the quality of management is vital in the process (Zenin et al., 2023). This understanding of the quality of management processes is the basis of this study. The quality of management processes should be assessed both at the beginning and throughout a project's life cycle (Petrina et al., 2023). On the one hand, this allows to assess the success of implementing advanced production technologies at enterprises. On the other hand, it is used to identify problems to make adequate decisions.

LITERATURE REVIEW

When analyzing product quality in project management, it is necessary to consider business processes (Bin Muda & Panoutsos, 2021; Jae-Yoon et al., 2011) ensuring such quality, which is also confirmed by the relevant international standards. However, modern studies pay less attention to the quality of management processes. There are no methods for assessing the quality of project management for the introduction of advanced production technologies at enterprises.

The entropy concept of management considers project management, including enterprise management, and resistance and struggle against entropy. This approach is explained by the specific conditions of modern business, regardless of its essence. A high level of turbulence and uncertainty (Boulaares et al., 2022) conditions the need for the reorientation of control. According to M. Saidi et al. (2018), it is impossible to ensure the success of a project or an organization, especially in the long term, without considering entropy and taking appropriate actions aimed at its decrease. In (Ibl & Capek, 2016), methods for estimating the entropy of projects were provided. In (Kong et al., 2019; Kozin, 2023; Xiang et al., 2023), actions aimed at reducing entropy were described. Under the entropy concept of management, it reflects the object of management, i.e., a project from the standpoint of the impact of a set of factors, including internal ones, such as management (Han & Zhu, 2017).

The idea of using information entropy (Shannon's entropy) in project management was realized in various studies, where entropy was used as a measure of project uncertainty and risk assessment (Kostromina et al., 2022; Trofimov et al., 2022). Thus, the entropy concept of management was the accumulated experience of using information entropy to assess the state of a particular project.

We believe that the method for assessing the quality of project management at Industry 4.0 enterprises should be developed with due regard to the entropy concept, which creates the logical chain "quality – entropy – success".

In view of the above, the study is to substantiate the entropy approach to assessing the quality of project management processes and developing an appropriate mathematical model.

METHODS

In conformity with the above-mentioned approach to the implementation of a mathematical model for assessing the quality of project management at Industry 4.0 enterprises, we selected a qualitative-quantitative approach based on the integral entropy indicator.

The study was conducted from April 10, 2023 to May 10, 2023 through a desk study by university staff from the Russian State Social University, Kazan Federal University, Peoples' Friendship University of Russia, Financial University under the Government of the Russian Federation, and Kuban State Agrarian University named after I.T. Trubilin, which included an analysis of scientific sources on the research topic.

The methodological basis of the study was the method presented in (Ibl & Capek, 2016) for assessing the information entropy of H projects based on Shannon's approach, which reflects the degree of uncertainty of the project results:

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

Where A_k is the options for the project results; $p(A_k)$ is the probabilities of these results; K is the total number of options. In relation to performance indicators characterizing the quality of management processes and underlying information entropy (the main indicator of the quality of these processes), it is proposed to use the following set "time – budget (expenses) – result (value)":

$$A_k = (T_k, R_k, V_k), k = 1, K \quad (2)$$

Where T_k is the project implementation time; R_k is the project budget; V_k is the result (value) of the project.

RESULTS

It can be argued that the higher the *H* value in (1), the more uncertain the results of the project, which can be an assessment of both the risk and the quality of a project at the planning stage. The latter is true if *the quality of management processes as a component of project quality* is assessed from the viewpoint of the ability of the enterprise management system to achieve the necessary result of a project related to Industry 4.0. Thus, a project's information entropy in the context of Industry 4.0 is characterized by the *confidence* of the enterprise management in the project results which can be both a risk assessment and an assessment of the quality of the management itself.

The ideal variant, i.e., full confidence in one specific variant of the project implementation corresponds to the entropy equal to H=0. Therefore, the closer the project entropy is to 0, the more confident the project management (project team) is in the results. In the worst-case scenario, the level of information entropy is proposed as a comparison base, including in a situation where available results have an equal probability. In other words, the management system cannot provide conditions for a certain option or cannot adequately assess possible situations in the process of project implementation. The worst-case scenario is characterized by the following level of entropy:

$$H^w = - \sum_{k=1}^{K} 1/K \cdot \ln(1/K) \quad (3)$$

Where $P(A_k) = p_k = 1/K$ and K as the number of options for implementing the project under consideration is fair with due regard to the entire group of events for the A_k results, k = 1, K.

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

$$0 \leq H \leq H^w \quad (4)$$

We propose the following scale for assessing the project entropy and determining the quality of project management (Table 1).

Table 1. Scale for assessing the project entropy level

Project entropy ranges	Features of the project and the quality of management
$0 \leq H \leq 0.4\ H^w$	– A project with certain results – The level of risk is low – The quality of management is high
$0.4\ H^w < H \leq 0.6\ H^w$	– A project with sufficiently defined results – The level of risk is moderate – The quality of management is assessed as fairly high
$0.6\ H^w < H \leq 0.8\ H^w$	– A project with rather uncertain results – The level of risk is high – The quality of management is not fully satisfactory
$0.8\ H^w < H \leq H^w$	– A project is high-risk with practically uncertain results – No justification at the proper level – The quality of management is unsatisfactory

DISCUSSION

Unlike traditional probabilistic methods for assessing project risks, for example, market factors (Nikolenko & Semina, 2022) that affect the project, the H entropy is an integral indicator that reflects not only the uncertainty of market factors but also the ability of the management system to cope with this uncertainty, including other negative factors affecting the project, its implementation, and result.

We fully agree with the studies (Khrustalev et al., 2022) claiming that the nature of project risks is diverse and is associated not only with market factors but also with suppliers, investors, and other stakeholders. For some projects, natural and climatic factors can also have a significant impact (for example, on agriculture) (Khoruzhy et al., 2023).

In our opinion, both the main strength and weakness of s project is the project management system (project team) (Zinina et al., 2022). It determines an adequate assessment of risks, as well as the possibility of minimizing them through either preventive and/or adaptive measures (Altaf et al., 2023; Rong et al., 2009). Thus, project risks and information entropy have a common system of factors. However, the existence and manifestation of risks do not determine a project’s success or failure but rather the ability of the management system to cope with them, which is ensured by a certain level of quality of management processes. Even under favorable conditions for project implementation, the management system can be a source of project failures (Stroev et al., 2022). In (Kolganov et al., 2022), the incompetence of managers in making certain decisions contributed to a decrease in project effectiveness. For two similar projects implemented in the same conditions (i.e., with the same risk factors), the information entropy might be different depending on the competence of management and the quality of management processes. Thus, the quality of project management should be evaluated from the standpoint of the ability of the management system to adequately assess and minimize a project's information entropy.

Based on the study results, we concluded that a project's quality, consisting of the quality of the product and the quality of the management process, has a direct impact on its success (the required product of a required quality on time, within the expected budget and with the planned result). The whole set of factors that can be partially controlled and managed by the project management system affects the quality of a product and the success of a project. In (Saidi et al., 2018), one of the postulates of the entropy management concept is expressed, where the project entropy (the organization as a whole) is reduced through partial control over the external environment. Therefore, the quality of management processes determined by the project management system is the basis for reducing a project's information entropy and the impact on its success.

Various approaches can be used to evaluate different options for project results and their possibilities. It is possible to take the project network as a basis and evaluate the project results with due regard to the possible characteristics of each task within the network (Kong et al., 2019). Indeed, the characteristics of many tasks are random variables, for example, the duration of some tasks depends on weather conditions as already noted in (Khoruzhy et al., 2023). In addition, it is necessary to consider the human factor (force majeure, diseases, mistakes, including such emergency events as the imposition of sanctions and restrictions). The larger and longer the project, the greater the likelihood of deviation from its planned characteristics, which directly affects the cost of work (Panasenko et al., 2023). The termination of the contract with suppliers for various reasons and the attraction of resources at higher prices are examples of reasons for the possible increase in a project's cost (Postnikova et al., 2023). As a rule, planned indicators and resulting indicators are based on probable estimates (mathematical expectation) (Kozin, 2023). Such circumstances should be regarded as part of the project risk analysis which estimates the possible increase in time and costs for each activity. These estimates can be obtained in different ways: expert estimates or distribution law. In the latter case, options for changing characteristics for different probabilities can be considered (Kozin, 2023).

If we specify the main reasons (uncertain conditions, insufficient justification of the project expediency, incomplete description of the project implementation conditions), it determines a high level of the project entropy at the initial stage of the life cycle.

At the initial stage of its life cycle, a high level of entropy indicates either the turbulence of the external environment and a high level of uncertainty in the conditions for the implementation of the project, or the low quality of management processes, which is expressed in an inadequate substantiation of the project expediency or not prepared environment for the project implementation.

A high level of project entropy does not always mean that a bad project should be abandoned. Entropy can be lowered by changing the composition of the project participants or management actions in relation to such participants and choosing a different structure of suppliers or certain areas (for example, logistics marketing). All this reduces the project entropy as an indicator of improving the quality of management processes.

CONCLUSION

Within the framework of this article, entropy is considered an integral indicator for assessing project management processes aimed at the introduction of advanced production technologies. The main theoretical conclusion is that the use of information entropy does not contradict existing theories and approaches, but rather complements and develops them. Practical conclusions include the ability to assess the quality of management processes at each stage of the project life cycle for the early identification of problems and the formation of a theoretical basis for the further development of tools ensuring and improving the quality of project management processes aimed at the introduction of advanced production technologies.

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