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Research paper

Fuzzy reliability as a tool to estimate the technological and organizational solutions in construction projects

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Abstract: This paper presents a new framework for risk-based assessment of technological and organizational construction solutions using fuzzy reliability. In construction practice, there is a problem that often the actual duration and budget of the project is longer than the estimated figures at the design stage of the technological and organizational solution. In addition, individual construction activities during construction are affected by various risk factors, which can also increase the duration or budget of construction. At the same time, technological and organizational solutions and risks are often associated with the concept of reliability. Therefore, the authors analyzed various frameworks for assessing technological and organizational reliability in construction projects, identified strengths and weaknesses, and proposed a new approach to assessing technological and organizational reliability. In addition, the authors clarified the terms of serial and parallel systems used in the theory of reliability for technical systems taking into account the specifics of the construction process. This article presents an algorithm for fuzzy reliability assessment of technological and organizational solutions that considers the impact of risks on each work. The numerical example presented in this article allows us to evaluate the practical significance of the proposed assessment tool on the network model. The conclusion suggests further research and improvement of the proposed framework.

Keywords: technological and organizational solution, fuzzy reliability, risk assessment, selection of construction works, construction implementation

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1. Introduction

Technological and organizational solutions (TOS) in construction establish the time and budget for project implementation. Many authors, such as Alsuliman (2019) [1], Yaseen (2020) [2], Mahdi (2021) [3], Sanni-Anibire (2022) [4] focused their research on demonstration the negative impact of risk occurrences on the duration of construction projects across different countries, highlighting that one of the key issues is exceeding the planned time and budget established in the TOS due to the impact of risk factors [5, 6]. The TOS is a set of activities with technological and organizational dependencies between each other and located on the time scale of the project duration. The TOS also describes the possible risks that may affect the performance of this or that work. One type of graphical representation of the TOS is a network model that defines the duration and budget of a construction project. A graphical representation of the TOS is shown in Figure 1.

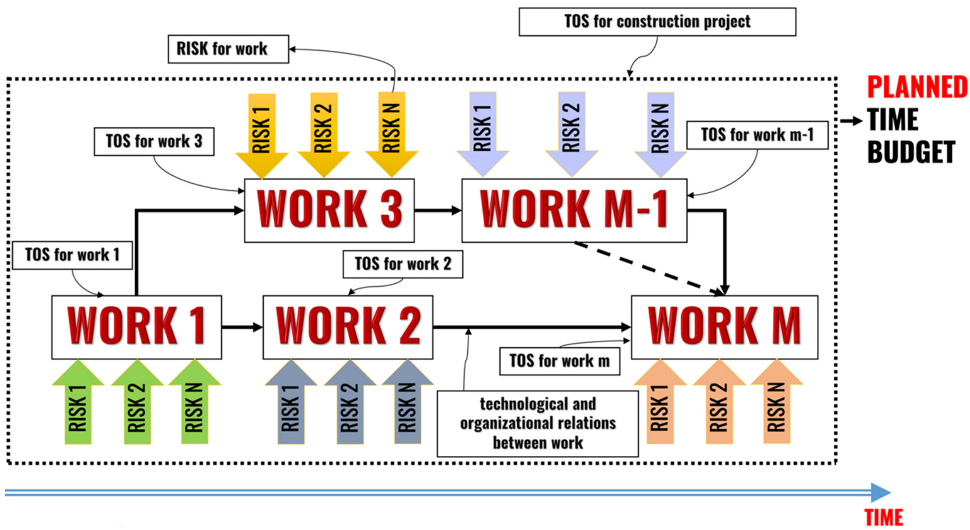

Fig. 1. TOS model of the construction project

To solve this problem, it is necessary to choose the correct technological and organizational solution for each work and to identify and consider the risk factors, which can affect the level of reliability of both individual works and the entire construction project. The papers [7, 8] present various definitions of risk, both negative and positive, as well as different approaches to applying risk assessment concepts [9] in construction projects for various components of the project, such as conducting construction work in low-temperature conditions [10], managing human resources [11], and communication among project participants [12].

Therefore, various authors have paid much attention to the reliability of TOS in the planning of construction projects. For example, highlight the works of A. A. Gusakov, which are based on the theory of reliability of machines and mechanisms and formulated the term “technological and organizational reliability in the field of construction”, where he described the definition reliability of TOS – the ability of organizational, technological, managerial, and economic decisions to ensure the achievement of a given result of construction production under conditions of uncertainty inherent in construction as a complex probabilistic system [13].

The basis of Gusakov's framework [13] is the statement that construction systems are characterized not by complete failures but by partial failures, which are eliminated in the continuous operation of the system. At the same time, the method of determining technological and organizational reliability in his framework is that the probability of construction of an object is determined using the Laplace function based on the duration of work obtained at separate time intervals with the same composition of work and number of workers without dividing the work into critical and non-critical. It should be emphasized that critical path works are of fundamental importance in planning the implementation of construction projects. Therefore, ignoring critical works (critical path) in his approach is a lack of his framework.

The second disadvantage is that failures in TOS are partial rather than complete. It should be noted that if even a partial failure occurs in the work, which is located on the critical path, the total duration of the project will be increase.

The other works of technological and organizational reliability was written K.M. Jaworski, who developed a set of models based on the classical theory of machine and system reliability and probability theory. A certain disadvantage of this approach is the definition of reliability of the classical theory of probability, which is based on real numbers, and there is no possibility of determining the reliability of network models and linguistic methods.

Some studies apply the classical reliability theory for machines and mechanisms with fuzzy set theory. For example, Tao and Tam [14] evaluated the reliability of TOS in terms of cost using the fuzzy reliability theory of technical systems for individual work packages. The main disadvantage of this approach is the consideration of different types of work (e.g. concrete beam and concrete wall) as a parallel system. In classical reliability theory, the term parallel system of elements in technical systems is understood as a connection in which all elements are interchangeable. This study does not present arguments to confirm this approach.

There are also different classifications of construction project risks in the literature. For example, Mustafa and Al-Bahar [15] classify risks depending on their origin into 6 categories (acts of God, physical, financial and economics, political environment, design, job site-related).

Tah and Carr [16] categorize the risk factors of a construction project as external and internal. Xenidis and Angelides [17] categorized risks on the basis of their stage of occurrence in the project and their sources. Chapman [18] categorizes risks into primary, secondary, etc. based on the nature of their origin and degree of impact. Zavadskas, Turskis and Tamosaitiene [19, 20] suggest dividing all risks in a construction project into 3 groups: external (includes political, economic, social and weather risks); project (includes time, cost, work, construction, and technological risks); and internal (resource, project members, construction site, documents and information risks).

In a study by Tamosaitiene, Ali, Holschemacher, Choudhry, and Iqbal [21], they identified the following 10 most significant risks on the example of construction projects: payment delays; project funding problems; accidents/safety during construction; defective design;

inaccurate execution plan/schedule; poor performance of subcontractors; exchange rate fluctuation and inflation; improper scope of work definition in a contract; poor quality of materials and equipment; and shortage/delay of material supply.

Sharma and Swain [22] categorize risks into four groups: external and controllable, external and uncontrollable, internal and controllable, internal and uncontrollable.

Mahendra, Pitroda, and Bhavsar [23] distinguish seven types of risks: technical, construction, physical, organizational, financial, socio-political, and environmental.

Archana and Francis [24] distinguish six categories of risks: financial, legal, management, policy, political, technical, and environmental.

Yadeta [25] subdivides risks into two groups: internal (comprises of the uncertainties within the project) and external (comprises of environmental impacts), and in each group, subgroups of risks are distinguished.

Srinivasan and Rangaraj [26] identified six groups of risks that affect construction projects: market, management, technical, social, legal, and environmental.

Nassar [27] identified risks for construction projects in Iraq, which are divided into three groups: owner, contractor, and consultant risks.

Rajesh and Keshav [28] divided risks into three subgroups: external (includes political, economic, social, weather), internal (resources, project members, construction spot, documents, and information), and project (time, cost, work quality, constructions, technological) risks.

In [29, 30], various risk factors for TOS in construction and individual works are described.

Despite the presence of different classifications of risks of construction projects, note that in each classification there is a group or groups of risks that are associated with TOS and have an impact directly on the construction work (processes) of the construction project.

In the authors' opinion, it would be sufficient to identify the factors that are the most important in the context of the problem under consideration. For example, these could be factors that can be considered risk factors for the non-performance of individual works. They are largely due to the so-called technological and organizational factors, such as the difficulty of performing individual works, the availability of construction materials, the organizational complexity of individual works, the availability of qualified personnel in a given technology, and the availability of necessary equipment, machines, and devices in a given technology.

The implementation of any construction project is multivariate; each construction work (process) can be performed using different construction technologies and organizational solutions. For example, N. Ibadov and J. Kulejewski described an approach for selecting the optimal TOS and determining time and cost using fuzzy decision nodes which is presented in the studies [31–35]. There are studies that have solved the problem of determining time and cost and selecting the optimal technological and organizational solution using fuzzy logic [6, 36–38].

It should also be emphasized that the correct solution of technological and organizational issues, considering properly selected risk factors, determines the level of reliability of both individual works and the entire construction project.

This paper presents a framework for assessing the reliability of the technological and organizational solution by considering the risks that affect each work separately using fuzzy set theory.

2. Framework of fuzzy reliability for technological and organizational solutions

The proposed risk-based TOS assessment framework is based on the fuzzy reliability for machines and mechanisms proposed by Zadeh [39]. The definitions were clarified in view of the specifics of the construction process and network model by the authors.

First, it should be emphasized that in any network model, there is a critical path and a noncritical path. Therefore, the authors propose to separately consider each path (critical and noncritical) and determine the fuzzy reliability for each path by considering the risks for each individual work. The final reliability will be equal to that on the critical path; however, on the other paths, the reliability should be equal to or greater than that on the critical path.

Second, formulate the concepts of parallel and serial system as applied to individual construction activities in the network model when considering each individual path.

Parallel system of separate construction works with each other is the connection of separate construction works with each other that: 1. are performed in the same time; 2. have the same technology (e.g. concrete works); 3. in case of failure to meet the deadline or budget for at least one of them, the total duration and budget of the linked parallel system will not increase.

The fuzzy reliability of the parallel subsystem P_i is represented by the fuzzy number R_i shown in Figure 2, $R_i = (m_i - \alpha_i, m, m_i + \beta_i)$, and $1 \leqslant i \leqslant n$ can be evaluated and is equal to Formula (2.1). The triangular function will be used as a membership function, as it allows modeling a precise number with some degree of uncertainty.

$$P = R_1 \cup R_2 \cup \cdots \cup R_n \tag{2.1}$$

where: $R_1, R_2, \ldots, R_n$ – fuzzy number of the reliability for every elements.

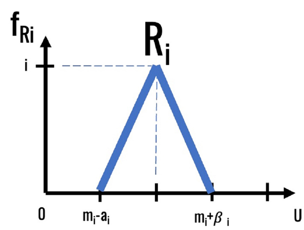

Fig. 2. Membership function of triangular fuzzy number

Series system of individual construction works is the connection of individual construction works with each other, whereby in the event of failure to complete at least one work on time or within the work budget, all other works will not be completed on time and/or within the budget.

The reliability of the parallel subsystem P_i is represented by the fuzzy number R_i shown in Figure 2, $R_i = (m_i - \alpha_i, m, m_i + \beta_i)$, and $1 \leqslant i \leqslant n$ can be evaluated and is equal to Formula (2.2) [39].

$$P = R_1 \cup R_2 \cup \cdots \cup R_n \tag{2.2}$$

where: $R_1, R_2, \ldots, R_n$ – fuzzy number of the reliability for every elements.

Consider the application of these definitions to the construction process example shown in Figure 3.

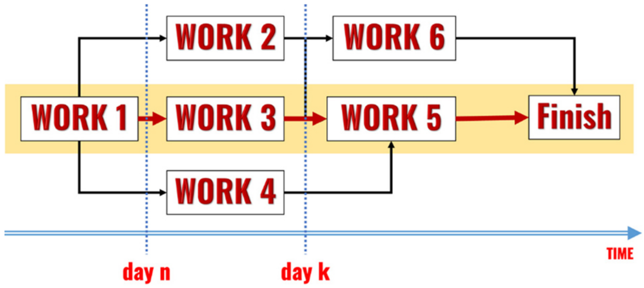

Fig. 3. Configuration of a parallel system

There is a network model, which includes 6 activities (work 1, work 2, work 3, work 4, work 5, work 6). There are 3 paths in the network model: the critical path passes through work 1, work 3, and work 5; the non-critical path #1 passes through work 1, work 2, and work 6; and the non-critical path #2 passes through work 1, work 4, and work 5.

Suppose that work 3 and work 4 are concrete works for constructing concrete columns and walls. These works are performed by two different crews, but they start on day n and finish on day k in a parallel timeline. For example, one of the brigade is sick and will not be able to finish the work on day k, but at the same time, the second brigade in the time interval day n-day k can perform its full amount of work, and the amount of work of the brigade that is sick and work 3 and 4 will be completed on day k without increasing the budget and loss of quality. In this case, work 3 and work 4 can be considered in parallel. In all other cases, it is necessary to consider separately the chain of work 1, work 3, and work 5 and separately the chain of work 1, work 4, and work 5.

As basic rules for determining the fuzzy reliability of the network model based on reliability theory, the authors of this article adopt the following: by the term fuzzy reliability of an individual construction work the probability is the duration and/or cost of this construction work will not exceed the planned one at a given risk level.

The term network model failure will be understood to mean that a failure has occurred in the critical or non-critical path activities that has resulted in an increase in the duration and/or cost of the construction of the facility as a whole.

Under the term failure in a serial system work the authors of this article understand that due to the influence of an internal or external factor on a separate work the duration or value of this work has been forced to increase. In this case, the value by which the duration of the work has increased is greater than the value of the total time reserve for this work.

Let us assume that the network model before optimization and the network model after optimization are two different network models.

The fuzzy reliability of the network model is the fuzzy reliability value for the critical path. This will indicate the fuzzy reliability for other paths within the network model, which may be critical paths if the work starts late, the total stock on the entire critical path is zero when the work starts late, and at least one of the works on this path has a failure during implementation.

The fuzzy reliability of each study can be represented either linguistically or by a real number.

The authors of this article propose to introduce coefficients that allow the estimation of the level of reliability an individual operation or network model is relative to the maximum level of reliability, which can be achieved by an individual operation or network model with minimal impact of risk factors. The reliability coefficient of the network model is the ratio between the actual reliability of the network model at a given level of risk exposure and the maximum reliability that can be achieved by this network model at a minimum risk exposure and is determined by Formula (2.3).

$$k_{\mathrm{TOS}} = \frac{P^{a}_{\mathrm{TOS}}}{P^{p}_{\mathrm{TOS}}} = \left(\frac{(m_i-\alpha_i)^{a}_{\mathrm{TOS}}}{(m_i-\alpha_i)^{p}_{\mathrm{TOS}}};\frac{(m_i)^{a}_{\mathrm{TOS}}}{(m_i)^{p}_{\mathrm{TOS}}};\frac{(m_i+\alpha_i)^{a}_{\mathrm{TOS}}}{(m_i+\alpha_i)^{p}_{\mathrm{TOS}}}\right) \tag{2.3}$$

where: P^{a}_{TOS} – the actual fuzzy level of reliability for network model; P^{p}_{TOS} – the maximal fuzzy level of reliability for network model.

The reliability coefficient of individual work is the ratio between the actual reliability of work at a given level of exposure to risk factors and the maximum reliability that can be achieved by this work at a minimum exposure to risk factors and is determined by Formula (2.4).

$$k_{w} = \frac{P^{a}_{w}}{P^{p}_{w}} = \left(\frac{(m_i-\alpha_i)^{a}_{w}}{(m_i-\alpha_i)^{p}_{w}};\frac{(m_i)^{a}_{w}}{(m_i)^{p}_{w}};\frac{(m_i+\alpha_i)^{a}_{w}}{(m_i+\alpha_i)^{p}_{w}}\right) \tag{2.4}$$

where: P^{a}_{w} – the actual fuzzy level of reliability for the each work; P^{p}_{w} – the maximal fuzzy level of reliability for the each work.

Also, these coefficients will allow to estimate, firstly, what maximum level of reliability can be at the individual work or network model, for example, by increasing its duration and/or cost;

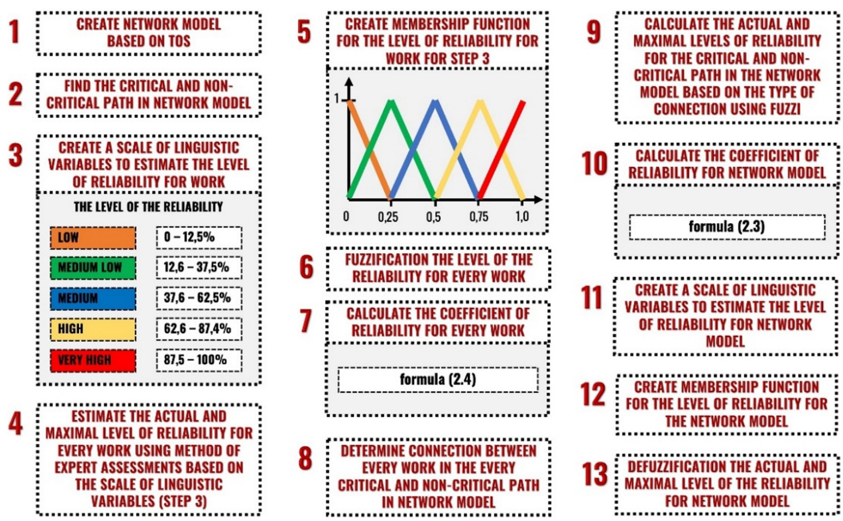

Fig. 4. Algorithm to estimate fuzzy reliability of TOS

secondly, to estimate the actual level of reliability of the work or network model in relation to the maximum possible; thirdly, it gives an understanding of the need to optimize the network model or change the TOS of individual work or the network model as a whole.

On the basis of the definitions described above, an algorithm for determining the fuzzy reliability of the network model based on the fuzzy reliability data of individual construction activities was developed and is presented in Figure 4.

3. Case study

To illustrate the application of the proposed fuzzy reliability tool for estimating TOS of construction projects, we applied this model to a typical construction project as a case study.

To determine the fuzzy reliability of TOS, we propose to consider a fragment of the network model of building erection, which includes 9 interrelated technological works. In this fragment, there is no parallel connection between separate construction works. The network model is presented in Figure 5, and the main parameters are presented in Table 1.

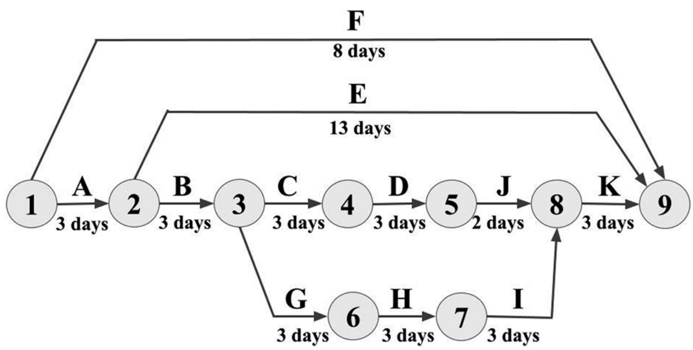

Fig. 5. Network model for case study

Table 1. The sets of works and their predecessors and duration

	Duration	Predecessors	Slack	EST	EFT	LST	LFT
A	3	–	0	0	3	0	3
B	3	A	0	3	6	3	6
C	3	B	0	6	9	7	10
D	3	C	0	9	12	10	13
E	13	A	1	3	16	5	18
F	8	–	9	0	8	10	18
G	3	B	2	6	9	6	9
H	3	G	2	9	12	9	12
I	3	H	2	12	15	12	15
J	2	D	0	12	14	13	15
K	3	J,I	0	15	18	15	18

Define the critical and non-critical paths in this network model and present them as follows in Table 2.

Table 2. Sequence of works for the critical and non-critical paths

Critical path	A-B-C-D-J-K
Non-critical path No1	F
Non-critical path No2	A-F
Non-critical path No3	A-B-G-H-I

Create a scale for reliability levels in the form of a linguistic term and their corresponding probability levels that the work will be completed on time in Table 3.

Table 3. The scale of the level of the reliability for work

Linguistic terms	**Level of reliability**
Low (L)	0–0.125
Medium Low (ML)	0.126–0.375
Medium (M)	0.376–0.625
High (H)	0.626–0.874
Very High (VH)	0.875–1.000

Furthermore, using the method of expert assessment with the involvement of one expert, we determined the actual level of reliability for each construction work taking into account the assumed risks and the maximum possible level of reliability using the assessment scale presented in Table 3. The results of the assessment are presented in Table 4.

Table 4. The results of the estimate for the level of the reliability for every work

Works		**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**
Input data	Actual level of reliability for each work	H	H	ML	L	M	H	L	VH	M	H	H
	Maximum level of reliability for each work	H	H	H	H	H	H	H	VH	H	H	VH
	Type of works (critical or non)	critical	critical	critical	critical	–	–	–	–	–	critical	critical

Carry out fuzzyfication of reliability levels and pass from linguistic variable to fuzzy numbers. The belonging function of the reliability level for individual construction works is presented in Figure 6.

Calculate the fuzzy reliability level of the network model using formula (2.2) for serial system connected individual construction activities for 4 paths (critical and 3 non-critical paths).

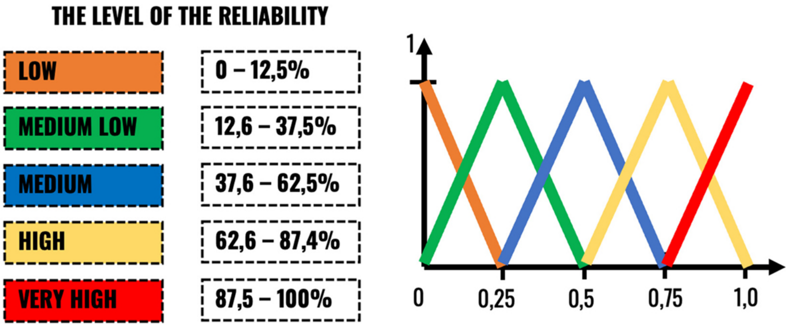

Fig. 6. The membership function for work

Determine the reliability coefficient for each work in the network model and the reliability coefficient of the network model. Defuzzification of the obtained reliability coefficient using the center of mass method and establishment of the probability level of TOS.

Define the membership functions for the output value of the reliability coefficients and for the reliability level of the network model, which are described in Table 5.

Table 5. The membership function for the coefficient of reliability

Linguistic terms	Fuzzy number
Low (L)	(0;0;0.5)
Medium (M)	(0;0.5;1)
High (H)	(0.5;1;1)

4. Results and discussion

The following results were obtained from the calculations using the proposed fuzzy reliability assessment tool TOS, which are presented in Table 6.

Note that the assessment framework makes it possible to see at the stage of expert assessment of the actual and maximum reliability level that there are some works that are located on the critical path and have a low reliability level, although there is a potential to improve the reliability of this work without changing the execution technology. For example, works C and D are critical and could improve reliability according to the expert without changing the TOS of each work. Also apply this principle to non-critical path activities.

The proposed reliability coefficient for each individual work further signals that there are works that can improve reliability without changing their execution technology.

The overall reliability of the proposed TOS is at the LOW level, indicating that the probability of completing the work as planned is low. That is, even at the design stage, the project manager can realize that changes need to be made to the TOS to improve its reliability.

Table 6. The results of calculation

	Works	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**
Input data	Actual level of reliability for each work	H	H	ML	L	M	H	L	VH	M	H	H
	Maximum level of reliability for each work	H	H	H	H	H	H	H	VH	H	H	VH
	Type of works (critical or non)	critical	critical	critical	critical	–	–	–	–	–	critical	critical
Output data	Reliability coefficient for each work	H	H	L	L	–	–	–	–	–	H	H
	Reliability for network model (Critical path)	L										
	Reliability for network model (Non-critical path No 1)	H										
	Reliability for network model (Non-critical path No 2)	H										
	Reliability for network model (Non-critical path No 3)	L										
	Reliability coefficient for network model (Critical path)	L										
	Reliability coefficient for network model (Non-critical path No 1)	H										
	Reliability coefficient for network model (Non-critical path No 2)	H										
	Reliability coefficient for network model (Non-critical path No 3)	L										

5. Conclusion

The long-term use of reliability indicators for technical systems has shown its effectiveness. Many technical systems are improved and enhanced on the basis of the reliability of the system as a whole and its individual elements.

The network model of TOS for building construction can be compared to a complex technical system, where each work is an element of the technical system and failure of any element that is located on the critical path will negatively affect the overall reliability of the system.

The method of technological and organizational solution assessment using fuzzy reliability for construction projects considers the main lacks of previously proposed methods of reliability determination based on classical probability theory and is simple and understandable for application.

This method solves one of the problems faced by project managers of construction projects: it allows estimation of the impact of risk factors on each work and the network model as a whole using linguistic variables.

The proposed reliability coefficients allow estimation of the reliability level of a work or network model relative to the maximum possible reliability level that can be ensured for each specific work. This will allow project managers to evaluate each work and network model from several points of view: first, how close each work and network model in the current version is to the maximum reliability level for the work or network model. If the reliability coefficient for a work or network model is low, this signal the need for optimization of network model.

Second, if the coefficient for a work or network model is at a high level, but the fuzzy reliability of each work or network model is low, this will be a signal that it is necessary to improve the reliability of the work or network model.

The reliability level and reliability coefficients for each work and the network model as a whole allow evaluation of the proposed technological and organizational solution from different sides, which will allow, if necessary, to restructure or optimize the technological and organizational solution by considering the investor's needs.

In the future, it is planned to propose an algorithm for reliability assessment for each individual construction work, to establish dependencies between reliability improvement within the potential and the duration of work production.

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Ocena rozwiązań organizacyjno-technologicznych z wykorzystaniem rozmytej niezawodności

Słowa kluczowe: rozwiązanie technologiczno-organizacyjne, rozmyta niezawodność, oszacowanie ryzyka, wybór robót budowlanych, realizacja budowy

Streszczenie:

Główną ideą artykułu jest przedstawienie narzędzia oceny rozwiązań organizacyjno-technologicznych przedsięwzięcia budowlanego (procesu budowlanego), które opiera się na rozmytej niezawodności zarówno dla każdej pojedynczej roboty budowlanej (czynności) wchodzącej w skład modelu sieciowego, jak i dla całego modelu. Stąd, celem artykułu jest opracowanie narzędzia oceny niezawodności każdej czynności oraz modelu organizacyjno-technologicznego (sieci zależności, harmonogramu) uwzględniającego wpływ ryzyka z wykorzystaniem teorii zbiorów rozmytych. Rozwiązanie organizacyjno-technologiczne najczęściej opisywane (przedstawiane) jest w formie harmonogramu lub modelu sieciowego, który obliczany jest metodą ścieżki krytycznej lub metodą PERT (ang. Program Evaluation Review Technique). Najczęściej czas trwania poszczególnych robót ustalany jest na podstawie przeciętnych wartości, jakie uzyskano podczas realizacji poprzednich przedsięwzięć. Jednocześnie samo rozwiązanie organizacyjno-technologiczne jest często złożone, wielowariantowe i obarczone dużym stopniem niepewności realizacji w założonym przez projekt terminie czy budżecie, ze względu na wpływ różnych czynników na proces. W praktyce menadżer planista ocenia i opisuje różne czynniki zewnętrzne – ryzyka, które mogą mieć wpływ na czas trwania i koszt budowy. Ryzyka charakteryzują się dwoma głównymi parametrami – prawdopodobieństwem ich wystąpienia oraz wpływem tego ryzyka na robotę w momencie jego wystąpienia. Należy podkreślić, że zazwyczaj planista ma trudności w opisaniu tych dwóch parametrów za pomocą oceny ilościowej. Potwierdzają to liczne pracy publikowane w tym zakresie. Aby ułatwić opisywanie niepewności związane z realizacją przedsięwzięcia, w niektórych artykułach proponowane jest wykorzystanie elementów teorii zbiorów rozmytych. Także niektórzy autorzy, proponują wprowadzić ocenę rozwiązań organizacyjno-technologicznych biorąc pod uwagę klasyczną niezawodność z uwzględnieniem zewnętrznych czynników ryzyka. Wobec powyższych, w niniejszym artykule autorzy proponują koncepcję łączącą zalety dwóch wcześniej opisanych podejść: koncepcję rozmytej niezawodności modelu sieciowego, która opiera się na klasycznej teorii niezawodności i teorii zbiorów rozmytych. Warto zaznaczyć, że przez rozmytą niezawodność modelu sieciowego rozumie się prawdopodobieństwo, że czas i/lub koszt budowy przy zastosowaniu danego modelu sieciowego nie przekroczy obliczonego czasu trwania i/lub kosztu budowy, a przez rozmytą niezawodność poszczególnych robót rozumie się prawdopodobieństwo, że czas trwania i/lub koszt nie przekroczy obliczonej wartości dla

ustalonego poziomu ryzyka. Z kolei przez awarię elementu (roboty) modelu sieciowego rozumie się, że w skutek wpływu czynnika wewnętrznego lub zewnętrznego na robotę, czas trwania lub koszt tej roboty przymusowo zostanie zwiększony. W tym przypadku wartość, o którą wzrósł czas trwania roboty, jest większa niż wartość całkowitego zapasu czasu. Za zadania równoległe w modelu sieciowym uważa się zadania, które występują równolegle w czasie, co oznacza, że awaria któregokolwiek zadania w połączeniu równoległym nie wydłuża czasu trwania zarówno pojedynczych robót jak i ich całości. Za zadania sekwencyjne uważa się zadania, które następują po sobie na osi czasu i jeśli awaria lub opóźnienie w jednym zadaniu przekroczy wartość całkowitej rezerwy czasu dla tego zadania, to model sieciowy ulegnie tzw. awarii. Zakładano także, że model sieci przed optymalizacją i model sieci po optymalizacji to dwa różne modele sieciowe. Rozmyta niezawodność każdej roboty można opisać zarówno lingwistycznie jak i tzw. ostrą liczbą. W artykule autorzy proponują wprowadzenie pojęć współczynnika niezawodności sieci zależności oraz współczynnika niezawodności roboty. Współczynniki te umożliwiają ocenę poziomu niezawodności roboty lub modelu sieciowego w stosunku do maksymalnego poziomu niezawodności, jaki model sieciowy może osiągnąć przy minimalnym narażeniu na czynniki ryzyka. Algorytm wyznaczania rozmytej niezawodności modelu sieciowego to sekwencja kroków od oceny rozmytej niezawodności każdej pojedynczej czynności do oceny ogólnej rozmytej niezawodności rozwiązania organizacyjno-technologicznego z uwzględnieniem poszczególnych czynności. Artykuł zawiera także przykład obliczeniowy z wykorzystaniem zaproponowanego algorytmu. Należy zauważyć, że w wyniku obliczeń przeprowadzonych za pomocą zaproponowanego algorytmu w celu wyznaczenia rozmytej niezawodności modelu sieciowego oraz współczynników niezawodności dla każdego pojedynczego zadania i modelu sieciowego. Uzyskane wyniki dla dwóch wariantów z wykorzystaniem liczby rzeczywistej (ostrej) i terminów lingwistycznych są zgodne. Dodatkowo, sprawdzając uzyskane wyniki rozmytej niezawodności modelu sieciowego dla liczby rzeczywistej przy zastosowaniu klasycznej teorii niezawodności, uzyskano wynik, który numerycznie pokrywa się z wynikiem uzyskanym przy zastosowaniu teorii rozmytej niezawodności.

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