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Research paper

Evaluation of the influence of selected factors on hazardous events in construction

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Abstract: The article analyzes factors that may have an impact on Occupational Safety in a construction company and the issues of work safety in construction were discussed. An attempt was made to analyze the management of work safety in construction companies in order to identify important factors and determine the significance of their participation in the occurrence of accidents at work. The research was carried out on the basis of data obtained from the register kept at the District Labor Inspectorate in Krakow. Cases which were discussed included accident protocols prepared pursuant to the law, as well as cases found in protocols of ad hoc inspections carried out on construction sites. There were quantitative and qualitative features in the analyzed data set. Logistic regression was used to analyze the data to build the model. Such action made it possible to model and determine the significance of the influence of individual variables characterizing the way of managing work safety in construction companies, in the case of an accident. The results obtained, and in particular the significance of factors shown in the model, even not directly related to the construction site, may be an indication for creating a functional strategy in the enterprise. The strategy assuming: smaller number of accidents or adverse events, shorter downtime will build a reputation of an institution that cares for the employee. This will allow the construction company to become more competitive and shall attract the best professionals available on the labor market. The end result is the identification of key factors that have a direct impact on work safety and the competitiveness of a construction company.

Keywords: work safety, management, construction company

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1. Introduction

A large number of accidents in the construction industry makes the problem of work safety in construction companies of particular importance. It is very actual and requires constant commitment. This reality suggests that despite many publications on the subject of occupational safety [1–5], research should still be carried out and actions taken to effectively prevent accidents. The reality on construction sites in terms of the scale of negligence, factors and disorderly phenomena leading to accidents at work indicate a low level of implementation of occupational health and safety management systems or deficiencies in its application. It exemplifies itself in neglection of the availability of relevant documentation provided for by law and instructions, as well as employee training. Bearing the above in mind, an attempt was made to examine the actual level of implementation of occupational health and safety management systems in construction companies operating in Małopolska. The research used accident protocols and reports on ad hoc inspections prepared by the District Labor Inspectorate in Krakow in 2018–2020. A research problem was formulated consisting assessment of the significance of the factors obtained as part of the analysis in the available documents. The following factors were analyzed: the level of implementation of the OHS management system and available documentation, employee motivation, the type of impact on the employee in a construction company and methods of employee training. In particular, during the research, attention was paid to factors that have so far been overlooked or marginalized, appearing in the protocols, both in the linguistic and procedural form. The often-descriptive information on the advancement, regularity and quality of training was analyzed. When analyzing the OHS documentation and employee motivation, attention was paid to compliance with the standards of working time and the availability of personal protective equipment for employees. In terms of methodology, and a statistical classifier was used in the form of logistic regression. The research method proposed in the article and the subject of research are a proposal to expand the knowledge base in terms of the development of scientific methods of assessing work safety on construction sites and in terms of the possibility of using them in practice.

2. Health and safety documentation in a construction company

Complete, structured OHS documentation, in line with the existing or implemented safety management system in a construction company, form a basis on which to build a company's functional strategy[1], and thus gain an advantage in the market of construction companies. Moreover, properly completed and maintained health and safety documentation [13] at the construction site and throughout the construction company should be kept not only for the purpose of OIP labor inspections, but also for the benefit of employees and own safety. The tasks of the labor inspection include carrying out inspections after

[1] H. Mintzberg: Structure in Fives, (functional strategies – activities at the operating unit level).

an accident. Properly prepared records, required by law, constitute one of the sources of evidence in the post-accident proceedings. For a construction company, duly kept documentation provides arguments for defense, in the case of allegations of non-compliance with the requirements and provisions of health and safety at work.

The occupational health and safety documentation [12] in the construction company and at the construction site was divided into documentation related to:

– construction process (works) [14],
– employment of employees,
– operation of machinery and technical devices [15].

Legal requirements included in the labor code, ordinances and guidelines define the basic documents that must be held when running a business in a construction company [15–19]. Among the other:

– notification to the district labor inspection,
– health and safety plan:
  • organization of traffic on the construction site,
  • instructions for safe execution of works,
  • OHS instruction for the storage and storage of materials and raw materials.
– appointment of a health and safety coordinator,
– list of particularly dangerous works,
– health and safety requirements for particularly dangerous works,
– health and safety instructions,
– risk assessment,
– geological documents.

Considering the specificity and type of works carried out on the construction site, the variety of erected buildings and their location, not all of the described documents must be present when conducting a specific investment.

3. Structurising and ordering data

The following information was used and analyzed in the analysis of the data. The data contained in accident reports and reports on ad hoc inspections performed by Labor Inspectorates are arranged in the manner presented in Tables 1, 2, 3, 4 and 5.

The analysis of the protocols allowed to compile the obtained data in a tabular form:

– Table 1 – the specificity of the construction site includes information directly related to the conducted construction activity for a given investment, corresponding to health and safety.
– Table 2 – the employee training method includes information often in a descriptive form, on the advancement, regularity and quality of training.
– Table 3 – the type of impact on the employee includes information on supervision over the employee, both direct (e.g., supervision over hazardous works) and indirect (e.g., time records).

Table 1. Specifying the construction site

X1	Number of employees
X2	Work experience of the injured [years]
X3	Type of works (1 – at height, in a trench, 0 – none)
X4	State of mechanization of works (1 – mechanized works, 0 – none)
X5	Conditional sources of technical negligences stated (technical/human)
X6	Personal protective equipment (1 – available, 0 – none)
X7	Collective protection measures (1 – available, 0 – none
X8	Scaffolding safety railings (1 – available, 0 – none)
X9	Covers and protection of dangerous elements of machines and devices (1 – available, 0 – none)
X10	Tolerance by supervision of deviations from OHS rules (1 – tolerated, 0 – no tolerance)

Source: own study.

Table 2. Employee training method

X11	Employee training method
–	complete set of documents (no reservations)
–	detailed instructions to familiarize the employee with the existing health and safety documentation (5 stages of training) and message evaluation
–	detailed instructions to familiarize the employee with the existing health and safety documentation (5 stages) and evaluation of the knowledge and verification of the acquired knowledge
–	detailed instructions to familiarize the employee with the existing health and safety documentation (5 stages) and evaluation of the knowledge and verification of the acquired knowledge and familiarizing the employee with the required existing health and safety instructions
–	only the basic course provided for by the regulations (workplace training)
–	lack of employee training

Source: own study.

Table 3. Type of impact on the employee

X12	Supervision of hazardous works (1 – available, 0 – none)
X13	Log of OHS trainings (1 – available, 0 – none)
X14	Record of working time (e.g. crane operator) (1 – available, 0 – none)
X15	Occupational risk (employee self-knowledge declaration) (1 – available 0 – none)

Source: own study.

- Table 4 – employee motivation includes information on the form of employment of an employee, his identification with a construction company, as well as obtained rights and qualifications. The data also shows care for such aspects of work as equipping the employee with clean, efficient and ergonomic protective clothing and access to personal protective equipment and sanitary facilities.
- Table 5 – covers issues related to the level of implementation of the OHS system and the correctness of the documentation kept.

Table 4. Employee motivation

X16	Form of employment – sole proprietorship
X17	Form of employment – employment contract for an indefinite period
X18	Form of employment – employment contract for a specified time
X19	Form of employment of the employee – civil contract
X20	Qualifications and permission for the operation of construction machinery and equipment under supervision (1 – available, 0 – none)
X21	Hygienic and sanitary rooms (1 – available, 0 – none)
X22	Medical certificates (1 – available, 0 – none)
X23	List and documentation of clothing, footwear and personal protective equipment in the company (1 – available, 0 – none)
X24	Record cards for the employee for clothing, footwear and personal protective equipment in the company (1 – available, 0 – none)
X25	Training certificates and documentations upon admission to work (1 – available, 0 – none)

Source: own study.

Table 5. The level of implementation of the OHS system – documentation

X26	Notification to the labor inspection (1 – reported, 0 – none)
X27	Safety and health protection plan (1 – available, 0 – none)
X28	Health and Safety Coordinator (1 – appointed, 0 – none)
X29	List of particularly dangerous works (1 – available, 0 – none)
X30	OHS instructions (1 – available, 0 – none)
X31	Occupational risk assessment (1 – available, 0 – none)
X32	Health and safety documentation related to the operation of machinery and technical devices (1 – available, 0 – none)
X33	Operation and maintenance manual (1 – available, 0 – none)
X34	Documentation from technical inspection authority (1 – available, 0 – lack)

Source: own study.

The obtained data was imported to the Statistica [10] program and then cleaned and prepared for analysis [9]. The transformations that have been made include:

– Transformation of the six binary variables marked with X11 into one categorical variable.
– Removal of cases with missing data.

As a result, a data set containing 37 variables and 425 cases was obtained:

– Two-state dependent variable Y; NO – no accident, YES – occurrence of an accident.
– Three-state ordinal dependent variable Y3, S – fatal accident, C – severe accident, L – light accident.
– Quantitative dependent variable Y1.
– Two quantitative independent variables (X1, X2).
– Thirty-one categorical independent variables (X3-X34).

4. Characteristics of the study sample

Quantitative variables

Standard descriptive statistics were calculated for continuous variables [8]. They have been collected in Table 6.

In addition, the distribution of values for these variables is shown in Fig. 1.

Table 6. Descriptive statistics of the variable X1 and X2

	Valid N	Average	Minimum	Maximum	Standard deviation.
X1	431	35.39	3.00	241.00	43.85
X2	431	1.15	0.00	16.00	3.33

Source: own study.

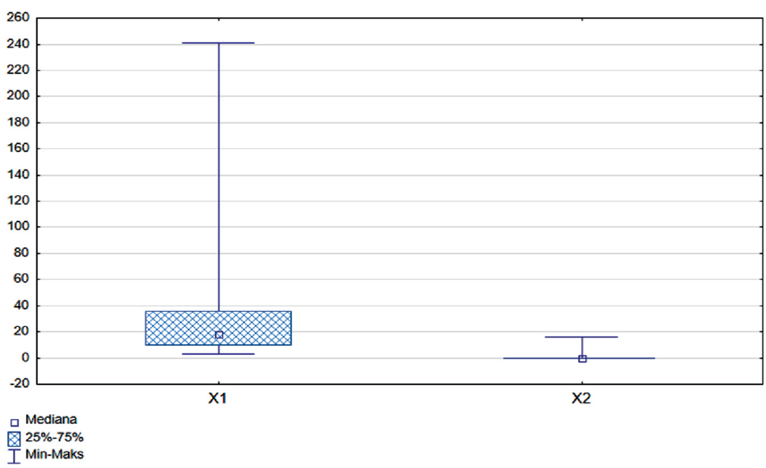

Fig. 1. Frame chart of quantitative variables: X1 – the number of employees and X2 – the length of service of the injured person. Source: own study

Categorical variables

Frequency tables were created for categorical variables. From the tables, we can read how often the selected variable took a given value. Below (Table 7), for example, there are results for the variable X3, where the variable X3 takes the value 1, for works at height or in a excavation and 0 for other works.

Table 7. Descriptive statistics of variable X3 (type of works)

	Number	Percent
0	288	66.82
1	143	33.18
Deficiencies	0	0.00

Source: own study.

The data set includes 143 works carried out at heights, which accounted for 33.18% of the considered construction sites. 288 are construction sites where work was carried out in the excavation. There were no missing data for this variable. The described results were also presented by means of a histogram (Fig. 2), thanks to which it is easy to quickly assess which group was the largest [11].

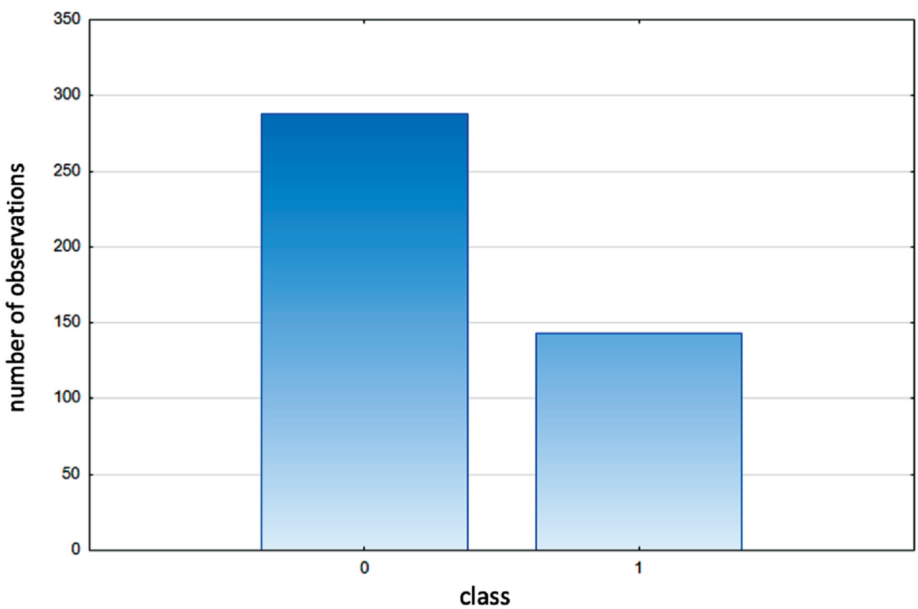

Fig. 2. Histogram of variable X3 – type of works. Source: own study

5. Model of logistic regression

Logistic regression was used to solve the research problem. In the construction of the multivariate logistic regression model [6], the independent variables for which the existence of a statistically significant relationship with the occurrence of an accident at an earlier stage of the work were found and were taken into account. The p-value was cut off as 0.1.

As a result, the following variables were considered: X3, X5, X7, X8, X11, X12, X13, X14, X20, X21, X22, X23, X24, X25, X27, X28, X29, X33. The data set has been divided into two parts – the so-called training set and the test set. The use of the division into the training set and the test set is the most frequently used technique for building and verifying the model. Thanks to this, it is possible to avoid the overfitting effect (over-fitting to historical data), as well as to check the ability of the model to generalize, and thus the usefulness of the model in practice. In order to build a model containing only statistically significant variables, a stepwise algorithm was used [7]. It is a method that allows to narrow the set of variables in the model only to those for which a statistically significant relationship with the dependent variable has been demonstrated. The results are presented in Table 8.

Table 8. Step algorithm narrowing the set of variables

	Level	Rating	Confidence interval lower boarder	Confidence interval upper boarder	p
Constant term		–0.62	–1.71	0.48	0.27
X8	1	–2.88	–3.94	–1.81	< 0.001
X3	1	3.68	2.69	4.68	< 0.001
X23	1	–1.21	–1.98	–0.44	< 0.01
X28	1	1.35	0.40	2.31	0.01
X13	1	–0.41	–1.25	0.42	0.33
X7	1	1.10	0.36	1.83	0.00

Source: own study.

The logistic function determining the probability of an accident has been read from the table above:

$$\begin{aligned}(5.1)\quad \mathrm{logit}(Y = YES) = -0.62 - 2.88 \cdot X8(1) + 3.68 \cdot X3(1) - 1.21 \cdot X23(1)\\ + 1.35 \cdot X28(1) - 0.41 \cdot X13(1) + 1.10 \cdot X7(1).\end{aligned}$$

The entry X8 (1) means a situation when the variable X8 takes the value 1 – in this case it is the presence of protective railings, X3 (1) means work at height, X23 (1) list and documentation of clothing, ob. work and industrial protection measures. in the company, X7 (1) application of collective protection measures, X28 (1) OHS coordinator, X13 (1) OHS training logbook.

The importance of these variables is shown in Fig. 3.

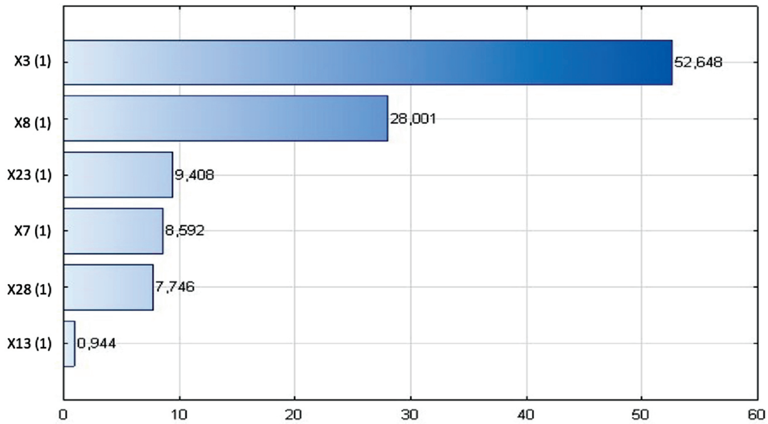

Fig. 3. Predictor Importance Graph. Dependent variable: Accident. Source: own study

As before, for easier interpretation, the coefficients were converted into odds ratios (references to individual rows / cells are color-coded, Table 9).

Table 9. The odds ratio (OR)

	Level	The odds ratio (OR)	Confidence interval lower boarder	Confidence interval upper boarder	p
X8	1	0.06	0.02	0.16	< 0.001
X3	1	39.81	14.72	107.68	< 0.001
X23	1	0.30	0.14	0.65	< 0.01
X28	1	3.87	1.49	10.05	0.01
X13	1	0.66	0.29	1.52	0.33
X7	1	3.00	1.44	6.25	0.00

Source: own study.

An exemplary interpretation is as follows: if the variable X23 takes the value 1, then the linear part of the model decreases by 1.21, and consequently the accident odds ratio decreases by a factor of 0.3 (we can read it from the Odds ratio column in Table 7). This means that the chance of an accident is reduced by 70% (1–0.3).

Match evaluation

In order to assess the usefulness of the model, it was checked how well it separates "good" from "bad" cases. The better is the model, the more the results calculated for accident situations differ from those in which the accident did not occur. The quality of the model can be explored, inter alia, using the described measures and ROC curves. The model quality measures for the two-state dependent variable are determined based on the error matrix (Table 10). It is an array made up of two rows and two columns. Rows show the target classes and the columns show the actual classes. The cells contain values that indicate the number of systems of a given type when comparing the actual values with those predicted by the model.

Table 10. Error matrix

		Real class	
		Positive	Negative
Anticipated class	Positive	TP	FP
	Negative	FN	TN

Source: own study.

where:
- TP (True positive) means how many times the model correctly predicted the event (positive class),
- TN (True negative means how many times the model correctly predicted the absence of an event (negative class),
- FP (False positive) means how many times the model has incorrectly predicted the event (positive class),
- FN (False negative) is the number of times the model has incorrectly predicted the absence of an event (negative class).

The assessment of the model fit is presented in Table 11

Table 11. Evaluation of the model fit

Fitting	Training set	Test set
Sensitivity	0.52	0.61
Specificity	0.94	0.94
PPV	0.72	0.73
NPV	0.88	0.89
Precision	0.86	0.86

Source: own study.

where:

• **Sensitivity (TPR)**

Sensitivity tells us what percentage of objects that actually belong to the state distinguished by the model has been correctly classified.

$$\text{Sensitivity} = \frac{\text{TP}}{\text{TP} + \text{FN}} \tag{5.2}$$

- **Specificity (TNR)**

Specificity tells you what percentage of objects that actually belong to the undifferentiated state has been correctly classified by the model.

$$\text{Specificity} = \frac{\text{TN}}{\text{TN} + \text{FP}} \tag{5.3}$$

- **Precision (PPV)**

Precision tells what percentage of objects classified by the model to the distinguished state actually belongs to it.

$$\text{Precision} = \frac{\text{TP}}{\text{TP} + \text{FP}} \tag{5.4}$$

- **Negative predictive value (NPV)**

The negative predictive value tells what percentage of objects not classified by the model to the distinguished state actually do not belong to it.

$$\text{Negative predictive value} = \frac{\text{TN}}{\text{TN} + \text{FN}} \tag{5.5}$$

- **Accuracy (ACC)**

Accuracy tells what fraction of objects was positively classified

$$\text{Accuracy} = \frac{\text{TP} + \text{TN}}{\text{TP} + \text{TN} + \text{FP} + \text{FN}} \tag{5.6}$$

The table above shows that the model in the test set correctly classified 86%, including 61% correctly predicting the occurrence of an accident, and its absence in 94%. The values of the measures on the training and test sets are similar, which means that the model is not overfitted -and there has been no excessive adjustment to the data and the predictions are reliable. The sensitivity and specificity plot for the fitted model is shown in Fig. 4.

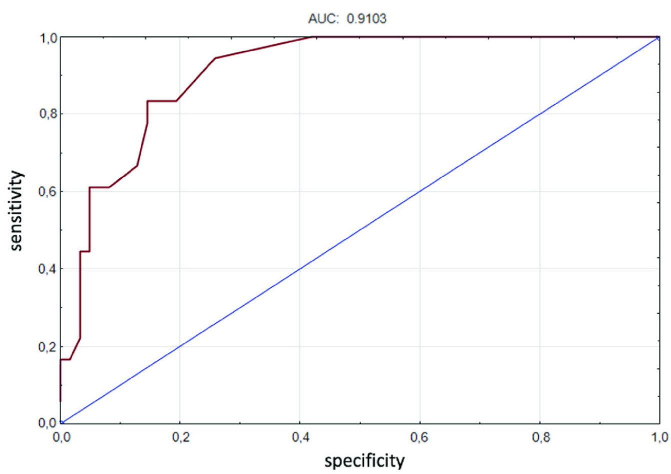

Fig. 4. ROC curve for the selected model. Source: own study

The area under the graph for this curve is AUC = 0.91. It can be assumed that the probability that for a randomly selected situation the model will correctly indicate a higher risk of an accident is 91%.

The result of the conducted analysis is the indication of important factors having a direct impact on safety. In addition, attention should be paid to stronger demonstration at work of those factors that may be used to improve the health and safety system in a construction company, not directly related to the place of the construction investment.

6. Summary

The research presented in the article makes it possible to assess the relationship between adverse events at the construction site (accident) and factors directly related to work safety management in a construction company (employee motivation, OHS coordinator, level of implementation of the OHS management system, type of impact on the employee). As the analysis proves, the main factor influencing the occurrence of a hazardous event is the type of works carried out, in particular activities related to works in a deep excavation and at height. These are types of work, protected especially by law and subject to additional training for employees; the persons performing them should have appropriate permissions and qualifications. Another accident-causing factor is the use of appropriate security in the form of protective railings on scaffolding. An important factor influencing safety on the construction site is the use of collective protection measures. The above-mentioned factors occur directly on the construction site and are related to the specific nature of a given investment. Their range of occurrence has been described, inter alia, in [3–5]. The analysis of data from accident protocols and ad hoc inspections carried out in 2018–2020 at the District Labor Inspectorate in Krakow also showed the influence of factors not directly related to the construction site but occurring in work safety management systems in a construction company. These factors are:

– list and documentation of clothing, footwear and personal protective equipment in the company,
– employment of a person responsible for health and safety coordination,
– reliable keeping of a log of health and safety trainings.

One of the results of the logistic regression model is the probability that individual observations belong to the modelled class: there was or was not an accident. The values of this probability can be used to support the decision-making process in occupational safety management in construction companies. Moreover, the presence of factors not directly related to the construction site in the analysis and their significance demonstrated in the proposed regression model constitute a practical guide in the organization and implementation of the safety system, and more broadly in the creation of a functional strategy. By ensuring continuous supervision over employees, providing employees with clean, undamaged, periodically replaceable clothing and personal protective equipment, and by conducting regular training courses, you can gain a competitive advantage for a construction company. However, further work is needed to calibrate the model. It is planned to use the scoring method, based on the data obtained from the District Labour Inspectorate, which carries out the control directly. This will allow for the development of a more precise model of the functional strategy taking into account the data contained in the accident protocols as well as the protocols of ad hoc inspections, presented in a linguistic form.

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Ocena wpływu wybranych czynników na zdarzenia niebezpieczne w budownictwie

Słowa kluczowe: przedsiębiorstwo budowlane, bezpieczeństwo pracy, zarządzanie

Streszczenie:

Artykuł porusza problematykę bezpieczeństwa pracy w budownictwie. Podjęto w nim próbę analizy zarządzania bezpieczeństwem pracy w przedsiębiorstwach budowlanych, w celu wskazania istotnych czynników i wyznaczenia istotności ich udziału w zaistnieniu wypadków przy pracy. Badania zrealizowano na podstawie danych uzyskanych z rejestru, prowadzonego w Okręgowym Inspektoracie Pracy, w Krakowie. Do analizy danych i budowy modelu posłużono się regresją logistyczną. Dyskutowano przypadki ujęte zarówno w protokołach powypadkowych, sporządzanych z mocy prawa, jak i przypadki ujęte w protokołach z kontroli doraźnych, przeprowadzanych na terenach budów. W analizowanym zbiorze danych występowały cechy ilościowe i jakościowe. Działanie takie dało możliwość zamodelowania i określenia istotności wpływu poszczególnych zmiennych, charakteryzujących sposób zarzadzania bezpieczeństwem pracy w przedsiębiorstwach budowlanych, na zaistnienie wypadku. Otrzymane wyniki, a w szczególności wykazana w modelu istotność czynników, nie związanych bezpośrednio z terenem budowy, mogą być wskazówką do budowy strategii funkcjonalnej w przedsiębiorstwie. Strategii zakładającej: mniejszą ilość wypadków lub zdarzeń niepożądanych, krótsze przestoje oraz budowę renomy instytucji dbającej o pracownika. Pozwoli to na uzyskanie większej konkurencyjności firmy budowlanej i przyciąganie najlepszych fachowców dostępnych na rynku pracy. Efektem końcowym jest wskazanie kluczowych czynników mających bezpośredni wpływ na bezpieczeństwo pracy i konkurencyjność firmy budowlanej.

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