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An analysis of the influence of selected factors
on the accident rate in the construction industry

Analiza wpływu wybranych czynników na wypadkowość
w budownictwie

Abstract

This paper presents the results of research aimed at constructing a linear mathematical model that determines the influence of selected factors characterising construction production on the accident rate in the construction industry. A number of linear multi-factor mathematical models were developed, which were then compared with each other, and those that best described the analysed phenomena were selected.

Keywords: accident factor, occupational accident, construction and assembly production, linear multi-factor mathematical model

Streszczenie

W artykule zawarto rezultaty badań, których celem było zbudowanie liniowego modelu matematycznego określającego wpływ wybranych czynników charakteryzujących produkcję budowlaną, na wypadkowość w budownictwie. Opracowano kilkanaście liniowych wieloczynnikowych modeli matematycznych, które następnie porównano ze sobą i wytypowano te, które najlepiej opisują analizowane zjawisko.

Słowa kluczowe: czynnik wypadkowy, wypadek przy pracy, produkcja budowlano-montażowa, liniowy wieloczynnikowy model matematyczny

1. Introduction

The construction industry is a very diverse area of human activity. Due to the large variety of buildings and construction works related to their execution, and also the ever-changing conditions of construction, there are a number of factors that may affect the accident rate in the construction industry. These include factors directly related to the manufacturing process which directly generates causes of accidents and also many unidentified factors that indirectly influence the development of accidents. Whilst the direct factors are well recognized [1–10], knowledge about indirect factors is limited [11].

When analysing the statistical data published by the Central Statistical Office (CSO), it can be noted that the values of indicators that describe the construction industry with regards to occupational safety and also the size of construction and assembly production are changing each year. Based on this observation, the authors of the article undertook research that aimed to define the factors that describe the specificity of the construction industry and also investigate whether and how these factors affect the accident rate.

The final result of the research is a collection of mathematical models describing the phenomenon of accidents in the construction industry which takes into account the influence of the defined factors on the occurrence of accidents. These models can be used to forecast the number of people who will be injured in occupational accidents in the construction industry in relation to the changing structure of construction and assembly production.

2. Factors describing the construction industry

Table 1 summarises the factors that characterise the construction industry which were defined on the basis of statistical data published by the CSO [12, 13].

Table 1. Analysed factors with their designations

Lp.	Main factor	Component factors	Adopted designation
1	the size of construction and assembly production	size of production executed by: construction entities – in general	W
2		entities employing more than 9 people	W_+
3		entities employing less than 10 people	W_-
4		the size of production associated with: construction of buildings	W_B
5		construction of civil engineering objects	W_{LW}
6		specialised construction works	W_S

7		size of production associated with: the construction industry – in general	I
8	the size of construction and assembly production with regards to investments	construction of buildings	I_B
9		construction of residential buildings	I_{BM}
10		construction of non-residential buildings	I_{BN}
11		construction of civil engineering objects	I_{LW}
12	the size of construction and assembly production with regards to renovation works and other works	size of production associated with: the construction industry – in general	R
13		renovation of buildings	R_B
14		renovation of residential buildings	R_{BM}
15		renovation of non-residential buildings	R_{BN}
16		renovation of civil engineering objects	R_{LW}
17	occupational safety	total number of people injured in occupational accidents	P

Each of the factors defined in Table 1 is described numerically by adding the corresponding value of the construction works to it. The occupational safety aspect (factor 17) is described by the number of people injured in occupational accidents. By knowing the numerical values of the above factors, it is possible to determine the degree of dependence between a given factor and the number of occupational accidents. Statistical data [12, 13] for 16 voivodships in Poland from 2005 to 2015 was used in the calculations. Some of the data concerning the voivodship of Lower Silesia which was adopted for the calculations is presented in Table 2.

Table 2. Fragment of statistical data for the voivodship of Lower Silesia that was adopted for the calculations

No.	Factor - according to the adopted designations		Year				
			2005	...	2010	...	2015
1 17	W	PLN mln	6888.7	...	13036.9	...	14656.7
	I		1976.1	...	3766.4	...	4208.7
	R		999.4	...	2565.7	...	2518.7
	P	people	593	...	776	...	443

3. General mathematical model of the analysed phenomenon

A multiple linear regression model was adopted for the description of the impact of the defined factors on occupational safety [14]. In this model, a response variable is the number of victims, and explanatory variables are the values of appropriately selected factors. The choice of such a model is dictated by the fact that it is the simplest and most correct method of determining the impact of factors on the accident rate when the functional form of this dependence is unknown. In addition, as has been demonstrated in previous studies [15], all analysed factors show relationships that are close to being linear. The analysis was performed using the MATLAB package, and the general form of a model for i explanatory variables is as follows:

$$P = b_0 + b_1 x_1 + b_2 x_2 + ... + b_i x_i + ... + b_I x_I + \varepsilon \tag{1}$$

where:

P – the response variable – the number of people injured in occupational accidents in the construction industry,

x_i – the independent explanatory variables – the numerical values of factors defined in Table 1, $(i=1,...,I)$,

b_0 – the absolute term,

b_i – the parameters of the model, $(i=1,...,I)$,

ε – a random component – the rest of the model.

The least squares method was used to estimate the parameters. This method applies such an adjustment to the model's b_i parameters so that the mean square error of the difference between the individual $\hat{P}$ values generated by the model and the empirical values P corresponding to them was as small as possible. As quality meters for the assessment of the adjustment of the model to empirical values, the following were used [14, 16]: the multiple correlation coefficient R_p; coefficient of determination R^2; Mean Squared Error (MSE) and Root Mean Squared Error (RMSE).

4. Mathematical model of the dependence between the number of occupational accidents on the value of construction and assembly production

Due to the complexity of the phenomenon, ten different mathematical models were developed which take into account various factors. The selection of explanatory variables for each model was made on the basis of the analysis of the structure and also the correlation matrix of factors. In the analysed case, the structure of factors is strongly hierarchical. For example, factor W can be decomposed into factors W_+ and W_-, while the sum of the values of these factors is equal to the value of production described by factor W. The choice of explanatory variables was based on the desired level of detail. Table 3 summarises the obtained mathematical models.

Table 3. Summary of mathematical models

No.	Mathematical models
1	$P = 132.335 + 0.041W$
2	$P = 129.042 + 0.039W_+ + 0.044W_-$
3	$P = 119.080 + 0.028W_B - 0.022W_{LW} + 0.183W_S + 0.036W_-$
4	$P = 152.551 + 0.008I + 0.211R$
5	$P = 133.290 + 0.003I + 0.194R + 0.014W_-$
6	$P = 127.237 + 0.031I_B + 0.00465I_{LW} + 0.048R_B + 0.278R_{LW}$
7	$P = 91.487 + 0.035I_B - 0.013I_{LW} + 0.004R_B + 0.270R_{LW} + 0.023W_-$
8	$P = 119.388 - 0.014I_{BM} + 0.048I_{BN} - 0.001I_{LW} + 0.518R_{BM} - 0.147R_{BN} + 0.294R_{LW}$
9	$P = 89.386 - 0.027I_{BM} + 0.057I_{BN} - 0.017I_{LW} + 0.419R_{BM} - 0.165R_{BN} + 0.286R_{LW} + 0.022W_-$
10	$P = 80.032 - 0.368W_B - 0.334W_{LW} - 0.289W_S + 0.015W_+ + 0.368I_{BM} + 0.364I_{BN} + 0.335I_{LW}$ $+ 0.742R_{BM} + 0.187R_{BN} + 0.618R_{LW}$

In the next stage, the models were compared. For this purpose, the above-mentioned factors were used: R_P, R^2, R_S^2, MSE and $RMSE$. The values of these coefficients for all the models are given in Table 4. The best adjustment of the model to the actual values is obtained when R_P, R^2, and R_S^2 are close to unity, and MSE and $RMSE$ have low values.

Table 4. Summary of parameters characterising the obtained mathematical models

No.	R_P	R^2	R_S^2	MSE	$RMSE$
1	0.82	0.68	0.68	45283	212
2	0.82	0.68	0.67	45526	213
3	0.82	0.69	0.68	44465	210
4	0.87	0.77	0.77	34314	185
5	0.87	0.77	0.77	34128	184
6	0.91	0.84	0.84	20751	144
7	0.92	0.85	0.85	19841	140
8	0.92	0.85	0.84	20188	142
9	0.92	0.78	0.76	19419	139
10	0.93	0.87	0.85	18806	137

Based on analysis of Table 4, it can be seen that the "best" models:
- due to the value of the R_P coefficient, are models 10, 9, 8 and 7;
- due to the value of the R^2 coefficient, are models 10, 8, 7 and 6;
- due to the value of the R_S^2 coefficient, are models 10, 7, 8 and 6;
- due to the value of the measure of variability MSE and $RMSE$, are models 10, 9, 7 and 8.

Although model 10 has the best values of the analysed indicators, it will not be considered in further analysis due to the large number of parameters included in it; practical use of this model is more laborious. Out of the remaining 4 models, model 9 was also eliminated due to the lower value of the R_S^2 coefficient when compared to the other models.

Finally, it should be stated that the best and most consistent models are models 8, 7 and 6. They show similar values of coefficients R_p, R^2 and R_S^2, and small differences in values of *RMSE*. These models will be used in further studies to predict the number of victims of occupational accidents in the construction industry.

5. Summary

On the basis of statistical data published by the CSO, 16 factors were identified that describe construction and assembly production, and these characterise: business entities performing construction works, the size of construction production related to investments and renovations, and also the type of executed building objects.

A linear multiple regression model was used to describe the impact of the defined factors on occupational safety. In this model, the response variable is the number of victims injured in occupational accidents and the explanatory variables are the analysed factors. As a result of the conducted analyses, ten mathematical models that describe the studied phenomenon were obtained, each of which differed in the number and type of explanatory variables.

Based on the analysis of the values of the evaluation measures, models 8, 7 and 6 were selected as the best models. These models will be used to assess the risk of the occurrence of construction disasters, accidents and hazardous events at workplaces that involve construction scaffolding in order to predict the number of people injured in occupational accidents in the construction industry.

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