Construction projects planning using network model with the fuzzy decision node

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Abstract

In the construction practice, at the stage of planning of a construction project, planners are trying to take into account the possibility of unfavorable situations and their consequences during the project execution. Therefore, planning decisions should use appropriate tools for uncertainty modeling as well as consider alternative options for the implementation of the entire undertaking or the most sensitive (critical) works. Taking into account the fact that the management and planning of construction projects is carried out in conditions of non-stochastic uncertainty, the authors propose to create an alternative model with a fuzzy decision node based on classical network models. This approach allows to model activities that are alternative to each other. An important methodological element is the fuzzy assessment of the considered alternatives with the use of fuzzy set theory. The proposed alternative network model with a fuzzy decision node gives the possibility to conduct a comprehensive analysis with the possibility of taking into account and modeling the uncertainty of input data in an easy way. The numerical example shows the possibility of quick selection of the best variant based on the adopted assessment criteria and allows to serialize work variants, which gives additional information in the alternative activities of the network model in the form of preferences. The combination of a decision model in the form of a decision node with a network model can be useful in both strategic and tactical planning of the implementation of construction projects.

Keywords Fuzzy decision node · Fuzzy preferences relation · Planning of construction projects · Network analysis · Non-dominated alternative

Introduction

Planning is a very important function in the management of a construction project. The planning process begins before the approval of the scope of works and continues during the execution of the project and implementation of change orders. This means that the decisions made at the planning level are of fundamental importance in the further stages of the project.

The main goal of planning construction projects is to build a certain model of the project's course. Usually these are network models and schedules. A large number of articles on this topic have already been published, presenting attempts to

streamline the classic network models and scheduling using different approaches (Bendotti et al. 2017; Ibadov 2018a; Połowski and Pruszyński 2013; Radziszewska-Zielina et al. 2017; Rostami et al. 2018). It should be emphasized that in the various approaches listed above, the use of elements of the fuzzy sets theory created by Zadeh (1999) prevails. Application of this theory to solve problems in Civil Engineering is becoming wider (Uğur and Baykan 2016).

Noteworthy is also the study by Chanas and Zieliński (2001), Soltani and Haji (2007), Elizabeth and Sujatha (2013) and Narayanamoorthy and Maheswari (2017), who used the fuzzy set theory for network analysis. Mazlum and Güneri (2015) used fuzzy logic along with the critical path method (CPM) and Project Evaluation and Review Technique (PERT).

Other authors, in order to create an efficient schedule, try to determine the risk factors affecting the characteristic time–cost parameters (Skorupka 2008; Jaśkowski and Biruk 2010; Juszczyk 2014; Anysz and Buczkowski 2018; Leśniak et al. 2018).

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It should be emphasized that planning and scheduling are carried out under uncertain conditions, which numerous authors try to model in different ways (Kulejewski 2010b; Huang et al. 2013; Dolabi et al. 2014; Khalilzadeh et al. 2017; Rosłon 2017; Francis 2017; Roghanian et al. 2018). Also noteworthy is the proposal by Masmoudi and Haït (2013), who presented the technique of modeling uncertainty along with solving the process of the fuzzy/possibilistic approach. Plebankiewicz and Karcińska (2016) proposed methods of building schedules based on fuzzy values of the productivity of work teams. The proposed procedure allows to determine the actual date of the project implementation taking into account the variable factors affecting the duration of individual construction works. Castro-Lacouture et al. (2009) analyzed the implementation of the schedule when time, costs and resources were limited. Each of the models presented above supports planning decisions in construction projects with uncertain conditions of implementation. However, traditional CPM and PERT methods are still popular in the practice of planning (Aguei 2015; Yamín and Harmelink 2011; Zareei 2018).

It should be emphasized that the use of traditional network models (CPM and PERT) in planning complex projects, which are undoubtedly construction projects, does not give the opportunity to analyze alternative solutions in the field of technology and organization of selected or all works to be carried out. Meanwhile, rational planning of a construction project requires consideration of alternative variants of the implementation of each work (or the most “sensitive” works) in the project and making the right choice from a set of possible alternative variants. This choice is usually made on the basis of evaluation based on the multi-criteria analysis (Bangian et al. 2012; Chernov et al. 2012; Ibadov and Rosłon 2015). The evaluation criteria should refer to the essential features of a given project in a given decision situation (Ibadov 2017; Afsordegan et al. 2016; Vaagen et al. 2017; Narayanamoorthy and Maheswari 2017). This means that in the planning process we also have to deal with the decision-making process, which most broadly concerns: the entity, subject, period, elements and characteristics of the plan. It is important here to determine the conditions (environment) of making decisions. The authors are convinced that due to the complex structure of construction projects and the uniqueness of the implementation conditions, decision making is carried out under conditions of non-stochastic uncertainty. This is due to the fact that the possibility of occurring unfavorable situations during the construction project and its consequences should not be described in the concepts of probability theory, because this approach implicitly assumes knowledge of the distribution of probabilities of interfering factors. However, from a practical point of view, in the implementation of construction projects the probability distribution of any hypothetical event, as a rule, cannot be determined.

Taking into account the issues discussed above, we can conclude that the planning tool must ensure: (1) the possibility of modeling alternative works; (2) the ability to apply an appropriate decision model, taking into account the conditions for making decisions and selecting appropriate alternatives; (3) the possibility of analyzing the entire network model including alternative, mutually independent works.

For this reason, the authors propose to create, on the basis of classical network models, an alternative model with a fuzzy decision node. This approach will allow to model activities which are alternatively with each other. The decision-making node will enable the planner to choose the most appropriate variant in the given circumstances (decision situations) and to conduct the analysis of the network model.

In the decision-making node of the network model, the authors suggest making a multi-criteria choice of alternatives based on fuzzy relation of preferences.

Materials and methods

From a methodological point of view, this article deals with the modification of planning methods for construction projects using network models. The proposed modification takes into account the possibility of a variant (alternative) execution of works in the network model and presents a method of choosing alternatives in the decision nodes applied in the network. For this purpose, elements of the decision-making theory (multi-criteria decision making), the fuzzy sets theory and network planning methods are used.

Alternative options for both works and the entire project are evident both in the pre-investment phase as well as in the preparation phase and in the execution phase of the project. Multi-variant solutions to any problem at any planning level make it necessary to make the right decisions regarding the selection of the most suitable variant to the decision-making conditions. In turn, this causes the necessity to develop a planning tool that would include the above-mentioned planning aspects.

Below, an important theoretical basis of planning was considered, taking into account the multi-variant tasks.

Planning of construction projects: basic concepts

In construction practice, planning is understood as defining the goal of the project and ways to achieve it within the set time and cost. This means that during planning there is developed a certain model of achieving the project's objective(s), based on the real possibilities and resources available at the time the decision is made. The main project parameters are determined in the planning process, such as

scope of work, demand for resources, duration of works, costs of works and technological and organizational relationships between works.

All project plan parameters are interrelated. For example, the amount of work determines the need for material, labor and financial resources. In turn, the accepted (selected) technology of construction works determines their duration, delivery time of various materials, the number and time of involved contractors, etc. The plan with appropriate (possible at a given planning stage) accuracy should take into account the impact of many factors, constraints and conditions of the project, including uncertain and random impact factors.

Planning takes place in accordance with established hierarchical management levels, according to which three levels of planning and systems of general, strategic and tactical project plans are created. The general plan is a conceptual plan, reflecting the place and objectives of the project in the general spatial development plan of the district, the city. When developing a general (conceptual) plan based on the analysis of the location (territory), condition of the real estate market and the economic condition as a whole, the overall scope (content) of the project is defined: goals, possible alternative options to achieve the goal, main directions of the project implementation (thematic areas), integrated structure of works, preliminary estimation of the duration and cost of the project). The general plan is the basis for planning at the second level—the development of a strategic plan.

A strategic plan is a long-term plan covering the whole life cycle of the project, which breaks the project's goals into meaningful and technologically full stages. This is the level of the life cycle of a separate project in which key stages, subprojects and milestones are analyzed, as well as for each stage the terms and conditions for the preparation of works fronts, their commencement and completion, delivery time of equipment and cash flows for particular periods of work.

A tactical plan is a short-term plan developed for up to 1 year. Tactical plans are diverse and numerous and include work plans of individual project participants, types of works, stages of the project's life cycle, etc. The tactical plans include: current plans, in which activities of individual project participants of responsible contractors are planned; operational plans, in which tasks based on current plans are specified for a month, a decade or a week; summary plans, in which all work related to the project of the planned year is coordinated; detailed plans of stages and types of works developed during the month or year.

In the planning of construction projects, for the creation and modeling of their scope, structure, organizational and technological dependencies and work sequences, the most common methods are network planning and scheduling. Network planning is a collection of methods for modeling

and graphic imaging of project works and the relationships between them.

In modern management of a construction project, planning becomes a continuous function that covers all stages of the project's life cycle. The development of project plans is synchronous with the phases of the project's life cycle.

Planning of a construction project is almost always a repetitive activity. All planning processes can be repeated, and plan parameters can be improved and changed several times throughout the entire life cycle (repetitive analysis of resources, costs, time, expert decision making, selection of a better variant, etc.). It should be emphasized that as a result of changing the conditions of implementation (both internal and external), it is necessary to review and check the plan each time, whether the decisions made and the chosen methods of implementation are appropriate.

This means that planning requires a planning tool that will allow to make the right decisions as well as to consider and select alternative solutions (variants). The most sensitive changes are the technological changes in the performance of particular types of works, as they affect the resource, cost and time, as well as the organization and preparation of work fronts for both the works under consideration and the following works. Therefore, in the technological and organizational design of building construction, its multi-variant character should be taken into account. The main factors determining multivariate construction production are: structural characteristics of the building or its part; space planning and building design characteristics; technology for the implementation of particular types of work; duration of works; sequential execution of works; restrictions on the dates of commencement and completion of individual works as well as the set of works in full, etc.; the level of connection possibilities for construction and installation works, etc.; used mechanization means with different power, with different composition and quantity; climatic and other conditions for the execution of works. Therefore, the execution of each specific structure can be organized in accordance with schemes that provide for a different division of labor between individual flows, which determine different durations and intensity of works. The necessity of taking into account and analyzing various mutually interchangeable variants requires further improvement of organizational and technological models—both schedules and network models. This means that in order to improve the organization and technology of construction of any construction, it is necessary to use such network models that will have expanded topological capabilities, capable of imaging and describing a set of different methods of construction execution and technological variants of performing some (selected) types of works. On the other hand, the multi-variant feature imposes also making decisions regarding the selection or arrangement of alternative variants, taking into account planning data.

Additionally, taking into account the fact that practically management and planning of construction projects is carried out in conditions of uncertainty, the authors suggest an alternative network model with a fuzzy decision node.

An alternative network model with a fuzzy decision node

Traditional network models (CPM and PERT) do not allow for the consideration of alternative solutions. In these networks, each activity must be completely completed in order for the task to be completed. The network model proposed in this article allows to model independent and alternative activities. An alternative network model with a fuzzy decision node is an acyclic multi-graph, where some (or selected) nodes (events) are linked to multiple (multi) arrows that correspond to the various alternatives of the works (Ibadov 2018b). On the basis of the fuzzy decision node applied in the network, the level of favors of alternative works is determined, taking into account the relevant characteristics of the undertaking. This approach is very helpful when it is expected that the implementation of works may change in relation to the plan. The update boils down to choosing a different previously predicted path leading to the goal. Figure 1 shows a conceptual network model with a fuzzy decision node.

Let $G = (X, A, S, W_d)$ be an acyclic multi-graph as an alternative network model, having a set of vertices $X = \{1, 2, \dots, k\}$ —named events, a set of oriented arches modeling all alternative variants of works $A = \{a_1, \dots, a_i, \dots, a_n\}$, a set of oriented arches modeling all individual works $S = \{s_1, \dots, s_i, \dots, s_u\}$ and a set of decision nodes $W_d = \{1, 2, \dots, m\}$ allowing—based on a specific decision model—to choose the most preferred variant of works. It should be emphasized that if there is only

one variant of the work, the decision node is deleted. A preference level $\mu \in [0, 1]$ of a work (i, j) in r alternatives is determined on the basis of the developed decision model. The appearance of the decision node in the network model announces the emergence of a set of possible alternative paths (works). After selecting the most preferred way, further network calculations are carried out in a traditional way (e.g., as in the CPM). An important methodological element proposed by the authors is the application in the decision-making node of a multi-criteria choice of alternatives on the basis of a fuzzy relationship of preferences, where the preferences of particular paths (work variants) are determined by calculating non-dominance levels (μ^{nd}) of individual alternatives.

Theoretical basics of the multi-criteria choice of alternatives based on fuzzy relations of preferences

This part of the article presents a method of making decisions, which consists in building a set of non-dominated alternatives based on fuzzy relation of preferences. The problem statement in a short form is as follows. Let A be a set of alternative works, which are characterized by several criteria (both qualitative and quantitative) with index numbers $j = 1, \dots, n$. Information on pairwise comparison for each criterion is presented in the form of preference relation R_j . Therefore, there are n preference relations R_j on set A . There is a need to choose the best alternative from the set $\{A, R_1, \dots, R_m\}$. This is based on the following propositions:

Proposition 1 The fuzzy relation of preferences on the set A is any reflexive fuzzy relation defined on this set, whose membership function is calculated as follows:

$$\mu_{R^s}(a, b) = \begin{cases} \mu_R(a, b) - \mu_R(b, a) & \text{if } \mu_R(a, b) \geq \mu_R(b, a) \\ 0 & \text{if } \mu_R(a, b) \leq \mu_R(b, a) \end{cases} \quad (1)$$

Proposition 2 Let A be a set of alternatives and let μ_R be a relation of preferences given on a set A . A fuzzy subset of non-dominated alternatives of a set $\{A, \mu_R\}$ is described by the membership function:

$$\mu_R^{nd}(a) = 1 - \sup_{b \in A} (\mu_R(b, a) - \mu_R(a, b)), \quad a \in A \quad (2)$$

where μ_R^{nd} is a degree of non-dominance of an alternative a .

It should be emphasized that when $\mu_R^{nd}(a) = 1$, the alternative a is strongly non-dominated.

Fig. 1 An exemplary network model with a fuzzy decision node

The procedure for choosing and determining the degree of non-domination is presented on a numerical example.

Results and discussion

Numerical example

The example concerns the planning of the project modeled as in Fig. 2.

It is foreseen that the planned way of execution of a work a may change as a result of the occurrence of new management circumstances and there are three variants of the execution of this work: a_1, a_2 and a_3 . Then, according to the proposed method, the network model in Fig. 2 takes the shape as shown in Fig. 3.

It is important to determine the appropriate selection criteria that best reflect the requirements of a given decision situation and, at the same time, the characteristics of a given technology. This will enable a comparative analysis (evaluation) of alternative technological solutions and a selection of the most optimal variant of the execution of works.

In practice, it is usually limited to time and cost evaluation. In this respect, the optimal technological solution is characterized by the most favorable cost and/or implementation time ratio. Meanwhile, technological processes usually have a structure of varying complexity. This complexity requires a proper front for their execution of specialized work brigades, equipped with appropriate equipment. The degree of technological and organizational complexity may cause additional disruptive factors in the scope of work synchronization of particular specialties, impede the smooth organization of works, etc. This fact may result in the extension of the planned implementation times of individual works and increase in production costs. Therefore, from the point of view of the authors, it is reasonable to include additional criteria in addition to temporarily cost characteristics of the considered technologies, taking into account the priorities of a given decision situation as much as possible. It may be a generally defined criterion of technological and organizational complexity in the scope of which, depending on the decision-making situation, purely technical and market aspects should be taken into account, namely: the degree of difficulty in performing a given technology,

Fig. 2 A network model of an exemplary project

Fig. 3 A network model with a fuzzy decision node

availability of materials used in a given technology, availability of qualified specialists in the field selected technology, availability of necessary machines and devices in a given technology, degree of difficulty in organizing works in a given technology; the impact of the following works on preparatory works of the following works, etc. However, for clarity, three assessment criteria are considered here: k_1 —duration (workday); k_2 —direct costs (1000 PLN per unit of work), and k_3 —technological and organizational complexity.

The set of alternative works is marked as $A = \{a_i\}$, where $i = 1, \dots, n$, while the set of criteria is marked as $K = \{k_k\}$, where $k = 1, \dots, 3$. Table 1 presents the data of individual variants against the evaluation criteria. Criterion k_3 —technological and organizational complexity—is presented on a scale from 0 to 5, where the difficulty of implementation increases with increasing value.

The information about the alternatives compared to each criterion k_k is presented in the form of a fuzzy relation of preferences R_k . As the result, m preference relations R_k on set A are obtained. The following describes how to choose the best alternative from the set $\{A, R_k\}$.

The membership functions of alternative works for each criterion are described by Eq. (3):

$$\begin{aligned}\mu_{k_1} &= 0.25/15 + 0.25/15 + 0.1/18; \\ \mu_{k_2} &= 0.9/18 + 1.0/15 + 1.0/15; \\ \mu_{k_3} &= 0.9/2 + 1.0/1 + 0.1/5\end{aligned}\quad (3)$$

Using these data, matrixes of fuzzy relations of preferences $R_1, \dots, R_3$ are created according to Eq. (1).

The matrix of fuzzy relations R_k is as follows:

Table 1 The data of individual variants

Evaluation criteria K	Alternative works A		
	a_1	a_2	a_3
k_1 [workday]	15	15	18
k_2 [th.PLN/work]	18	15	15
k_3 [0–5]	2	1	5

$$R_k = \begin{pmatrix} \mu_R(a_1, a_1) & \mu_R(a_1, a_2) & \cdots & \mu_R(a_1, a_n) \\ \mu_R(a_2, a_1) & \mu_R(a_2, a_2) & \cdots & \mu_R(a_2, a_n) \\ \cdots & \cdots & \cdots & \cdots \\ \mu_R(a_n, a_1) & \mu_R(a_n, a_2) & \cdots & \mu_R(a_n, a_n) \end{pmatrix} \quad (4)$$

Therefore, the relations for the individual criteria are as follows:

$$\mu_{R_1} = \begin{pmatrix} 1 & 0 & 0.15 \\ 0 & 1 & 0.15 \\ 0 & 0 & 1 \end{pmatrix}; \quad \mu_{R_2} = \begin{pmatrix} 1 & 0 & 0 \\ 0.1 & 1 & 0 \\ 0.1 & 0 & 1 \end{pmatrix}; \quad \mu_{R_3} = \begin{pmatrix} 1 & 0 & 0.8 \\ 0.1 & 1 & 0.9 \\ 0 & 0 & 1 \end{pmatrix} \quad (5)$$

Then, the intersection of all fuzzy relations $P_1 = R_1 \cap \cdots \cap R_3$ is determined, where P_1 is a $n \times n$ matrix, which individual elements $\mu_{P_1}(a_i, a_j)$ are defined by Eq. (6):

$$\mu_{P_1}(a_i, a_j) = \min_k \mu_{R_k}(a_i, a_j), \quad k = 1, \dots, 3 \quad (6)$$

Hence, $\mu_{P_1}(a_i, a_j)$ is:

$$\mu_{P_1}(a_i, a_j) = \begin{matrix} & a_1 & a_2 & a_3 \\ a_1 & 1 & 0 & 0 \\ a_2 & 0 & 1 & 0 \\ a_3 & 0 & 0 & 1 \end{matrix} \quad (7)$$

Then, a subset of non-dominated alternatives a_i in a set $\{A, \mu_{P_1}\}$ is determined for every i and $j (i \neq j)$:

$$\mu_{P_1}^{nd}(a_i) = 1 - \sup_{a_j \in A} (\mu_{P_1}(a_j, a_i) - \mu_{P_1}(a_i, a_j)) \quad (8)$$

The calculated degrees of non-dominance of each alternative are as follows:

$$\begin{aligned} \mu_{P_1}^{nd}(a_1) &= 1 - \sup[(0 - 0), (0 - 0)] = 1 \\ \mu_{P_1}^{nd}(a_2) &= 1 - \sup[(0 - 0), (0 - 0)] = 1 \\ \mu_{P_1}^{nd}(a_3) &= 1 - \sup[(0 - 0), (0 - 0)] = 1 \end{aligned} \quad (9)$$

The calculated values of a subset of the non-dominated alternatives are:

$$\mu_{P_1}^{nd} = \begin{bmatrix} 1 & 1 & 1 & 1 \end{bmatrix} \quad (10)$$

In the next step, validity coefficients w_k are assigned to every criterion k_k , fulfilling the condition:

$$\sum_{k=1}^m w_k = 1, \quad w_k \geq 0 \quad (11)$$

It is assumed in the example that $w_1 = w_2 = w_3$; therefore, $w_i = 1/3$.

Then, taking into account the validity of individual criteria k_k , a $n \times n$ matrix of fuzzy relationship P_2 is created. The elements of this matrix are defined by Eq. (12):

$$\mu_{P_2}(a_i, a_j) = \sum_{k=1}^3 w_k \mu_{R_k}(a_i, a_j) = \frac{1}{3}(\mu_1(a_i, a_j) + \mu_2(a_i, a_j) + \mu_3(a_i, a_j)) \quad (12)$$

Hence,

$$\begin{aligned} \mu_{P_2}(a_1, a_1) &= \frac{1}{3}(1 + 1 + 1) = 1 \\ \mu_{P_2}(a_1, a_2) &= \frac{1}{3}(0 + 0 + 0) = 0 \\ \mu_{P_2}(a_1, a_3) &= \frac{1}{3}(0.15 + 0 + 0.8) = 0.32 \end{aligned} \quad (13)$$

$$\begin{aligned} \mu_{P_2}(a_2, a_1) &= \frac{1}{3}(0 + 0.1 + 0.1) = 0.07 \\ \mu_{P_2}(a_2, a_2) &= \frac{1}{3}(1 + 1 + 1) = 1 \\ \mu_{P_2}(a_2, a_3) &= \frac{1}{3}(0.15 + 0 + 0.9) = 0.35 \end{aligned} \quad (14)$$

$$\begin{aligned} \mu_{P_2}(a_3, a_1) &= \frac{1}{3}(0 + 0.1 + 0) = 0.03 \\ \mu_{P_2}(a_3, a_2) &= \frac{1}{3}(0 + 0 + 0) = 0 \\ \mu_{P_2}(a_3, a_3) &= \frac{1}{3}(1 + 1 + 1) = 1 \end{aligned} \quad (15)$$

Therefore, $\mu_{P_2}(a_i, a_j)$ is:

$$\mu_{P_2}(a_i, a_j) = \begin{matrix} & a_1 & a_2 & a_3 \\ a_1 & 1 & 0 & 0.32 \\ a_2 & 0.07 & 1 & 0.35 \\ a_3 & 0.03 & 0 & 1 \end{matrix} \quad (16)$$

Then, a subset of non-dominated alternatives a_i in the set $\{A, \mu_{P_2}\}$ is determined for every i and $j (i \neq j)$:

$$\mu_{P_2}^{nd}(a_i) = 1 - \sup_{a_j \in A} (\mu_{P_2}(a_j, a_i) - \mu_{P_2}(a_i, a_j)) \quad (17)$$

The calculated degrees of non-dominance of each alternative are as follows:

$$\begin{aligned} \mu_{P_2}^{nd}(a_1) &= 1 - \sup((0.07 - 0), (0.03 - 0.32)) = 0.93 \\ \mu_{P_2}^{nd}(a_2) &= 1 - \sup((0 - 0.07), (0 - 0.35)) = 1 \\ \mu_{P_2}^{nd}(a_3) &= 1 - \sup((0.32 - 0.03), (0.35 - 0)) = 0.65 \end{aligned} \quad (18)$$

Hence,

$$\mu_{P_2}^{nd}(a_i) = \begin{bmatrix} 0.93 & 1 & 0.65 \end{bmatrix} \quad (19)$$

The resulting set of non-dominated alternatives is the intersection of sets $\mu_{P_1}^{nd}$ and $\mu_{P_2}^{nd}$:

$$\mu_{p_1}^{nd} \cap \mu_{p_2}^{nd} = \{(1 \ 1 \ 1) \cap (0.93 \ 1 \ 0.65)\} = \{(0.93 \ 1 \ 0.65)\} \quad (20)$$

Conclusion: The choice of the alternative a_2 , which has the maximum degree of non-domination μ^{nd} , should be considered rational, next a_1 and then a_3 .

Calculated individual degrees of preferences (degrees of non-dominance μ^{nd}) are entered into the network. This shows which path in the network is more preferred, according to the planning conditions. The rest of the network is solved in the traditional way, not presented in this paper. However, it should be underlined that it is important in analyzing this type of network whether an alternative path coincides with the critical path or not, and—if not—how does it affect other non-critical activities. The chosen alternative path may affect, in plus and in minus, the time and cost of the project (also the length of the critical path). Therefore, the degrees of subcriticality of non-critical paths should be considered.

A possible drawback of the proposed method seems to be the duplication of alternative paths in the network by introducing alternative works. This requires analyzing as many network models as there are alternative options. This means that the scope of calculations needed for network analysis increases. However, the introduction of a fuzzy decision node into the network model immediately after the alternative works and the proposed decision-making model (fuzzy relation of preferences) allow to obtain additional information about the non-domination of alternative works and solve the network model for the preferred network structure (in the context of the above-mentioned numerical example, the network model that contains the a_2 activity). It should be emphasized that from a practical point of view, such an analysis should be carried out in the planning of a construction project so that it can be reasonably concluded that the adopted technical and technological solution is rational and reflects the decision-making situation in which the company operates. As a result of changing the broadly defined conditions of implementation, these decisions are made separately and then the network model is updated. Therefore, the combination of the decision model (in the form of a decision node) with the network allows to conduct a comprehensive analysis, to learn about the variability spread of significant characteristics of alternative models and to manage and plan better with a single model. And this, in the authors' opinion, is the most important advantage of the approach proposed in this article. As it results from the numerical example, the mathematical tool proposed in the article (fuzzy relation of preferences) for decision making in decision-making nodes better describes the formal aspect of the multi-criteria decision-making model than the traditional approach and gives the possibility of easy and quick decision making based upon simple calculations.

Conclusion

The proposed alternative network model with a fuzzy decision node allows to model selected (or all) activities alternative to each other. This approach gives the opportunity to analyze several variants of the selected works in terms of the relevant characteristics of the construction project and the conditions for implementation. This is important for the practical planning of construction projects.

The decision node applied in the network model together with the proposed decision model allows for conducting a comprehensive analysis of the network model with the possibility of taking into account the multi-variant works and making a choice in one planning model.

The decision-making model used in the fuzzy decision-making node is based on fuzzy relations and scheduling of works by determining the degree of non-dominating of alternatives. This allows for an easy way to make a selection taking into account the relevant existing or forecasted conditions of implementation and to adapt the network model to the planning conditions.

The authors are aware that the inclusion of alternative variants in one network increases the computational complexity of the network, but practically speaking, additional information on activities in the form of preference level obtained from the decision node indicates which network variant to solve first.

In this paper, the authors confined themselves to the presentation of the conceptual network model and its importance in planning construction projects together with a detailed development of the selection model. In future, the authors plan to apply the concepts in various network models together with their detailed analysis taking into account the issues raised in the previous point and the development of the suitable computer software.

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