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Evaluation of Construction Process Safety Solutions Using the TOPSIS Method

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The paper discusses the problem of selecting construction process safety solutions which secure employee health and safety on construction sites. To achieve this, the causes of severe accidents on construction sites have been analyzed, factors which cause accidents at work in construction companies have been studied; a comprehensive literature review has been made, assesing all statistical data and employee health and safety improvement perspectives as well as their application in construction practice. The selection problem is stated as a mathematical multi-purpose solution making task. It expresses the management solution making problem mathematically.

Investigation of severe accidents on construction sites shows that over two thirds of accidents are caused by poor work organization, lack of supervision and control as well as underestimation of professional risks. This high level of injuries is brought about not only by noncompliance with employees' health and safety requirements, but also by factors and violations having to do with traffic, noncompliance with fire and electricity safety requirements, lack of work discipline, which is mainly displayed by usage of alcohol at work, as well as other causes. Other important factors that directly impact the number of accidents in the construction sector are the lack of training and knowledge as well as the lack of awareness of safe execution of assigned work.

Studies of the dependencies between workplace accidents and their causes show that the prevailing accidents are the following: high falls, collisions with vehicles, stumbling and falling as well as falling objects. They usually result in severe and lethal outcomes.

The paper emphasizes that work safety in various building construction activities can be achieved not only by collective and individual means, evaluation of professional risk, employee briefing on safety measures, but also by efficient work organization and appropriate working environment. To implement the above mentioned, the most effective solution must be found. One of the methods used to determine the priorities of safe operation in a construction company is the TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) method.

The effectiveness level of safety solutions for a construction process depends on numerous quantitative and qualitative indices affecting the process; their impact is evaluated in terms of their value and significance. Since the significance of quantitative and qualitative indices depends on their values, the latter should be taken into consideration. Furthermore, it is necessary to coordinate the significances of quantitative and qualitative indices in terms of their value and significance. To achieve the above-mentioned goals, the authors developed an integrated index significance determination method, in view of their quantitative and qualitative characteristics.

The paper discusses the selection of objects and indicators that are under consideration. An anonymous survey was carried out with the help of questionnaires designed for the purpose. Six average-size construction companies engaged in constructing individual dwelling-houses participated in the survey. A single-storey house with an attic and no basement was selected as a study object.

Keywords: *the TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) method, accidents, occupational disease, hazard, risk factor, construction process, safety solution.*

Introduction

Although the EU law acts have been implemented in Lithuania, statistical data point to an increase in accidents in Lithuania's construction sector (Apanaviciene, Liaudanskiene, 2008; Liaudanskiene, Apanaviciene, Ustinovicius 2008; Hola, 2007; Zavadskas, Kaklauskas, Banaitis, 2004; Stankiuviene, Sukys, Cyras, 2006, 2007; Sukys, Cyras, Stankiuviene, 2005; Cyras, Sukys, Jakutis, Stankiuviene, 2004; Statistics department, Government of The Republic of Lithuania, 2008). Compared with other EU sector workers, workers in construction industry on average run a twice higher risk of non-lethal accidents at work (Work and Health in the EU, 2004; Hämäläinen, Takala, Saarela, 2006).

In order to prevent accidents and occupational disease, increase work efficiency and workers' job satisfaction, it is necessary to take measures to make work in construction sites safe (Idoro, 2008; Grybaite, Tvaronaviciene, 2008; Alinaitwe, Mwakali, Hansson, 2007; Schieg, 2006; Sukys, 2004; Dejus, Viteikiene, Dejus, 2004).

Investigation of severe accidents on construction sites finds that over two thirds of accidents are caused by poor work organization, lack of supervision and control as well as underestimation of professional risks (Stankiuviene, Cyras, Vakriniene, 2008). This high level of injuries is brought about not only by noncompliance with employees' health and safety requirements, but also by factors and violations having to do with traffic (about 30 per cent annually), noncompliance with fire and electricity safety requirements, lack of work discipline, which is mainly displayed by usage of alcohol at work (about 35 per cent casualties occur at work with nearly half of construction workers not sober at work) as well as other causes (Annual Report of the State Labour Inspectorate of the Republic of Lithuania, 2007).

Other important factors that directly impact the number of accidents in the construction sector are lack of training and knowledge, lack of awareness of safe execution of assigned work; in other words, carelessness, apathy or complete negligence. This is called unsafe behavior. It is said to be one of the main factors increasing the number of accidents at work; it also signals poor safety culture in the company (Dester, Blockley, 1995; Halsam, Hide, Gibb, Gyi, Pavitt, Atkinson, Duff, 2005; Macedo, Silva, 2005).

Other authors study causes of workplace accidents in terms of the following aspects of the working environment: historical, economic, phychological, ergonomical, procedural and organizational (Reinhold, Tint, Tuulik, Saarik, 2008; Gervais, 2003; Sawacha, Naoum, Fong, 1999).

In the light of general evaluation of workplace hazards, it can be said that both safe work and health hazards tend to occur in any activity of a company, however, construction company workers face the greatest risk of injuries (Behm, 2005; Fang, Vie, Li, 2004; Kartam, Flood, Koushki, 2004).

Studies of the dependencies between workplace accidents and their causes show that the prevailing ones are the following: high falls, collisions with vehicles, stumbling and falling as well as falling objects (Leamon, Murphy, 1995; Eurostat, 2008). They usually bring about severe and lethal accidents.

According to Stewart (Stewart, 1986), in many cases it is not sufficient to simply establish the principal cause of accidents, moreover, it is essential to determine other factors influencing a system in operation.

Accidents generally occur when numerous hazard factors interact, and their risk level is simply not identified. According to Kletz (Kletz, 1994), non-prevailing risk factors and their interaction do not receive due attention.

The failure to forecast a system's operation, even though the key factors are known, signals the lack of knowledge about their interactive impact (Hadad, Laslo, Ben-Yair, 2007). The interactions and combinations of factors tend to have specific impact on each factor.

According to Peters et al. (Peters, Meyna, 1985), the "dangerous combinations" method will undoubtedly increase safety levels in systems, in which the main causes of accidents alone were analyzed previously, or in which common procedures failed due to organizational, technological or financial limitations.

Work safety in various building construction processes can be achieved not only by collective and individual means, evaluation of professional risk, employee briefing on safety measures, but also by efficient work organization and appropriate working environment (Sawacha, Naoum, Fong, 1999; Jorgensen, Sokas, Nickels, Gao, Gittleman, 2007; Kumpikaite, 2007). To implement the mentioned aspects above, the most effective solution must be found.

One of the helpful methods used to determine the priorities of safe operation of a construction company is the TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) method (Hawang, Yoon, 1981; Zavadskas, 1986; Yoon and Hwang, 1981; Arditi, Patel, 1989; Arditi, Gunaydin, 1998; E Costa, Correa, 1998; Triantaphyllou, 2000).

The effectiveness level of safety solutions for a construction process depends on numerous quantitative and qualitative indices affecting the process. Their impact is evaluated in terms of their value and significance.

Since the significance of quantitative and qualitative indices depends on their values, they should be taken into consideration. Furthermore, it is necessary to coordinate the significances of quantitative and qualitative factors depending on their values and significance. To achieve the above goals, the authors created an integrated indices' significance determination method, depending on their quantitative and qualitative characteristics.

The aim of this paper is to implement the TOPSIS method with a view to finding the most effective solution for a construction company, engaged in building residential houses and eager to secure work safety standards during the building process.

Twelve experts participated in the survey. The data presented by the experts were systematized and the significance of indices was determined.

Index significance determination was performed on the basis of solution adoption matrix (Table 1) and formulas (1-9). All calculations were carried by means of "Microsoft Excel 2007" program.

Selection of Objects and Indices Investigated

Collective and individual measures, employee briefing on safety and health issues, regular medical check- ups are not sufficient for securing sound safety solutions during construction processes. Apart from the mentioned above, it is essential to obey valid legal acts and regulations, as well as properly organize work /rest time, selection of technological processes, workplace environment hazard evaluation, incident management, use of skilled labour and machinery. (Kazlauskiene, Rinkevicius, 2006; Vegso, Cantley, Slade, Taiwo, Sircar, Rabinowitz, Fiellin, Russi, Cullen, 2007; Bagdanavicius, Jodkoniene, 2008; Babichenko, Babichenko, 2008; Hernaus, Skerlavaj, Dimovski, 2008).

An anonymous survey was carried out with the help of questionnaires designed for that purpose. Six average size construction companies (with 20 – 499 employees) constructing individual dwelling-houses participated in the survey.

A single – storey house with an attic and no basement was selected as study object. Monolithic foundation was designed. Silicate bricks and wooden battens were used for the finish of the exterior walls. The exterior ground floor walls consist of three layers of bricks with air gap inside. Silicate brick masonry was used for finish. Interior walls and partitions on the ground floor were made of masonry. Wooden battens were used as exterior wall of the attic finish. The ground floor ceiling was made of reinforced concrete, while the roof construction was wooden. Graded steel slates (tile imitation) were used as roofing. Rainwater pipes and gutters were designed to shed rainwater. Window frames were made of plastic and wood. The exterior door was made of wood. No interior finish is being carried out.

The following served as the criteria for selecting the construction companies: size of the company; magnitude of available funds; responsibility; profit distribution; management peculiarities and company control; tax peculiarities. The mid-sized construction companies selected can be characterized by their regional nature of activity. Company owners work as company managers and are responsible for all the results of the company's activities.

Successful activities of a construction company depend on the following: the most up-to-date special construction technologies applied; efficient systems of company management; efficiency of construction work organization; efficiency of labour both in construction and preparatory engineering preparation work.

Contracts with various other construction and consulting companies are made in order to execute construction projects. In this way the company uses its intellectual potential, previous experience and its personal connections with clients as well as other participants in construction industry. This contributes to effective execution of the project and successful application of employee safety and health legal acts requirements during construction. This does not only help to secure safe workplace environment for company employees, but also to compete successfully.

Since any undesirable factor/incident may cause severe losses, securing employee health and safety improves the company's performance under highly competitive conditions (Vakriniene, Cyras, Sukys, 2004; Dorman, 2000; Andreoni, 1986; Dembe, 2004; Sheu, Hwang, Wang, 2000).

The companies participating in the survey are referred to as six alternatives: $a_1, a_2, a_3, a_4, a_5, a_6$ in this paper.

The priority and significance of the alternatives analyzed are directly proportional to the system of factors describing the alternatives, their values and significance values. Six indices $K_1, K_2, K_3, K_4, K_5, K_6$ were selected for this purpose: evaluation of construction process safety solutions (max = 10, min = 1); labour expenditures (workers/ workdays); level of mechanization (in %); level of labour qualification (in points); coefficient of construction work coordination; coefficient of effective use of work resources.

Evaluation of solutions to construction process safety was proposed by a group of independent State Labour Inspectorate employees. They analyzed solutions to construction process safety according to general criteria, and later evaluated them as the best or worst in terms of their meeting the requirements (10 points for the best solution, 1 point for the worst).

Work and machinery expenditures as well as employee qualification level were calculated in accordance with „work, materials and machinery expenditure norms".

Work expenditures are defined as the sum total of employees' working days, obtained from the estimates of each individual alternative independently.

Work mechanization level is the estimation of demand for machinery from the calculated estimates of each individual independently.

Employee qualification level is the ratio between the average sum of worker categories, necessary for performing activities designed for the specific alternative and the total number of workers.

The coefficients of work coordination and efficient use of work resources are estimated in accordance with technological – organizational solutions. This evaluation was proposed by a group of people representing a construction company to be discussed on another occasion.

The TOPSIS method

The TOPSIS method is based on the formation of a generalized index $K_{bit,i}$ in accordance with the deviation of the compared alternatives from the ideal value, which consists of the optimal indices of the alternatives discussed.

Application of this method (Behm, 2005) makes it necessary for the fact that the efficiency function of each solution criterion increases or decreases monotonically. This means that a higher value of any index is always better or worse than a lower value of the same index, depending on whether the efficiency function increases or decreases. The TOPSIS method was developed as an alternative for the ELECTRE (*Elimination et Choice Translating Reality*) method.

Numerous theoretical and practical studies are dedicated to the theory and application possibilities of this method (Behm, 2005, Fang, Vie, Li, 2004; Kartam, Flood, Koushki, 2004; Leamon, Murphy, 1995; Stewart, Disasters, 1986; Kletz, 1994).

The algorithm of the TOPSIS method is shown in Figure1.

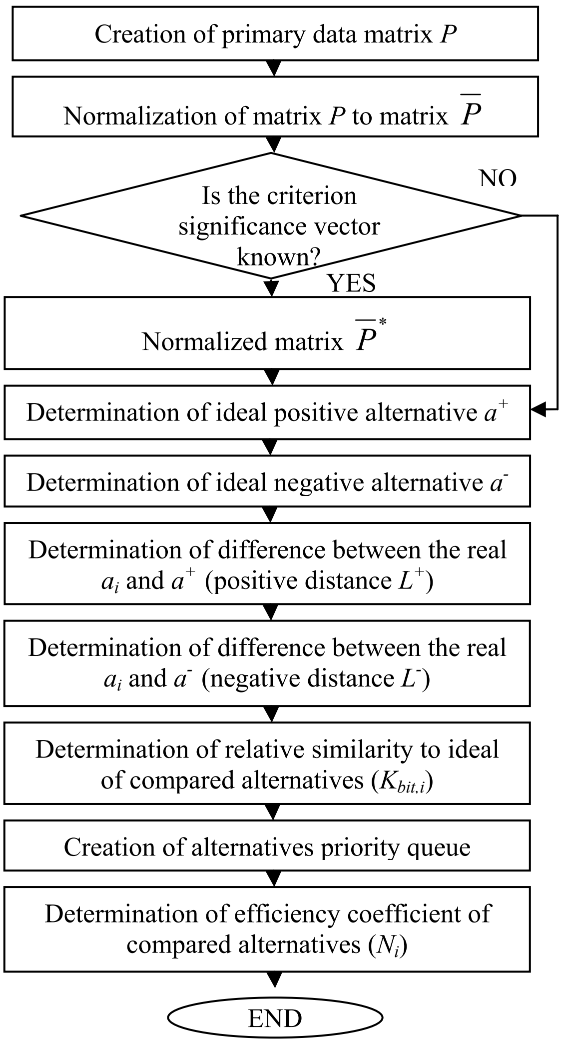

Figure 1. Algorithm of Similarity to Ideal Solution Method

In order to apply the TOPSIS method, it is necessary to design a solution matrix P from n alternatives, described by indicators m.

$$P = \begin{bmatrix} x_{11} & x_{12} & ... & x_{1m} \\ x_{21} & x_{22} & ... & x_{2m} \\ ... & ... & ... & ... \\ x_{n1} & x_{n2} & ... & x_{n0} \end{bmatrix}. \quad (1)$$

By applying the TOPSIS method, matrix P must be normalized to matrix $\overline{P}$. The normalization process of matrix P is performed by means of the following formula:

$$\overline{x}_{ij} = \frac{x_{ij}}{\sqrt{\sum_{j=1}^{n} x_{ij}^2}}; \; i = \overline{1,n}\,; \; j = \overline{1,m}. \quad (2)$$

Where $\overline{x}_{ij}$ is the element of the normalized matrix; x_{ij} is the evaluation of criterion j of alternative i; m is the number of criteria, n is the number of the alternatives compared.

Since the significance criteria are already known, the normalized matrix $\overline{P}^*$ is derived by means of the following equation:

$$\overline{P}^* = [\overline{P}] \cdot [\overline{q_j}]. \quad (3)$$

Where $\overline{q_j}$ is the significance criterion's.

In the next stage ideal positive alternative a^+ and ideal negative alternative a^- are determined:

$$a^+ = \left\{ \left(\max_i f_{ij} / j \in I \right), \left(\min_i f_{ij} / j \in I' \right) \Big/ i = \overline{1,m} \right\} = \left\{ f_1^+, f_2^+, K_{bit}, f_n^+ \right\}. \quad (4)$$

$$a^- = \left\{ \left(\min_i f_{ij} / j \in I \right), \left(\max_i f_{ij} / j \in I' \right) \Big/ i = \overline{1,m} \right\} = \left\{ f_1^-, f_2^-, ..., f_n^- \right\}. \quad (5)$$

Where I is a set of indices (which are maximized and their highest values are the best);

I' is a set of indices (which are minimized and their lowest values are the best).

Positive and negative distances L^+ between (a_i and a^+) and L^- between (a_i and a^-) are estimated.

$$L_i^+ = \sum_{j=1}^{n} \left| f_{ij} - f_j^+ \right|. \quad (6)$$

$$L_i^- = \sum_{j=1}^{n} \left| f_{ij} - f_j^- \right|. \quad (7)$$

Where L_i^+ is the positive distance, determination of the difference between real a_i and a^-;

L_i^- is the negative distance, determination of the difference between real a_i and a^-.

In the next stage relative similarity to the ideal point of the compared alternatives, $K_{bit,i}$ is obtained:

$$K_{bit,i} = \frac{L_i^-}{L_i^+ + L_i^-}. \quad (8)$$

Where $K_{bit,i}$ is the relative similarity of the compared s to ideal;

$K_{bit,i}$ alternative range is $0 \le K_{bit,i} \le 1$; if $K_{bit,i} = 1$, then $a_i = a^+$; if $K_{bit,i} = 0$, then $a_i = a^-$.

Priority queue is estimated according to $K_{bit,i}$ values.

In the last stage efficiency coefficient N_i of the compared alternatives is determined (Table 10).

$$N_i = \frac{K_{bit,i}}{K_{bit,\max}} \cdot 100 \;\%. \quad (9)$$

Where N_i is efficiency coefficient of the compared alternatives.

Practical Implementation of the TOPSIS Method in Selecting the most Efficient Solution to Construction Process Safety

The primary data obtained from the construction companies participating in the survey were systematized. Six alternatives (a_i) are compared in relation to six indicators (K_i), where:

K_1 is the evaluation of construction process safety solutions (max = 10, min = 1);

K_2 – labour expenditures, people/ workdays;

K_3 – level of work mechanization, %;

K_4 – level of worker qualification, in marks;

K_5 – coefficient of work coordination;

K_6 – coefficient of efficient use of work resources.

Primary data matrix P is created (Table 1).

Table 1

Indices / Alternative	K_1	K_2	K_3	K_4	K_5	K_6
a_1	8	3321	23	5.00	0.70	1.20
a_2	7	4010	20	4.75	0.78	1.45
a_3	8	3234	28	4.95	0.75	1.25
a_4	8	3506	22	4.60	0.68	1.50

Table 1 continued

a_5	7	3618	34	4.50	0.67	1.65
a_6	6	4312	25	4.30	0.60	1.70
Optimum	**max**	**min**	**max**	**max**	**max**	**min**

Matrix P is normalized to matrix $\overline{P}$ (Table 2).

Table 2

Indices / Alternative	K_1	K_2	K_3	K_4	K_5	K_6
a_1	0.443	0.368	0.365	0.435	0.409	0.333
a_2	0.388	0.444	0.317	0.413	0.456	0.403
a_3	0.443	0.358	0.444	0.431	0.438	0.347
a_4	0.443	0.388	0.349	0.400	0.397	0.417
a_5	0.388	0.401	0.539	0.392	0.391	0.458
a_6	0.332	0.478	0.396	0.374	0.350	0.472
Significance of indices %	**16.70**	**17.60**	**15.80**	**16.00**	**17.10**	**16.80**

Normalized matrix $\overline{P}^*$ is obtained (Table 3).

Table 3

Indices / Alternative	K_1	K_2	K_3	K_4	K_5	K_6
a_1	0.074	0.065	0.058	0.070	0.070	0.056
a_2	0.065	0.078	0.050	0.066	0.078	0.068
a_3	0.074	0.063	0.070	0.069	0.075	0.058
a_4	0.074	0.068	0.055	0.064	0.068	0.070
a_5	0.065	0.071	0.085	0.063	0.067	0.077
a_6	0.055	0.084	0.063	0.060	0.060	0.079
Optimum indices	**max**	**min**	**max**	**max**	**max**	**min**

Evaluation of ideal positive alternative a^+ and ideal negative alternative a^-. According to the acquired data maximum and minimum values are selected (Table 4).

Table 4

Positive corresponds	0.074	0.063	0.085	0.070	0.078	0.056
Negative corresponds	0.055	0.084	0.050	0.060	0.060	0.079

Positive distance L^+ between (a_i and a^+) and negative distance L^- between (a_i and a^-) are determined (Tables 5-8).

Table 5

Positive difference	1	2	3	4	5	6
1	0.000	0.002	0.028	0.000	0.008	0.000
2	0.009	0.015	0.035	0.003	0.000	0.012
3	0.000	0.000	0.015	0.001	0.003	0.002
4	0.000	0.005	0.030	0.006	0.010	0.014
5	0.009	0.007	0.000	0.007	0.011	0.021
6	0.018	0.021	0.023	0.010	0.018	0.023

Table 6

Positive distance L^+					
L_1^+	L_2^+	L_3^+	L_4^+	L_5^+	L_6^+
0.037	0.075	0.021	0.065	0.056	0.113

Table 7

Negative difference	1	2	3	4	5	6
1	0.018	0.019	0.008	0.010	0.010	0.023
2	0.009	0.006	0.000	0.006	0.018	0.012
3	0.018	0.021	0.020	0.009	0.015	0.021
4	0.018	0.016	0.005	0.004	0.008	0.009
5	0.009	0.014	0.035	0.003	0.007	0.002
6	0.000	0.000	0.013	0.000	0.000	0.000

Table 8

Negative distance L^-					
L_1^-	L_2^-	L_3^-	L_4^-	L_5^-	L_6^-
0.088	0.051	0.105	0.061	0.070	0.013

Relative similarity to ideal of the compared alternatives $K_{bit,i}$ is determined (Table 9).

Table 9

Similarity of alternatives compared to Ideal Solution $K_{bit,i}$					
$K_{bit,1}$	$K_{bit,2}$	$K_{bit,3}$	$K_{bit,4}$	$K_{bit,5}$	$K_{bit,6}$
0.704	0.406	0.832	0.483	0.557	0.100

Priority queue is determined according to $K_{bit,i}$ values:
$K_{bit,3} < K_{bit,1} < K_{bit,5} < K_{bit,4} < K_{bit,2} < K_{bit,6}$;
0,832 < 0,704 < 0,557 < 0,483 < 0,406 < 0,100.

Finally, efficiency coefficient N_i of the compared alternatives is determined (Table 10).

Table 10

Efficiency coefficient N_i of the compared alternatives					
N_1	N_2	N_3	N_4	N_5	N_6
84.52	48.81	100.00	58.06	66.89	11.98

Results of calculation are given in Figure 2.

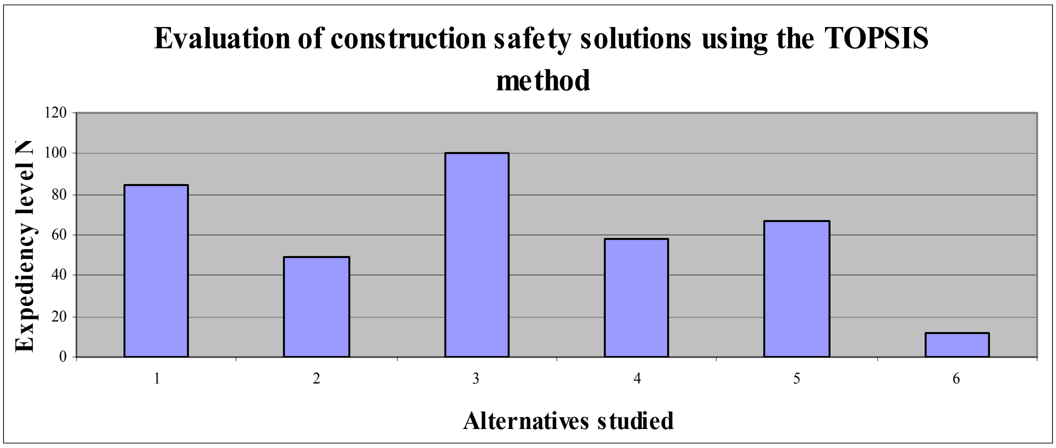

Figure 2. Results of calculations using the TOPSIS method

Conclusions

1. Upon accomplishing the similarity to ideal solution method calculation, the best safety solution from the six discussed alternatives was found, i.e., three (Figure 2): K_1 – 8 (evaluation of construction process safety solutions); K_2 – 3234 (labour expenditures), people/ workdays; K_3 – 28 (level of work mechanization), %); K_4 – 4.95 (level of worker qualification), in points); K_5 – 0.75 (coefficient of work coordination); K_6 – 1.25 (coefficient of efficient use of work resources).
2. This method allows construction companies to better evaluate (in terms of time and expenditure) issues which are not readily assessed quantitatively and qualitatively.
3. Application of this method together with criterion $K_{bit,i}$ makes it necessary to allow for the fact, that the efficiency function of each solution criterion increases or decreases monotonically. This means that a higher value of any index is always better or worse than a lower value of the same index, depending on whether the efficiency function increases or decreases.
4. The efficiency of construction process safety solutions depends on numerous quantitative and qualitative indices whose effect is estimated based on their value and significance.
5. This research shows, that when used for the evaluation of construction process safety solutions, the TOPSIS method makes it possible to better organize safe construction activities on the construction site.

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Statybos procesų saugos sprendimų nustatymas taikant artumo idealiam taškui metodą

Santrauka

Straipsnyje nagrinėjama problema, kaip pasirinkti statybos procesų saugos sprendimus, užtikrinančius darbuotojų saugą ir sveikatą statybos objektuose. Šiam tikslui pasiekti buvo išanalizuotos statybvietėse įvykstančių sunkių nelaimingų atsitikimų priežastys, išnagrinėti veiksniai, sukeliantys nelaimingus atsitikimus statybos įmonėse, išsamiai apžvelgta literatūra, įvertinanti statistinius duomenis bei darbuotojų saugos ir sveikatos gerinimo perspektyvas, panaudojimą atliekant statybos darbus. Pasirinkimo problema formuluojama matematiniu daugiatikslių sprendimų priėmimo uždaviniu. Šis uždavinys matematiškai išreiškia vadybinę sprendimo priėmimo problemą.

Šio darbo tikslas – taikant artumo idealiam taškui (TOPSIS) metodą nustatyti efektyviausią sprendimą, kurį turėtų priimti statybos įmonė, statanti gyvenamuosius namus tam, kad užtikrintų saugų darbą statybos procesų metu dirbantiems darbininkams.

Analizuojant statybvietėse įvykstančių sunkių nelaimingų atsitikimų priežastis, nustatyta, kad daugiau kaip du trečdaliai nelaimingų atsitikimų įvyksta dėl blogo darbų organizavimo, priežiūros ir kontrolės stokos, neįvertinus profesinės rizikos. Kad įvyksta daug traumų, lemia ne tik darbuotojų saugos ir sveikatos reikalavimų nesilaikymas, bet aplinkybės ir pažeidimai, susiję su eismo, priešgaisrinės bei elektros saugos reikalavimų nesilaikymu, taip pat darbo drausmės stoka, pasireiškiančia alkoholio vartojimu darbe, ir kitos priežastys. Kitos svarbios priežastys, turinčios tiesioginę įtaką nelaimingiems atsitikimams statybų sektoriuje, yra žinių ir mokymo stoka, supratimo, kaip saugiai atlikti pavestą darbą, stoka arba, kitaip sakant, neatsargumas. Tai vadinama „nesaugiu elgesiu" (angl. unsafe behavior). Yra teigiama, kad „nesaugus elgesys" yra vienas iš svarbiausių veiksnių, turinčių įtaką nelaimingiems atsitikimams darbe.

Nagrinėjant nelaimingus atsitikimus darbe statybos įmonėse pagal žalojančius veiksnius, dažniausiai pasitaikantys veiksniai yra kritimas iš aukščio, susidūrimas su transporto priemone, griuvimas ir suklupimas, krentantys daiktai. Dėl šių priežasčių įvyksta sunkūs ir mirtini nelaimingi atsitikimai.

Remiantis Stewart, daugeliu atvejų nepakanka tiesiog išsiaiškinti pagrindinę nelaimingų atsitikimų priežastį, todėl svarbu nustatyti kitus veiksnius, kurie turi įtakos sistemos veikimo laikotarpiu. Paprastai nelaimingi atsitikimai atsitinka sąveikaujant daugeliui pavojingų veiksnių, tarp kurių rizikos veiksniai paprasčiausiai nenustatomi. Anot Kletz, nedominuojantiems rizikos veiksniams ir sąveikai tarp pavojingų veiksnių neskiriama pakankamai dėmesio.

Šiame straipsnyje atsižvelgta į tai, kad vykdant įvairius statybos procesus saugų darbą gali užtikrinti ne tik kolektyvinių, asmeninių priemonių naudojimas, profesinės rizikos įvertinimas, darbuotojų instruktavimas saugos klausimais, bet ir tinkamas darbų organizavimas bei darbo sąlygų sudarymas. Norint visa tai įgyvendinti, būtina priimti geriausią sprendimą. Vienas iš metodų, padedantis lemti statybos įmonės atliekamų darbų saugaus darbo prioritetus, yra artumo idealiam taškui (TOPSIS) metodas.

Statybos proceso saugos sprendimų efektyvumo lygis priklauso nuo daugelio jį veikiančių kiekybinių ir kokybinių rodiklių, kurių įtaka yra vertinama pagal šių rodiklių reikšmes ir reikšmingumus. Kintant kiekybinių ir kokybinių rodiklių reikšmėms, kinta jų reikšmingumas, todėl būtina atsižvelgti į jų reikšmes. Taip pat būtina tarpusavyje suderinti kiekybinių ir kokybinių rodiklių reikšmingumus, atsižvelgiant į rodiklių reikšmes ir reikšmingumą. Minėtiems tikslams įgyvendinti buvo sukurtas autorių kompleksinis rodiklių reikšmingumo, atsižvelgiant į jų kokybines ir kiekybines charakteristikas, nustatymo metodas.

Straipsnyje trumpai aprašomas nagrinėjamų objektų ir rodiklių parinkimas. Atlikta anoniminė apklausa pagal parengtas apklausos

anketas. Apklausoje dalyvavo šešios vidutinio dydžio statybos įmonės, kurios stato individualius gyvenamuosius namus. Nagrinėjamu objektu pasirinktas individualus vieno aukšto su mansarda, be rūsio gyvenamasis namas.

Taip pat nurodomi statybos įmonių pasirinkimo kriterijai: įmonės dydis, turimo kapitalo dydis, atsakomybė, pelno pasiskirstymas, valdymo ypatumai ir įmonės kontrolė, mokesčių ypatumai.

Apklausoje dalyvavusios statybos įmonės straipsnyje įvardytos kaip šešios alternatyvos: a_1, a_2, a_3, a_4, a_5, a_6. Nagrinėjamų variantų prioretitiškumas ir reikšmingumas tiesiogiai ir proporcingai priklauso nuo alternatyvas apibūdinančių rodiklių sistemos, jų reikšmių ir reikšmingumo dydžių. Tam buvo parinkti šeši rodikliai K_1, K_2, K_3, K_4, K_5, K_6: statybos procesų saugos sprendimų įvertinimas (max = 10, min = 1); darbo sąnaudos, žm. d. d.; darbų mechanizavimo lygis, %; darbininkų kvalifikacijos laipsnis, balais; darbų suderinimo koeficientas; tolygaus darbo išteklių panaudojimo koeficientas.

Statybos procesų saugos sprendimų įvertinimą pateikė žmonių grupė, kurią sudarė nepriklausomi valstybinės darbo inspekcijos darbuotojai. Jie statybos procesų saugos sprendimus vertino pagal bendrus kriterijus, juos analizavo ir įvertino kaip maksimaliai atitinkančius poreikius (geriausiam sprendimui skiriama 10 taškų, blogiausiam sprendimui – 1 taškas).

Darbo ir mechanizmų sąnaudos, darbininkų kvalifikacijos laipsnis apskaičiuojamas remiantis „Darbo, medžiagų ir mechanizmų sąnaudų normatyvais“. Darbo sąnaudos – tai žmonių darbo dienos, susumuotos iš suskaičiuotų sąmatų kiekvieno nagrinėjamo varianto atskirai. Darbų mechanizavimo lygis – tai mechanizmų poreikio nustatymas iš suskaičiuotų sąmatų kiekvieno nagrinėjamo varianto atskirai. Darbininkų kvalifikacijos laipsnis – vidutinė visiems atitinkamo nagrinėjamo varianto darbams atlikti reikalingų darbininkų kategorijų suma, padalyta iš bendro jų skaičiaus.

Darbų suderinamumo ir tolygaus darbo išteklių panaudojimo koeficientai nustatyti remiantis technologiniais organizaciniais sprendimais. Šį įvertinimą pateikė žmonių grupė, kurią sudarė atskirai nagrinėjamos statybų įmonės darbuotojai.

Straipsnyje pateikiamas efektyviausio statybos proceso saugos sprendimo priėmimo praktinis pritaikymas taikant artumo idealiam taškui metodą. Artumo idealiam taškui metodo esmė – apibendrinto rodiklio $K_{bit,i}$ formavimas, remiantis lyginamųjų variantų nukrypimu nuo vadinamojo idealaus, susidedančio iš geriausių nagrinėjamų variantų rodiklių. Taikant šį metodą, reikia atsižvelgti į tai, kad kiekvieno sprendimų varianto kriterijaus naudingumo funkcija monotoniškai didėja arba monotoniškai mažėja, t. y. didesnė bet kurio rodiklio reikšmė visada geresnė arba blogesnė už mažesnę to paties rodiklio reikšmę. Tai priklauso nuo to, ar naudingumo funkcija didėja, ar ji mažėja. Kadangi kiekvieno rodiklio reikšmės nuolat didėja arba nuolat mažėja, tai leidžia nustatyti „idealų“ sprendimą, kuris sudarytas iš geriausių rodiklių reikšmių, ir „neigiamai idealų“ sprendimą, kuris sudarytas iš blogiausių rodiklių reikšmių.

Šiam tikslui pasiekti, naudojant apklausą, surinkti pradiniai duomenis iš apklausoje dalyvavusių statybos įmonių. Gauti duomenys buvo susisteminti. Lyginamos šešios alternatyvos (a_i) pagal šešis rodiklius (K_i).

Taip pat apklausoje dalyvavo dvylika ekspertų. Ekspertų pateikti duomenys buvo susisteminti ir nustatyti rodiklių reikšmingumai. Sukurta sprendimų matrica *P*. Rodiklių reikšmingumas nustatytas remiantis sprendimų priėmimo matrica (1 lentelė) ir (1 – 9) formulėmis.

Išvados:

1. Atlikus artumo idealiam taškui metodo skaičiavimą, paaiškėjo šešių nagrinėjamų alternatyvų efektyviausias saugos sprendimų užtikrinimas, t. y. trečias variantas (2 pav.): K_1 – 8 (statybos procesų saugos sprendimų įvertinimas); K_2 – 3234 (darbo sąnaudos, žm. d. d.); K_3 – 28 (darbų mechanizavimo lygis, %); K_4 – 4.95 (darbininkų kvalifikacijos laipsnis, balais); K_5 – 0.75 (darbų suderinimo koeficientas); K_6 – 1.25 (tolygaus darbo išteklių panaudojimo koeficientas).

2. Šio metodo nauda statybos įmonių veikloje yra ta, kad šiuo metodu gana greitai ir kuo mažesnėmis išlaidomis galima įvertinti sunkiai kiekybiškai ir kokybiškai apibūdinamus dalykus.

3. Taikant šį metodą ir naudojant $K_{bit,i}$ kriterijų, reikia atsižvelgti į tai, kad kiekvieno sprendimų varianto rodiklio naudingumo funkcija monotoniškai didėja arba monotoniškai mažėja, t. y. didesnė bet kurio rodiklio reikšmė visada geresnė arba blogesnė už mažesnę to paties rodiklio reikšmę. Tai priklauso nuo to, ar naudingumo funkcija didėja, ar ji mažėja.

4. Statybos proceso saugos sprendimų efektyvumo lygis priklauso nuo daugelio jį veikiančių kiekybinių ir kokybinių rodiklių, kurių įtaka yra vertinama pagal šių rodiklių reikšmes ir reikšmingumus.

5. Atlikti tyrimai parodė, kad statybos procesų saugos sprendimų organizavimo įvertinimas, taikant artumo idealiam taškui metodą, įgalina efektyviau organizuoti statybos procesų saugų vykdymą statybvietėje.

Raktažodžiai: *artumo idealiam taškui (TOPSIS – Technique for Order Preference by Similarity to Ideal Solution) metodas, nelaimingi atsitikimai, profesinė liga, pavojingas veiksnys, rizikos veiksnys, statybos procesas, saugos sprendimas.*

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