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MODEL OF ACCIDENT SITUATION DEVELOPMENT IN THE CONSTRUCTION INDUSTRY

MODEL ROZWOJU SYTUACJI WYPADKOWEJ W BUDOWNICTWIE

A b s t r a c t

The construction industry is characterized by a high level of hazards to the life and health of employees and by a high accident rate. Knowledge relating to the course of the accident process plays a major role in work safety assessment and in accident prevention. On the basis of GUS reports and the EUROSTAT accident model a comprehensive general model of accident situation development has been developed. The model enables one to trace the different possible configurations of the events occurring in accident processes in the construction industry and to determine the most probable scenario of events. It is essential to define such scenarios in order to correctly specify the directions of preventive measures.

Keywords: construction industry, occupational safety, accident rate, causal

S t r e s z c z e n i e

Budownictwo charakteryzuje się wysokim poziomem zagrożeń dla życia i zdrowia pracowników oraz wysoką wypadkowością. W ocenie bezpieczeństwa pracy oraz prewencji wypadkowej istotną rolę odgrywa wiedza dotycząca przebiegu procesu wypadkowego. Na podstawie analizy opracowań GUS oraz modelu wypadku zaproponowanego przez EUROSTAT opracowano ogólny kompleksowy model rozwoju sytuacji wypadkowej. Model ten pozwala na prześledzenie różnych możliwych konfiguracji zdarzeń występujących w procesach wypadkowych w budownictwie oraz określenie najbardziej prawdopodobnego scenariusza zdarzeń. Zdefiniowanie takich scenariuszy ma znaczenie dla prawidłowego sprecyzowania kierunków działań prewencyjnych.

Słowa kluczowe: budownictwo, bezpieczeństwo w pracy, wypadkowość, model przyczynowo-skutkowy

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1. Introduction

Compared with other sectors of economy, the construction industry is characterized by a high level of hazards to the life and health of employees and by a high accident rate [2]. According to statistical data, in 2012 the accident rate in the Polish construction industry amounted to 9.17 persons per 1000 in employment. It is considerably higher than the overall accident rate for all the sectors of national economy, amounting to 7.78 persons per 1000 employed. The high rates of minor, serious and fatal accidents put the construction industry among the top most accident-prone sectors. However, one should notice the developing downward trend in these rates over the last few years. From 2008 to 2012 the overall accident rate in the construction industry in Poland decreased by 25% relative to the rate for 2008, which was as high as 12.26 injured per 1000 employed.

Knowledge relating to the course of the accident process plays a major role in work safety assessment as well as in accident prevention. An attempt to build an accident situation development model based on a large amount of data set has been undertaken. The model, in the form of a directed graph, will make it possible to construct different accident process development scenarios and to select the most probable scenario for the construction industry. On this basis it will be possible to take more effective preventive measures.

2. Problem description

The National Accident at Work and Occupational Disease Insurance Act of 30 October 2002 [9] defines an accident at work as a sudden event brought about by an external cause, resulting in injury or death, which occurred in connection with work, i.e. in the course of or in connection with the performance of ordinary activities or orders from superiors by an employee; in the course of or in connection with the performance of activities for the benefit of an employer, even without an order; and while the employee remains at the employer's disposal on the way between the employer's registered office and the place of performance of a duty, stemming from the employment relationship. An accident which an employee had during a business trip, in the course of training in national civil defence, when carrying out tasks set by the trade unions operating at the employer is treated equally with an accident at work. A fatal accident at work is considered to be an accident which resulted in death within a period not exceeding 6 months from the date of the accident. A serious accident at work is considered to be an accident resulting in a serious body injury. A collective accident at work is considered to be an accident with which met, as a result of the same event, at least two persons.

Statistical data on the accidents at work which have taken place in the construction industry are collected by (among others): the Central Statistical Office of Poland (GUS), the National Labour Inspectorate (PIP) and the General Office of Building Control (UNB). However, each of the institutions mentioned above has a different set of data on accidents at work.

Each year GUS publishes a report entitled: "Accidents at Work. Statistical Data and Compilations". Data on accidents at work and on work conditions in the particular sectors of national economy, collected from employers are compiled there in tables. From this source one can learn, e.g., how many persons were injured in accidents, how many persons sustained injuries on building sites and in other places, how many people at the moment of accident were operating a machine, how many suffered from electric shock, and so on. It is apparent that this is general data from which no conclusions about the most probable course of accidents in the building industry can be drawn. The statistics contained in the sets were compiled in accordance with the Statistical Accident Card requirements. The Statistical Accident Card has been in force in Poland since 1 January 2005 [5]. It has been revised [6] and the current standard form of the Accident Card can be found in government order [7].

The branches of the National Labour Inspectorate in their data sets have accident reports on fatal accidents and reports on most of the serious accidents. In the county branches of the General Office of Building Control one can find information on construction disasters, which in many cases can be classified as accidents at work.

A survey of source data on accidents at work in the construction industry indicates that to date no model has yet been made available, which would make it possible to construct the most probable scenario of accident events in the construction industry. Such scenarios would allow one to take more effective preventive measures geared to specific situations in the construction industry.

3. Survey of accident-at-work models

The mechanisms of accidents at work and the accident related phenomena are being studied by many researchers. On the basis of these research findings, various models of accidents at work have been built. Many of the models which have been developed over the years deal with the different phases leading to accidents as well as taking human behaviour in the face of danger into account. Other models describe the causes of accidents while still other models form a systematized basis for the investigation of events or preparing accident statistics.

Classic accident-at-work models show the course of accidents, assuming that an accident is the result of a cause and effect chain. According to the theory of accidents at work, each accident is an effect of several causes which, in turn, are an effect of the hazards occurring in the workplace environment and of improper human actions [1, 3, 8]. Many factors contribute to an accident. The particular models focus on different areas of the impact of different factors on the human, which ultimately lead to an unintended, dangerous action resulting in an accident [4]. Exemplary accident models selected from the literature on the subject are presented below.

The OARU (Occupational Accident Research Unit) model divides the accident sequence into three phases: an initiating phase, a realization phase and an injury phase. Four transitional states: no control of over the situation, loss of control, exposure to a flow of energy, and an energy absorption end state are distinguished. The OARU model may pose difficulties in distinguishing the particular transitional states, e.g. the state initiating a given phase from the preceding phase (for simple accident events with a small number of identified facts). Nevertheless, the energy flow concept is helpful in drawing conclusions and in designing preventive, corrective measures.

The sequential accident event model KIK takes elements of occupational hazards into account. As opposed to the OARU model, four phases: a pre-accident phase, a deviation phase, a damage phase and an effects phase over the course of an accident have been distinguished. This model is highly useful for identifying the causes of accidents. Thanks to the correlations between the causes and the identified hazard elements, one can find the weakest link in the process and determine preventive measures which need to be taken so that similar accidents do not occur in the future.

The present study was based on the model proposed by EUROSTAT (European Statistical Office), shown in Fig. 1, developed as part of the European Statistics on Accidents at Work Project. The model was used to develop the standard form of the Statistical Accident Card [5, 6]. Three accident situation phases: a pre-accident phase, an accident phase and a post-accident phase are distinguished in the model. The data and information collected on the basis of this model relate to the work environment, the performed work, the physical action performed when the accident happened, the identification of the deviation in the work process from the normal state, the way in which the injury was sustained and the consequences of the event.

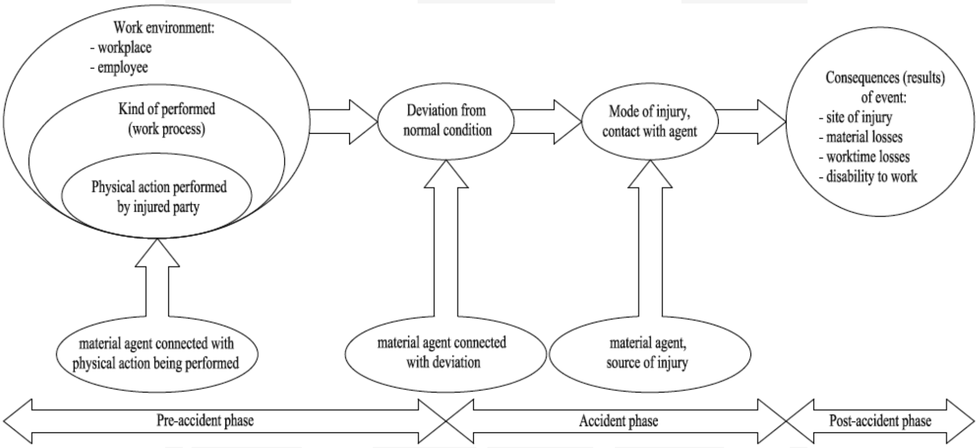

Fig. 1. EUROSTAT statistical model of accident

4. General model of accident development

On the basis of GUS reports and the EUROSTAT model a comprehensive general model of accident situation development has been created. It enables one to trace the different possible configurations of the events taking place in specific accident processes. If an appropriately large number of accident processes is analyzed, it will be possible to define the most probable scenarios of accidents in the construction industry.

The model, shown in figure 2, has the form of the directed graph:

$$G = \langle W, K \rangle , \tag{1}$$

which is defined as an ordered pair of sets W and K. Set $W$is any non-empty set of vertexes, whereas set K is a set of ordered pairs of different vertexes W called directed edges or arcs. Set K is a subset of the Cartesian product:

$$K \subseteq W \times W \ . \qquad (2)$$

Set W of vertexes consists of seven subsets, each of which contains selected information on accident events. These are:

1. Single element set WP – containing notional "accident at work" element wp, $WP = \{wp\}$.
2. Work environment, $A = \{a_i, i = 1, \ldots, n\}$.
3. Work processes, $B = \{b_j, j = 1, \ldots, o\}$.
4. Events being a deviation from the normal state, $C = \{c_k, k = 1, \ldots, o\}$.
5. Events causing an injury, $D = \{d_p, j = 1, \ldots, p\}$.
6. Kinds of injuries, $E = \{e_q, q = 1, \ldots, r\}$.
7. Kinds of accidents, $W = \{w_s, s = 1, \ldots, 3\}$, where: 1 – a minor accident, 2 – a serious accident, 3 – a fatal accident.

$$W = WP \cup A \cup B \cup C \cup D \cup E \ . \qquad (3)$$

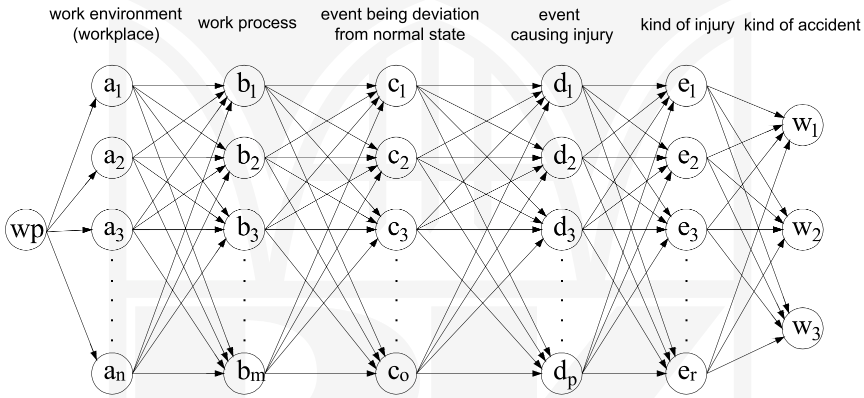

Fig. 2. Model used to analyze accident rate in construction industry

The relations between the particular events are represented by arcs (directed edges). The graph arcs connect the particular vertexes contained in the neighbouring sets, on the peer-to-peer principle and result from the possible theoretical sequence of successive events.

5. Description of model

An analysis of the definition of an accident at work, formulated in sect. 2, and of statistical data [10] indicates that accidents in the construction sector may happen: a_1 – on an industrial production site, a_2 – on a construction site, a_3 – on a cultivation site or in green areas, a_4 – in offices, research establishments, schools or service establishments a_5 – in health care units, a_6 – in public transport sites and means, a_7 – in households, a_8 – in sports facilities, a_9 – at heights, excluding construction sites, a_{10} – underground, excluding construction sites, a_{11} – on water or above water, excluding construction sites, a_{12} – in high pressure environment, and a_{13} – in other places.

At the moment an accident occurs the employee may be performing activities stemming from the job description or being outside the scope of her/his duties, but for the benefit of the employer and the organizations operating at the employer. The following activities have been distinguished and classified in the model: b_1 – operating machines, b_2 – working with hand tools, b_3 – steering or driving means of transport or operating mobile machines and equipment, b_4 – handling objects, b_5 – manual transport, b_6 – moving, b_7 – being present at the scene of an accident or other activity or no information.

The direct cause of an accident is a disturbance in the work process, being a deviation from the normal state. A deviation from the normal state can be connected with: c_1 – electricity, c_2 – an explosion, c_3 – a fire, ignition, c_4 – sliding down, dropping, collapsing of a material agent, c_5 – a strike, c_6 – drawing in, c_7 – slipping, stumbling, falling over of a person or c_8 – other event.

A deviation results in a dangerous event, which can be contact with: d_1 – electricity through direct touch, d_2 – a flame, and also a hot or burning object or environment, d_3 – dangerous chemical substances, and d_4 – sharp objects. Among dangerous events there are also: d_5 – drowning, d_6 – a strike by a moving object, d_7 – trapping, crushing, d_8 – the action of radiation, noise, light, pressure, d_9 – the manifestation of aggression of a human being or an animal, and d_{10} – other events.

Contact with a hazardous material agent causes injuries of various kinds. The following injuries have been specified: e_1 – wounds and superficial injuries, e_2 – bone fractures, e_3 – displacements, dislocations and strains, e_4 – traumatic amputations, e_5 – internal injuries, e_6 – flame or chemical agent burns, scaldings, frostbites, e_7 – poisonings, infections, and e_8 – other injuries. The types of injury listed above may apply to different locations, e.g., the head, the neck with the cervical spine, the back with the spine, the trunk and the internal organs, the upper limbs, the lower limbs, the whole body and its different parts.

Different configurations of the events listed above result in: w_1 – minor accidents, w_2 – serious accidents and w_3 – fatal accidents.

The sequence of vertexes and arcs, starting in the initiating phase in initial node *wp* and ending in last node w_s (defining the kind of accident), forms an accident process.

6. Case study

The model was used to analyze an accident which happened during the building of a chimney on a floor of a detached house located in Wrocław. On the day of the accident there were 2.9 m high load-bearing walls, two 4 m high end walls about and 1 m high knee walls on the floor in the house. At the moment of the accident the employer was performing works on the chimney being erected, while the injured party was cutting mesh to size with a knife, in a different area on the same floor. At some point the employer felt a strong gust of wind and heard a tremor. One of the end walls of the building had collapsed and crushed the employee. After the long resuscitation of the injured, by the employer and the emergency ambulance service medical personnel the injured party was pronounced dead.

The accident process was reconstructed and the events were classified in accordance with the model shown in Fig. 2 and with the symbols adopted in sect. 4, i.e.

- work environment: a_2 – a construction site,
- work process: b_2 – working with hand tools (cutting mesh to size with a knife),

- event being a deviation from the normal state: c_5 – the injured party was struck by a falling material agent (a gable wall of the house),
- event causing an injury: d_7 – crushing (by a gable wall of the house),
- kind of injury: e_5 – numerous injuries to the pelvis and abdomen regions, including the internal organs,
- kind of accident: w_3 – fatal.

The course of the accident according to the model is shown in Fig. 3. On the basis of an analysis of a larger number of accidents it will be possible to determine the weights of the particular graph arcs and the most probable scenario of accident events for the construction industry.

7. Conclusions

The following conclusions emerge from this study:

1. In the last five years there has been a 25% decrease in the overall accident rate in the construction industry. Despite this desirable tendency, the accident rate in the construction industry still remains very high;
2. Statistics published by the Central Statistical Office of Poland, the National Labour Inspectorate and other state-run institutions provide a general picture of the accident rate in the construction industry. However, on their basis alone one cannot draw precise conclusions concerning preventive measures;
3. In order to determine the range of preventative measures and the best way of implementing them, one must be aware of the most probable scenarios of an accident situation in the construction industry. A survey of existing accident process models showed that no model which would enable one to assess the probability of accident scenarios had yet been developed;
4. A model in the form of a directed graph has been proposed to assess the probability of particular accident events. Research executed on the model will allow the most probable scenario of accident situation development in construction industry to be forecast and will therefore define necessary preventive measures.

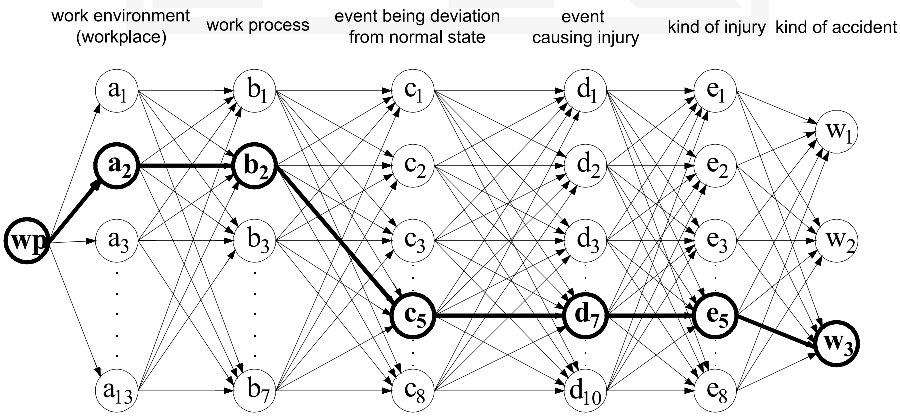

Fig. 3. Course of accident

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