WARSAW UNIVERSITY OF TECHNOLOGY Index 351733 | DOI: 10.24425/ace.2021.137163
FACULTY OF CIVIL ENGINEERING
COMMITTEE FOR CIVIL AND WATER ENGINEERING
ARCHIVES OF CIVIL ENGINEERING
POLISH ACADEMY OF SCIENCES ISSN 1230-2945 | Vol. LXVII ISSUE 2 2021
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s. 195–208

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Research paper

Decision making in choosing a network organizational structure in integrated construction projects

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Abstract: Recent research has shown that the increase in a number of participants of construction project elevated the cost and duration of construction. The use of integrated project delivery and the formation of a network organization structure can significantly reduce the costs, as the activities of the participants become more coherent and coordinated. The optimization of decisions is essential for the efficiency of a negotiation process, which in turn depends on the organizational structure. The article specifies three basic types of network organizational structure that can be applied in a construction project: focal (F1), dynamic (F2), multifocal (F3). In this study, a direct assessment of possible effectiveness of each of the three types of network organizational structures was carried out using a vector decision model. For each of the above-mentioned types of organizational structures, the potential effectiveness of negotiating act f0 and the total potential effectiveness F0 was calculated. The results of the study show that the most effective type of network organizational structure is the multifocal collective decisions in which a project manager has several "assistants".

Keywords: network organizational structure, integration, network, construction project

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1. Introduction

Carrying out construction projects in modern conditions is connected with a number of difficulties. Some of them are related to solving problems of resource and time planning [1, 2]. During an implementation of a construction project, the attention is focused on a resource organization and monitoring the implementation of tasks, any deviations from the plan and on corrective influence that can be taken. Other difficulties arise from an increase in the complexity of construction projects and a growth in the number of participants. From the very beginning of a project implementation (project development, pre-draft phase) the entire planning (design) is carried out by a team that involves not only an architect and a structural engineer, but also consultants in areas of construction management, MEP engineering, energy technology, building physics, acoustics, facade construction and, depending on the type of project, other specialists [3]. As a result, inadequate assimilation between design and construction phases affects project results. At the same time, social aspects such as communication and interdisciplinary interactions have become key success factors in implementing construction projects [4]. A large number of project participants forces to optimize a cooperation between them. Communication problems lead to segmentation of the construction process into phases, many changes and additional rework costs. This in turn, results in an increase in project duration and overall costs. Design and construction should move towards better coordination between project participants and more collaborative approaches [5]. In conditions of limited resources and time, successful project management often depends on the effectiveness of communication between members of a project team [6]. In the past, most communications in projects were through meetings, phone calls or written correspondence. Modern information technologies have fundamentally changed the methods and means of communication between project team members. Information Technology (IT) and Information Communication Technology (ICT) have been developing rapidly to cater for the rising complexity of diverse projects [7, 8]. The widespread introduction of Building Information Modeling (BIM) can be a breakthrough innovation that will revolutionize the construction industry. In addition to the benefits of improved planning and early recognition of errors and collisions, BIM can also significantly improve the quality of project management in general, and the level of communication in particular.

Information integration is one of the main types of integration and is the foundation of an information management system. Recent advances made in the field of ICT greatly facilitate informational integration, which is extremely limited in capability and is not functional beside organizational structure. The transition to modern management methods in construction is very closely connected to network organizational structures [9].

The article aims at analyzing three potentially possible network organizational structures and the choice of the optimal one in an integrated project delivery. The criterion of optimality represents the maximum effectiveness of using information links between project participants.

2. Literature review

Information integration and the prospects for using information modeling in construction are the subject of many studies [10, 11, 12]. For instance, Hlaoittinun et al. [13] studied the development of a new team building method, which was based on competency modelling in the field of project management. Meanwhile, Deng and Zhou [14] reviewed project stakeholder network mapped based on stakeholder theory and features of construction projects in China. Another research analyzed information and communication technologies that provide construction firms with new opportunities for enhancing communication, collaboration and information management processes [15]. The concept of a collaborative teamwork came to change conventional way that projects are managed in order to reach more competitive industries.

It is also necessary to highlight the recently popular area of interaction in construction - Integrated Project Delivery (IPD). Important features of the IPD are: early involvement of key stakeholders, common development and implementation of the project goal, one contract that unites key participants, cooperation in decision making, common responsibility of key participants, and finally, common participation in risks and profits. This approach relies on the collaboration of a multidisciplinary management team whose members make decisions together, based on a coherent perception of the project and a diverse view of problems [16].

Research on the possibilities of using networks in construction is diverse. One of first articles was devoted to communication problems between the main participants in the project implementation (client, project managers, architect and contractor) [17]. Pryke defined construction project as a network of organizations bounded by flows of information exchange and communicational networks of relationships [18] Madani et al. used network analysis to study intelligent buildings to find the most effective technologies and new innovative opportunities [19].[The work by Abbsaian-Hosseini et al. studied the relation between degree centrality and performance in the implementation of joint works construction brigades [20].

Many authors have lately used Social Network Analysis (SNA) to analyze construction projects networks. Chinowski and Songer analyzed the networks existing in construction projects and noticed that there are social and information relations between project participants [21]. The authors argue that successful teams demonstrate a high level of communication between team members and a high cooperation degree. Pryke sees a construction project as a relationships network and proposes that a construction project be represented as social network. The author of this study used SNA to analyze dissimilar network on four construction projects using traditional and partnering interactions. The SNA method helps to identify the benefits of integrated project delivery methods [22]. Also, prospects for the use of SNA were investigated to identify network gaps [23].

There are numerous studies which analyze the potential of sharing integration and networks in construction [24]. Pryke et al. analyzed self-organization network in implementation of an infrastructure project. Heylighen defined self-organization as the appearance of collective and coordinated links as a result of the agents' local cooperation, without any single agent being in control of the process [25]. The findings show that these networks exhibit a high degree of sparseness, short path lengths, and clustering in dense "functional" communities around highly connected actors [26]. Among recent studies, two articles should be noted, where the authors analyze communication in self-organizing network between the members of a construction project. Using SNA to study this network allowed to understand and identify some problems and dysfunctions of projects [27]. Later, the authors detected anomaly in communication between project members and developed the optimization method of improving communication effectiveness in construction project network [28]. Undoubtedly, the analysis of self-organization networks is of great interest and there is an important area of research in construction projects. However, there is a need for further research that could aid decision making in choosing network organizational structure in integrated construction projects.

3. Research Method

The research method is based on one of the basic principles of IPD - collaboration of a multidisciplinary management team, whose members make decisions together, based on a coherent perception of the project and a diverse view of problems. Since all participants are interested in the overall effectiveness of the construction project, most decisions are made in one direction.

This approach relies on methods of vector optimization [29].

The scheme of the decision-making process in construction project is as follows (Figure 1):

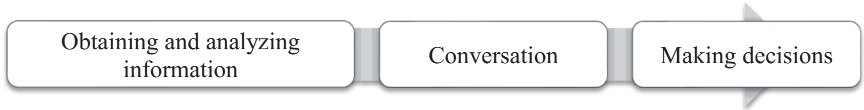


Figure 1. The scheme of a decision-making process when the investment project is realized in construction (own study)

Consequently, the optimality of the decision-making process essentially depends on the effectiveness of a negotiation process, which in turn depends on the enterprise organizational structure. Analyzing the decision-making efficiency, we consider three main types of NOS that can be used by enterprises: focal, dynamic and multifocal [9].

According to the focal type of NOS (Figure 2) all decisions are made in agreement with the project manager. The decision-making process involves negotiation actions. The effectiveness of this type of organization will largely depend on the extent to which the project manager is able to enter the negotiation process with all the participants. The effectiveness of the focal type of NOS is determined from the ratio:

$$F = k_i \times F_0, \tag{1}$$

where F_0 is the potential effectiveness of NOS, which is determined only by its structural scheme; k_1 is a coverage ratio, which determines the correlation between the number of conducted and completed negotiations l and the total number of requests n

$$k_1 = \frac{l}{n}, \tag{2}$$

According to expert estimations when the number of project participants is $n \geq 10$, the coverage ratio can be estimated as $k_1 \approx 0.5$

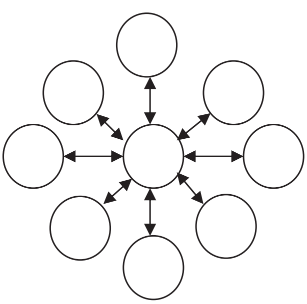


Figure 2. The scheme of the focal type of NOS [9]

The dynamic NOS (Figure 3) means that each participant has to agree their position with all other members of the network.

The effectiveness of such scheme is determined by the ratio:

$$F = k_2 * F_0, \tag{3}$$

k_2 is an overload ratio, which takes into account the reduction in performance made by employees who are forced to combine their production responsibilities with intensive negotiation activities. Experts evaluate that the overload ratio can be estimated as $k_2 \approx 0.5$.

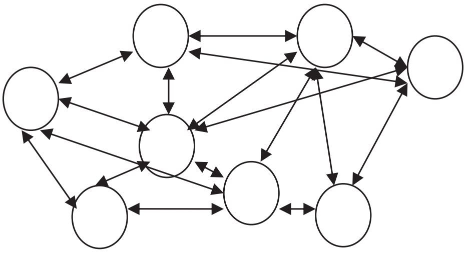


Figure 3. The scheme of the dynamic type of NOS [9]

The multifocal type of NOS (Figure 4) involves the presence of several “assistants” of a project manager, whose task is to negotiate and agree upon proposals for a specific area of activity.

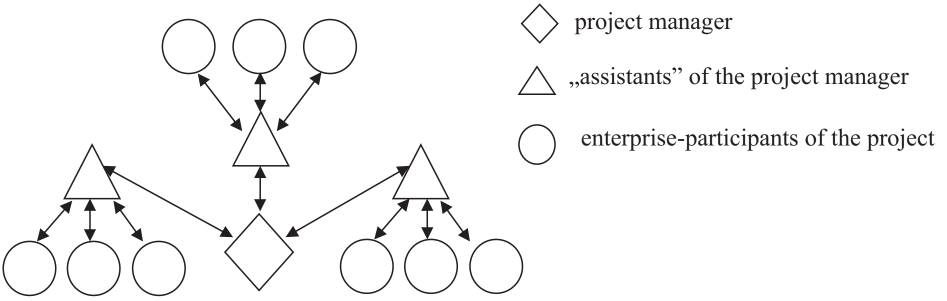


Figure 4. The scheme of multifocal type of NOS [9]

The effectiveness of such scheme is determined by the ratio:

$$F = k_3 * F_0, \tag{4}$$

k_3 is a coverage ratio, which in contrast to the focal structure, can be considered close to 1 because the workload on one "assistant" is significantly less than that on the project manager.

The next stage represents the direct evaluation of potential effectiveness of NOS, which is determined by the type of its structure. The negotiation process, that is the basis for decision-making, consists of separate negotiation actions (acts). Previous intentions of the participants and the final decision of a negotiation process will be presented in the form of two-dimensional vectors of unit length. We assume the vector of the optimal solution $\bar{R}$ (according to the effectiveness of the entire NOS) to be directed along the axis of *OX* (Figure 5).

The vector corresponding to opposite intentions is directed to the opposite side. Since all the participants in a varying degree are interested in the overall effectiveness of the project, let angle α, which expresses the deviation of the position the first participant has from the optimal position (axis *OX*) situate within

$$-\pi/2 \leq \alpha \leq \pi/2, \tag{5}$$

in other words, the vector of the *i* project participant's intentions cannot get into the left half-plane of the coordinate plan, because it means intentions that are opposite to the collective ones.

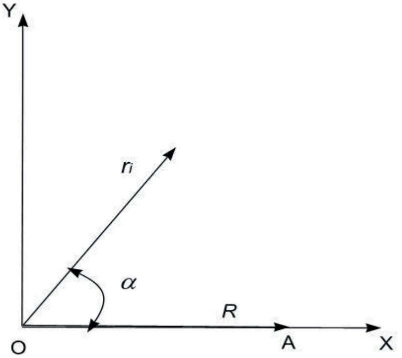


Figure 5. Vector decision-making model [29]

In addition, let the vector of the project manager intentions always coincide with the *OX* axis, id set, it coincides with the vector of the optimal solution (in terms of the entire NOS work effectiveness). Then, the vectors of the intentions of the project managers "assistants" are in the sector, which means that their positions are close to the vector of the optimal solution. Vectors of other project participants' intentions are in the sector

$$-\pi/4 \leq \alpha \leq \pi/4, \tag{6}$$

Vector model of negotiations while using the focal type of NOS is presented in Figure 6.

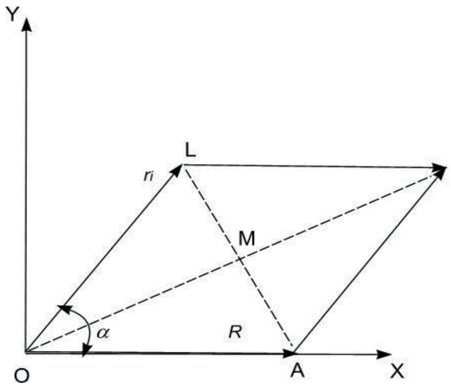


Figure 6. Vector model of negotiations for the focal type of NOS [29]

4. Results and discussion

The potential efficacy F_0 for the focal type of NOS was determined. As was noted before, the vector of project manager intensions always coincides with the direction of the vector that shows the optimal solution (axis *OX*). The vector of the project participants' intentions is characterized by the angle of deviation α from the axis *OX*. The length of both vectors equals 1. As long as the intentions of the project participants are determined not only by the common purpose but also by personal goals, they can be quite diverse. Therefore, the angle α is a random variable with uniform distribution and realizations $-\pi/2 \leq \alpha \leq \pi/2$.

The result of the negotiations is determined by the vector $\overline{OM}$ - half the vector amount of the vectors of intentions the negotiators have. This means that the wishes of both participants are equally taken into account in the final decision. The length of the resulting vector $\overline{OM}$ determines the effectiveness of the common decision. The maximum length 1 corresponds to the case $\alpha = 0$ (intentions of both participants coincide with the optimal solution (in terms of the efficiency of the whole system), the minimum length of the resulting vector $\sqrt{2}/2$ corresponds to the case $\alpha = \pm\pi/2$. In general, the length of the vector of the resulting solution $\overline{OM}$ is determined from the ratio

$$|\overline{OM}| = |\overline{OA}| * \cos\frac{\alpha}{2} = \cos\frac{\alpha}{2}, \tag{7}$$

The potential effectiveness of one negotiation act f_0 is determined by how close its resultant vector is to the vector of the optimal $\overline{OA}$ solution. The scalar product of two vectors $\overline{OM}$ and $\overline{OA}$ shows the following:

$$f_0 = |\overline{OM}| * |\overline{OA}| * cos\frac{\alpha}{2} = cos^2\frac{\alpha}{2}, \tag{8}$$

As long as the angle α is a random variable, the potential effectiveness of a negotiation process between project participants and the project manager is determined by the averaging of expression (8) for all possible values of the angle α

$$F_0 = \frac{1}{\pi}\int_{-\pi/2}^{\pi/2} cos^2\frac{\alpha}{2} d\alpha = \frac{1}{2} + \frac{1}{\pi} \approx 0.8, \tag{9}$$

Let us determine the potential efficiency of F_0 for a dynamic type of NOS. An elementary act of negotiations is carried out between two project participants whose vectors of intentions are characterized by a single length and angles of deviation from the axis of *OX* $\alpha 1$ and $\alpha 2$ (Figure 7).

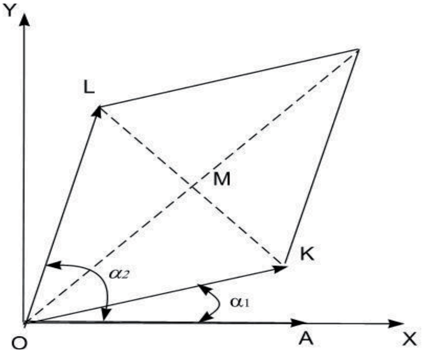


Figure 7. Vector model of negotiations for a dynamic type of NOS (own study)

The angles α_1 and α_2 are random variables with even distribution and range $-\pi/2 \le \alpha_1;\ \alpha_2 \le \pi/2$. The result of negotiations between project participants is determined by the $\overline{OM}$ vector - half the vector amount of the vectors of the intentions the participants have. The resulting $\overline{OM}$ vector, which determines the effectiveness of common decision, is characterized by the length

$$|\overline{OM}| = cos\frac{\alpha_2-\alpha_1}{2}, \tag{10}$$

and by the angle of deviation from the axis *OX*

$$\alpha = \frac{\alpha_1+\alpha_2}{2}, \tag{11}$$

The potential efficiency of one elementary solution f_0 is determined by the scalar product of the $\overline{OM}$ and $\overline{OA}$ vectors:

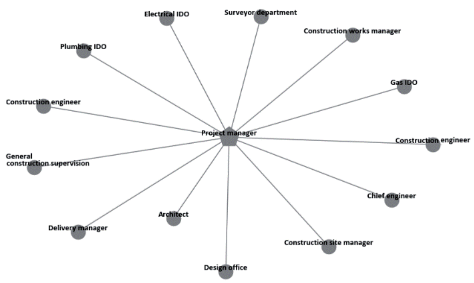
$$f_0 = |\overline{OM}| * |\overline{OA}\,| * cos\frac{\alpha_1+\alpha_2}{2} = cos\frac{\alpha_2-\alpha_1}{2} * cos\frac{\alpha_2+\alpha_1}{2} = \frac{1}{2}(cos\alpha_1 + cos\alpha_2), \tag{12}$$

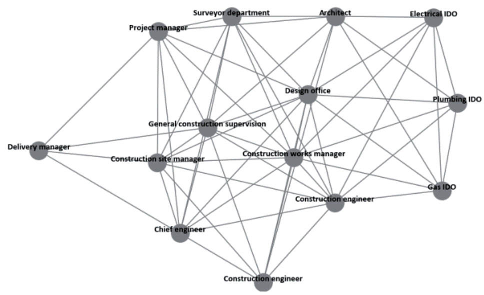
The potential effectiveness of the negotiation process between all project participants and the manager is determined by the averaging of expression (12) for all possible values of the angles $\alpha 1$ and $\alpha 2$

$$F_0 = \frac{1}{2\pi}\int_{-\frac{\pi}{2}}^{\frac{\pi}{2}} cos\alpha_1\, d\alpha_1 + \frac{1}{2\pi}\int_{-\frac{\pi}{2}}^{\frac{\pi}{2}} cos\alpha_2\, d\alpha_2 = \frac{1}{\pi}\int_{-\frac{\pi}{2}}^{\frac{\pi}{2}} cos\alpha\, d\alpha = \frac{2}{\pi} \approx 0.64 \tag{13}$$

By this means, according to expectations, if negotiating participants have different positions, the effectiveness of the negotiation outcome is lower than the model of negotiations for the focal type of NOS.

Let us determine the potential efficiency of F_0 for the multifocal type of NOS. In this case, the reasoning is similar to the previous one, but the deviation angle that shows the intentions of the project





manager's "assistant" is limited to the range $-\pi/4 \le \alpha \le \pi/4$. It happens because the position of "assistant" is always largely coordinated with a position of the project manager. Thus, the potential effectiveness of the negotiations between the project participants for the multifocal type of NOS is determined by the formula:

$$F_0 = \frac{1}{2\pi}\int_{-\frac{\pi}{2}}^{\frac{\pi}{2}} cos\alpha_1\, d\alpha_1 + 2 * \frac{1}{2\pi}\int_{-\frac{\pi}{4}}^{\frac{\pi}{4}} cos\alpha_2\, d\alpha_2 = \frac{1}{\pi} + \frac{\sqrt{2}}{\pi} \approx 0.77 \qquad (14)$$

The normalizing multiplier 2 near the second integral is explained by the continuity of the negotiation signal flow (the density of the deviation angle distribution function for the "assistant" is twice as high as the output signal density the project participants sent).

The research shows that the potential effectiveness of the multifocal type of NOS is higher in comparison with a dynamic type but is lower in comparison with a focal type.

However, if we take into account the coverage ratio of incoming requests and accept its value as $k1 = 0.5; k2 = 0.5; k3 = 1.0$, then we get $F1 = 0.40; F2 = 0.32; F3 = 0.77$. It follows that the multifocal type of NOS is the most effective type of collective decision making when the project manager has several "assistants".

As a practical example of using the method three communication networks of participants of construction project delivery were analyzed, with the same number of team members. NOS were presented as an undirected graph, in which the nodes represent the project participants, and the edges represent the communication links between them.

Visualization of networks were implemented using the Networkx library in the Python programming language and are shown Figures 8-10.

Figure 8. The focal type of NOS (own study) Figure 9. The dynamic type of NOS (own study)

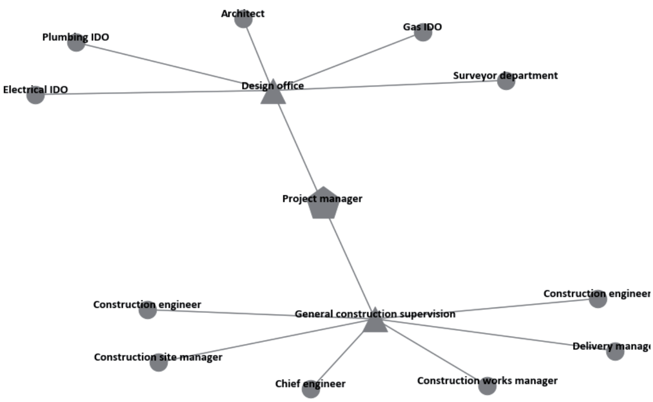


Figure 10. The multifocal type of NOS (own study)

Based on the communication links between the project participants, an adjacency matrix of 14×14 was formed and criterion the potential effectiveness of NOS (*F0*) was calculated. Various measures of centrality are used to analyze the level of communication in networks [22]. As *F0*, we have chosen the measure Eigenvector Centrality of the node [30]. The Eigenvector Centrality measure has an advantage over other centrality measures and its calculation takes the level of importance of a node in network according to two criteria:

- a node can have a high level when it has many connections with other nodes in the network;
- a node can have a high level when it has few connections but with influential nodes in the network.

The results of calculating the measure Eigenvector Centrality for each participant and the total value for the entire network are presented in Table.

Table. Results of calculating the measure Eigenvector Centrality

	Focal NOS	Dynamic NOS	Multifocal NOS
General construction supervision	0.196	0.28	0.602
Project manager	0.707	0.229	0.353
Construction site manager	0.196	0.259	0.218
Construction works manager	0.196	0.297	0.218
Construction engineer	0.196	0.218	0.218
Chief engineer	0.196	0.259	0.218
Architect	0.196	0.206	0.135
Construction engineer	0.196	0.274	0.218
Surveyor department	0.196	0.245	0.135
Delivery manager	0.196	0.119	0.218

Design office	0.196	0.319	0.372
Electrical IDO	0.196	0.165	0.135
Plumbing IDO	0.196	0.165	0.135
Gas IDO	0.196	0.165	0.135
Average	0.233	0.229	0.236

As can be seen from the calculation results, the *F0* criterion has the highest value in multifocal NOS *F3 = 0.236*. If we take into account the coverage ratio of incoming requests k1 = 0.5; k2 = 0.5; k3 = 1.0, then we get *F1 = 0.117; F2 = 0.115; F3 = 0.236*. The results of theoretical research and empirical calculations show that the multifocal type of NOS is the most effective type of collective decision-making.

5. Conclusions

Under the modern conditions of economic activity, the number of project delivery participants has increased remarkably as well as the information flow and its influence on particular enterprises and the results of their activity. An increase in the number of project participants is one of the factors that often leads to poor communication, which in turn can result in higher costs and longer construction duration. Modern methods of project management and their usage may significantly reduce expenses, as the activities of participants become more coherent and coordinated which leads to a reduction of errors and collisions and reduces the time of project implementation.

New and original idea of research are comparing three potentially possible network organizational structures: focal (F1), dynamic (F2), multifocal (F3) in terms of maximum effectiveness of using information links between project participants. The research method is based on collaboration of a multidisciplinary management team, whose members make decisions together. Since all participants are interested in overall effectiveness of the construction project, most decisions are made in one direction.

The study made direct evaluation of the potential efficiency of each of the three types of network organizational structures using the vector decision-making model. For each of the above-mentioned types of organizational structures, the potential effectiveness of negotiating act f0 and the total potential effectiveness F0 was calculated. The results of theoretical research and empirical calculations show that the multifocal type of NOS is the most effective type of collective decision-making when the project manager has several “assistants”. Further research should focus on practical verification of the proposed model on real construction projects.

Abbreviations

MEP - Mechanical, Electrical, Plumbing	IPD - Integrated Project Delivery
IT - Information Technology	SNA - Social Network Analysis
ICT - Information Communication Technology	NOS - Network Organizational Structure
BIM - Building Information Modelling	IDO - Installation Design Office

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Wybór sieciowej struktury organizacyjnej w zintegrowanym zarządzaniu przedsięwzięciami budowlanymi

Słowa kluczowe: sieciowa struktura organizacyjna, integracja, sieć, przedsięwzięcie budowlane.

Streszczenie:

W warunkach nowoczesnej działalności gospodarczej znacznie wzrosła liczba uczestników przedsięwzięć budowlanych. Ich wzrost prowadzi do zwiększenia przepływów informacyjnych i pogorszenia komunikacji, co z kolei może skutkować wyższymi kosztami oraz dłuższym czasem realizacji budowy. Wykorzystanie nowoczesnych metod zarządzania projektami pozwala zaprojektować taką strukturę organizacyjną, dzięki której działania uczestników stają się bardziej spójne i skoordynowane, co w konsekwencji prowadzi do zmniejszenia liczby błędów i kolizji oraz zmniejsza koszt i czas realizacji projektu.

Zaproponowana metoda wyboru struktury organizacyjnej oparta jest na założeniu, że członkowie zespołu największą ilość decyzje podejmują wspólnie i/lub w uzgodnieniu. Ponieważ wszyscy uczestnicy są zainteresowani efektywną realizacją całego przedsięwzięcia, większość decyzji będzie podejmowana na podstawie tych samych lub podobnych kryteriów. W artykule przeprowadzono bezpośrednią ocenę potencjalnej wydajności trzech wybranych rodzajów sieciowej struktury organizacyjnej (*SSO*) przy użyciu wektorowego modelu decyzyjnego. Przyjęto następujące rodzaje sieciowej struktury organizacyjnej (*SSO*), które mogą być stosowane przy realizacji przedsięwzięć budowlanych: focalna (*F1*), dynamiczna (*F2*), multyfokalna (*F3*). Wykonanie oceny potencjalnej wydajności *SSO* pozwala na wskazanie optymalnej struktury organizacyjnej. Kryterium optymalności reprezentuje maksymalną efektywność wykorzystania łączy informacyjnych między uczestnikami przedsięwzięcia. Dla każdego z analizowanych rodzajów *SSO* obliczono potencjalną skuteczność aktu negocjacyjnego $f0$ i całkowitą potencjalną efektywność $F0$. Wyniki badań teoretycznych i obliczeń empirycznych pokazują, że najefektywniejszym rodzajem sieciowej struktury organizacyjnej *SSO* jest sieć multyfokalna, w której kierownik projektu ma kilku asystentów. Dalsze badania skoncentrują się na praktycznej weryfikacji proponowanego modelu na rzeczywistych strukturach zarządzania przedsięwzięciami budowlanymi.

Received: 08.10.2020, Revised: 03.11.2020