EFFICIENCY EVALUATION OF ORGANISATIONAL PROCESSES SYSTEM IN A BUILDING PRODUCTION WITH SIMULATION MODELING FOR CONTRACTING COMPANIES

Purpose. This paper presents the innovative scientifically-based method on efficiency evaluation of the building production management for contracting companies. Optimisation models are substantially aimed at reducing the influence of negative factors and increasing the quality indexes of the organisational process of construction production. Methodology. Methodological approaches of the organisational processes optimisation of construction production are based on the establishment of a well-defined interconnection between the units of the functional structure, the definition of strategies hierarchy of the contracting company. The correlation of duration \( t \) and cost \( c \) in building production, its influence on the economic appropriateness for projects realisation in civil engineering are analyzed. Findings. Using mathematical analysing methods for cumulative distribution function \( S(t,c) \) of two-dimensional random value of construction duration and cost, the basic principles are shown that allow to qualitatively and quantitatively determine the level of influence of the construction market external factors on the implementation of organisational processes in the construction industry, in which a large number of forming elements are involved. The implementation of this methodology permits to assess the real state of organisational processes system in building production, its stability, the degree of determinate indicators structuring in a single functional system, to generate an economic justification in complex. On basis of simulation modeling, efficiency of organisational processes system in building production \( S(t,c) \) was determined and graphically illustrated. Originality. The results of the present study demonstrate that it amounted to 58.08 % within the established limits of acceptable risk (LAR) between 0.35 and 0.65. Practical value. It has been shown an implementation practicability of using this methodology by contracting companies at decision-making stage for construction projects initiation with determinate indicators of duration \( T_d \) and cost \( C_d \). The creation of theoretical and methodological foundations for the development of structural efficiency evaluation algorithms for the organisation of construction production will allow to achieve for contractor companies the highest level of competitiveness in the market of construction services.

Keywords: building production management; organisational process; limits of acceptable risk; simulation modeling; contracting company

Introduction

The organizational process is the fundamental unit of building production management. By definition it means systematic and targeted change in time and space of quantitative and qualitative characteristics of construction processes in order to produce finished products with specified quality indicators. In broader sense, building production management includes a whole cycle of production processes and consists of targeting organisational, technical, technological solutions, methods and activities of contracting companies to comply with requirements of production processes rational organisation; work implementers coordinated activities, accounting for their production and economic opportunities and interests; construction works producing with consideration of individual buildings characteristics and conditions; construction products quality, terms and cost of projects, taking...
into account the financial conditions (Radkевич, Арутюнян, Данкевич, & Сайков, 2017; Arutunian, & Saikov, 2019).

Methodology

The intensification of negative factors on construction market is reflected in building production management and implicitly generates an appearance of organizational failures at contracting companies. Resistance to failures is determined by a reliability of organisational processes system, in particular, the probability that at an arbitrary point in time the values of determinable parameters of duration \( t \) and cost \( C \) of organizational processes do not exceed the LAR (Панюков, 2008). According to the provisions of reliability theory, organizational systems in a process of purposeful functioning can be in two states: reliable and risky. The transition of system from the first state to the second is characterized by occurrence of organizational failure. In contrast to technical systems, in organizational processes system of building production this transition is not instantaneous, but parametric in time.

By the earlier researches (Мамотенко, 2003; Судаков, & Гусаков, (Ред.), 2004; Беркута, Осинська, Галінський, & Вахович, 2010; Радкевич, Арутюнян, & Сайков, 2018a), duration of organisational process \( t_{ij} \) and its cost \( c_{ij} \) are random variables \( x \), which are characterized by the principals of beta distribution with a probability density function \( P(x) \), where \( i \) – organisational start code, \( j \) – organizational end code. Scientifically, the efficiency evaluation of organisational processes system in building production with a set factor \( X_d \) is determined by the probability \( S(x) \) of random quantity \( x \) falling into the interval \([0, X_d]\) under the condition \( x \leq X_d \):

\[
S(x) = \int_0^x P(x) \, dx .
\]

Research of organisational processes in building production by simulation modeling showed that without stochastic works, the probability density function is described by the following equation (Мамотенко, 2003):

\[
P(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{[x-x_{\min}-(x-x_{\min})]^2}{2\sigma^2}} ,
\]

where \( x_0 \) – median of probability distribution; \( x_{\min} \) – minimum statistical value of random variable \( x \); \( \sigma \) – standard deviation of random variable \( x \).

Accordingly, probability that project in civil engineering with cost \( C_d \) can be complete on term \( T_d \):

\[
S(t) = \int_0^t \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{[t-t_{\min}-(t-t_{\min})]^2}{2\sigma^2}} \, dt , \quad (3)
\]

\[
S(c) = \int_0^c \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{[c-c_{\min}-(c-c_{\min})]^2}{2\sigma^2}} \, dc . \quad (4)
\]

For the purposes of this paper, as efficiency evaluation of organisational processes system in building production, it has been taken the optimal ratio value of cumulative distribution function for duration \( S(t) \) and cost \( S(c) \) of organisational processes within the LAR. Furthermore, it is the possibility of choosing such a plan for implementation of projects that can reduce the duration \( T_d \) for a set efficiency, or increase its efficiency for a set duration, in respect that indicator of the project cost \( C_d \).

It is important to emphasize that each organisational process of building production is characterized by the duration \( t_{ij} \), which is the boundary limits:

\[
t_{ij}^{\min} \leq t_{ij} \leq t_{ij}^{\max} , \quad (5)
\]

where \( t_{ij}^{\min} \) – minimum (emergency) duration of organisational process; \( t_{ij}^{\max} \) – maximum (optimal) duration of organisational process.

According to (Пивоваров, & Хижняк, 2014; Мартыш, 2015; Радкевич, Арутюнян, & Сайков, 2018b; Данкевич, 2020), the combination of indicators “duration-cost” suggests that a decrease in duration of organisational process is proportional to an increase in its cost, i. e. the cost \( c_{ij} \) is in the range from \( c_{ij}^{\min} \) (for optimal duration) to \( c_{ij}^{\max} \) (for emergency duration), and is shown in Fig. 1.

Using approximation in a straight line, it has been found the change in cost of organisational process \( \Delta c_{ij} \) when changing its duration:

\[
\Delta c_{ij} = (t_{ij}^{\max} - t_{ij}) h_{ij} \quad (6)
\]

\[
h_{ij} = \tan \alpha \left( \frac{c_{ij}^{\max} - c_{ij}^{\min}}{t_{ij}^{\max} - t_{ij}^{\min}} \right) \quad (7)
\]
where $h_{ij}$ – costs of building production accelerating compared to the normal duration per unit time; $\alpha$ – inclination angle of the approximation straight line to abscissa axis.

Let $P(x)$ is a probability density function of random quantity $x$ with boundary limits $[x_{ij}^{\text{min}}, x_{ij}^{\text{max}}]$.

Then, $\varepsilon_1$, $\varepsilon_2$ are two uniformly distributed random variables, with $\varepsilon_1$ uniformly distributed in the interval $[x_{ij}^{\text{min}}, x_{ij}^{\text{max}}]$, $\varepsilon_2$ is in the interval $[0, M]$, where:

$$M = \frac{16}{9(x_{ij}^{\text{max}} - x_{ij}^{\text{min}})}. \quad (8)$$

If $P(\varepsilon_1) \geq \varepsilon_2$, then value $\varepsilon_1$ is taken as the desired one; if $P(\varepsilon_1) < \varepsilon_2$, then the value $[\varepsilon_1, \varepsilon_2]$ is rejected and a new one is selected. This process continues until the relation $P(\varepsilon_1) \geq \varepsilon_2$ takes place. This method is especially effective in cases where the change of function $P(x)$ in the interval $[x_{ij}^{\text{min}}, x_{ij}^{\text{max}}]$ is low.

Based on the above, the values of random variables of duration $t_{ij}$ and cost $c_{ij}$ of organisational process are described by the following equations:

$$t_{ij} = (t_{ij}^{\text{max}} - t_{ij}^{\text{min}})\varepsilon + t_{ij}^{\text{min}}, \quad (9)$$

$$c_{ij} = \left(\frac{t_{ij}^{\text{max}} - t_{ij}}{t_{ij}^{\text{max}} - t_{ij}^{\text{min}}}\right)\varepsilon + c_{ij}^{\text{min}}. \quad (10)$$

Following the study of organisational processes system in building production by simulation modeling, research takes place on the basis of an enlarged project network (EPN). It is developed by a contracting company based on project indicators of buildings in civil engineering. Since duration of organizational process $t_{ij}$ and its cost $c_{ij}$ are random variables $x$, then the EPN is calculated at $x_{ij} = x_{ij}^{\text{min}}$ and $x_{ij} = x_{ij}^{\text{max}}$, resulting in $x_{\text{min}}$ and $x_{\text{max}}$ respectively. The interval $[x_{\text{min}}, x_{\text{max}}]$ is divided into intervals $\Delta x$ so that $x_{ij} = x_{\text{min}} + \Delta x$, $x_{ij} = x_{\text{max}} + \Delta x$, etc. (Мамотенко, 2003; Vanhoucke, Demeulemeester, & Herroelen, 2010; Данкевич, 2019). By repeatedly drawing the model of building production, the number of realisations $x_i$ for a random variable $x$ (the number of a random variable hits in each of the set intervals $x_i$) is generated, and the frequency of random variable is determined:

$$F_i = \frac{x_i}{n}, \quad (11)$$

where $n$ – draws number of the building production model.

At the same time, earlier work of authors (Данкевич, 2019; Огнёв, Степанова, & Фролова, 2019; Радкевич, Арутюнян, & Сайков, 2019)
shows that $10^3$ … $10^5$ draws are required to calculate the EPN of construction production by simulation modeling.

Hereby, the probability density of random variable $x$ is calculated as:

$$F_2 = \frac{F_1}{\Delta x}.$$  \hspace{1cm} (12)

Based on the obtained values $F_2$, the probability density functions of duration $P(t)$ and cost $P(c)$ for organisational process are generated. Using the values $F_1$, the cumulative distribution function of duration $S(t)$ and cost $S(c)$ in building production are modeled. By mathematical and graphical analysis of generated data, the efficiency evaluation of organisational processes system in building production is produced on the optimal ratio value of cumulative distribution function for the duration $S(t)$ and cost $S(c)$ of organizational processes within LAR, seeing the duration $T_d$ and cost $C_d$ due to the project (Ваколюк, 2013; Konior, 2015a; Konior, 2015b; Kasprowicz, 2017).

Results

Suppose, contracting company $A$ decides to initiate a project with duration $T_{d}=236$ days and cost $C_{d}=24,673$ USD ths. Based on the construction factors, the company develops the EPN indicating the sequences, durations and costs of the organisational processes of building production. The EPN developed for projects in civil engineering should determine the duration $t_{ij}$ and cost $c_{ij}$ of the main stages of individual work packages packages implementation as part of building production management. The purpose of developing the EPN illustrated in Fig. 3, is the rationale for a set organisational duration of construction; determination of deadlines for completion of building or structure individual parts, terms for construction works; determination of a capital investments value; setting delivery dates for the necessary constructions, materials and equipment; an appointment of required number and terms for using of personnel and the of construction equipment main types.

Since the cost of building production includes the costs of individual organisational processes $c_{ij}$ and the duration is their term intervals $t_{ij}$, and the value $c_{ij}$ depends on $t_{ij}$, it is assumed that the project cost of building production $C_d$ also depends on set duration $T_d$. Therefore, to determine the efficiency of organisational processes system in building production, the laws knowledge of one-dimensional quantities distribution $t_{ij}$ and $c_{ij}$ is not enough, and it is necessary to generate the probability density function $P(t, c)$ and the cumulative distribution function $S(t, c)$ of a random two-dimensional quantity. The early work (Данкевич, 2019) shows, the LAR have a range $0.35 \leq S(t, c) \leq 0.65$: when $S(t, c) \leq 0.35$, there is a violation risk of the building production terms and going beyond the established budget is extremely large, organisational project decisions should be reviewed; when $S(t, c) \geq 0.65$, the project initiation is not advisable, whereas the variability of excessive and irrational use of construction resources increases.

The draws number of the EPN is taken to $n=103$, the expected value are $M_t=229.05$ days and $M_c=24,596.55$ USD ths, the correlation coefficient is $k=0.75$. The number of realisations is calculated by simulation modeling described in par. 2, and based on the obtained data, a diagram of the realisations frequency $r(t, c)$ and a graph of probability density function $P(t, c)$ are constructed in Fig. 4, 5,
the cumulative distribution function of duration $t$ and cost $c$ of building production is modeled in Fig. 6.

Analysis of results shows that in the duration $T_d=236$ days with a limited cost of building production $C_d=24,673$ USD ths, the project can be implemented, since the efficiency of the developed organisational processes system in building production is $S(T_d,C_d)=0.5808$ in respect that the LAR $0.35 \leq S(T_d,C_d) \leq 0.65$. Therefore, contracting company A can begin the initiation of construction with the project indicators and organisational decisions adopted following the developed EPN for building production. It should also be noted that in order to the risk of an additional volumes occurrence and time for their implementation, the project cost $C_d$ can be increased to 24,686 USD ths, and the duration $T_d$ – continued to 238 days without changing the getting efficiency in 58.08%.

**Originality and practical value**

As can be seen from above, this efficiency evaluation of organisational processes system in building production by the simulation modeling allows the relationship tracking between construction works, implementing the organisational features of civil engineering, and also seeing the limited amount of financing (capital investment). As a result, the full interconnection of organisational processes determine indicators is regulated, which admits to generate a reliable solution for project initiating by contracting companies.

**Conclusions**

Using mathematical analysing methods for cumulative distribution function $S(t,c)$ of two-dimensional random value of construction duration and cost, the basic principles are shown that allow to qualitatively and quantitatively determine the level of influence of the construction market external factors on the implementation of organisational processes in the construction industry, in which a large number of forming elements are involved. The implementation of this methodology permits to assess the real state of organisational processes system in building production, its stability, the degree of determinate indicators structuring in a single functional system, to generate an economic justification in complex.

This study serves as a window to an understanding of that the proposed calculation procedure is practical and functional in use. It is possible to generate and develop an automated complex for calculating indicators considered in this paper.
Such a complex will adopt in a dialogue mode to make decisions on project initiation, to evaluate the efficiency and, if necessary, to quickly review them, based on modern information technologies and research theory methods. Clearly, some propositions of that research offered are not entirely unique. However, authors submit that the contribution of this paper rests on considering projects in civil engineering, which financed by private investors, as well as at initiation stage of participation in tender by contracting companies.

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