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Analysis of the Development of Accident Situations in the Construction Industry

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Abstract

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 the EUROSTAT accident model a comprehensive general model of the development of an accident situation has been developed. The model enables the different possible configurations of the events occurring in accident processes in the construction industry to be traced and the most probable scenario of the events to be determined.

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

1. Introduction

The construction industry is characterized by a high level of hazards to the life and health of employees and also a high accident rate. [5] On the basis of statistical data it can be stated that in 2012 the accident rate in the Polish construction industry was equal to 9.17 injured people per 1000 workers. This value is much higher than the accident rate for all sections of the national economy which was equal to 7.78 injured people per 1000 workers [1].

Knowledge about the course of an accident process plays an important role in the assessment of work safety and accident prevention [4, 6]. Accidents are a mass phenomenon. The state of security in the selected economy section is not indicated by a single accident but by a set of accidents that have occurred in a specified time interval. Knowledge about the trends which are noticeable in accidents is required in order to assess the level of security and also directions of changes. Based on a review of literature it can be concluded that there are no studies that can be used to build models describing permanent features of phenomena associated with accidents. This paper is an attempt to fulfill this research gap. The development of accident events in the construction industry has been analyzed based on a set of information about accidents at work.

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2. Examples of models used to investigate accidents at work

Scientific research carried out in the area of accidents uses a lot of different models depicting the analyzed phenomenon in an approach which reflects the objective of the conducted research. Individual models are focused on different areas of the influence of accidentogenic factors on people.

Figure 1 presents an example of a Fault Tree model which is used to study the causes of accidents and their different configurations in the accident process. An accident at work is the result of a cause and effect chain of events. The preceding event in this chain is the cause of the following event, and the following event is the result of the preceding event. According to the theory about the formation of accidents at work, every accident is the result of several causes, which in turn are the result of hazards occurring in the work environment and also the result of inappropriate human activities [2, 3, 8, 9].

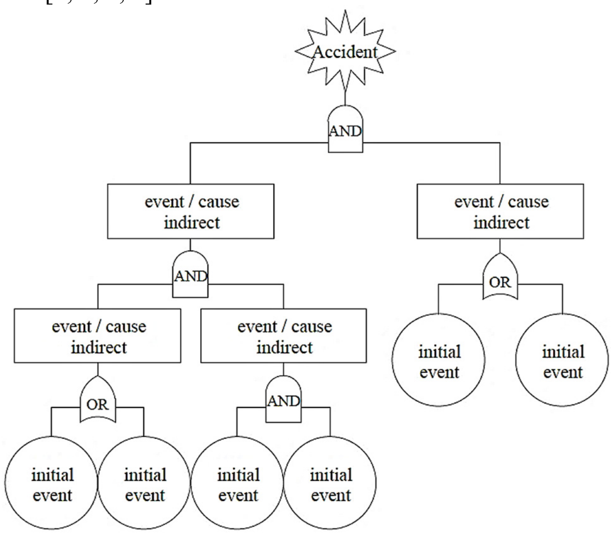

Fig. 1. Model of a Fault Tree FTA (Model Fault tree analysis).

Figure 2 presents a model of energy transfer. The idea of generated energy transfer, as a result of an accident event and failure of protective barriers, allows the examination of the accident to be focused on the power sources and the broader considered barriers. This approach allows an appropriate selection and targeting of preventive measures.

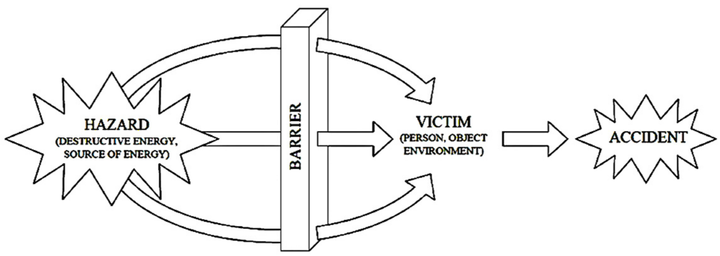

Fig. 2. The Energy Transfer Method.

Currently in European Union countries the model developed by the statistical department of the European Union (EUROSTAT) is valid in the field of statistical research. It was developed within the framework of the European Statistics on Accidents at Work project. This model is presented in Figure 3. It includes three phases of an accident, namely: pre-accident phase, accident phase and post-accident phase. The pre-accident phase includes those elements of the work process which relate to the employee and the task performed by him at the time of the accident.

The accident phase is separated from the pre-accident phase by an event which is a deviation from the normal state (incompatible with an appropriate course of work process) which caused the accident. With this deviation a material agent is commonly associated. The material agent is considered to be a machine, tool or other object or environmental agent which is directly related to the event being a deviation from the normal state. The source of an injury is a material agent with which contact was the cause of injury. The post-accident phase considers the consequences of an accident which are: the number of victims, types of injuries, location of injuries, disability to work, property and work time losses. This model has been applied in the development of the model of the Statistical Accident Card [7] and is used to investigate accidents at work and to collect statistical data.

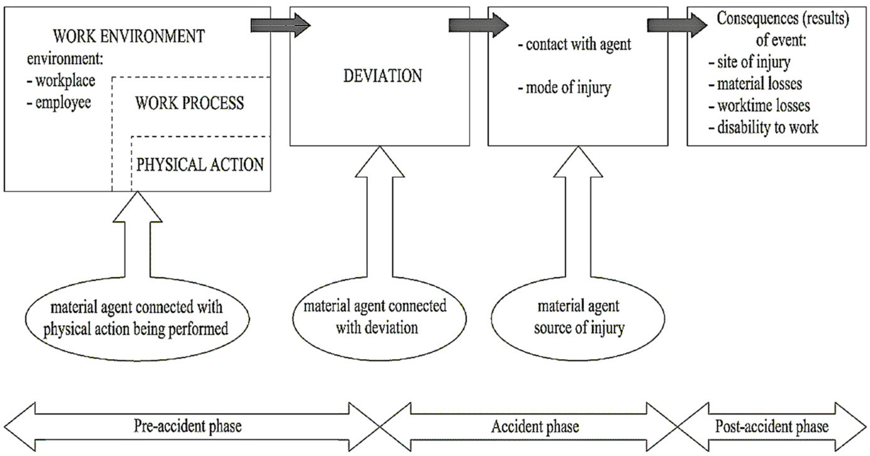

Fig. 3. Model of Accidents at Work by EUROSTAT.

The presented models explain the phenomena associated with accidents in the context of a single accident event. The objectives of formatting these models were:

- an explanation of how the specific accident occurred and thus a presentation of the sequences of events leading to an accident,
- determination of the way of proceeding when investigating the causes of an accident;
- comprehensive analysis of an accident and an explanation of its causes and also the enabling of the design of appropriate corrective actions.

3. Model of the development of an accident situation

3.1. A description of the EUROSTAT model elements

When analyzing the model of an accident proposed by EUROSTAT and statistical data [1] it can be concluded that accidents eligible for the construction industry section can happen in 9 identified locations. Among them: a_1 - industrial sites, a_2 – construction sites, a_3 – farming, breeding, forest zones, green zones, a_4 – offices, tertiary activity areas and schools, service establishments, a_5 – health care establishments, a_6 – public communication areas, a_7 – in the home, a_8 – sports areas, a_9 – other places.

At the time of an accident an employee can perform actions arising from his duties or obligations beyond the scope of his duties but executed for an employer and organizations working for an employer. Seven activities have been designated and classified in the model: b_1 – operating machines, b_2 – working with hand-held tools, b_3 – driving a means of transportation or handling equipment - mobile and motorized, b_4 – handling of objects, b_5 – carrying by hand, b_6 – movement, b_7 – presence and other specific physical activities or no information.

The direct cause of an accident is a disruption in the course of the work process which is a deviation from the normal state and may be associated with: c_1 – deviation due to electrical problems, c_2 – explosions, c_3 – fire, flare up, c_4 – slip, fall, collapse of material agents, c_5 – a strike from above, c_6 – drawing in from below, c_7 – slipping, stumbling, falling of persons or c_8 – other contacts.

As a result of a deviation, a hazardous event occurs which may be a contact with: d_1 – direct electricity, receipt of electrical charge in the body, d_2 – naked flame or a hot burning object or environment, d_3 – hazardous substances and chemicals, d_4 – sharp, pointed, rough coarse material agents.

To the hazardous events also qualify: d_5 – being drowned, buried, enveloped, d_6 – struck by an object in motion, collision, d_7 – trapped, crushed – in, under, between, d_8 – physical stress – due to radiation, noise, light or pressure, d_9 – aggression of humans or animals or d_{10} – horizontal or vertical impact with or against a stationary object, d_{11} – physical stress – on the musculoskeletal system, d_{12} – mental stress or shock or d_{13} – other contacts.

Contact with a hazardous material agent causes various types of injuries specified as: e_1 – wounds and superficial injuries, e_2 – bone fractures, e_3 – dislocations, sprains and strains, e_4 – traumatic amputations (loss of body parts), e_5 – concussion and internal injuries, e_6 – burns, scalds and frostbite, e_7 – poisonings and infections, e_8 – other injuries.

The result of a different configuration of the above mentioned events are: w_1 – lighter accidents, w_2 - serious accidents and w_3 – fatal accidents.

3.2. Model of the development of an accident situation

A general model of the development of an accident situation which allows the tracing of different possible configurations of events that occur in the specified accident processes has been developed. This model is presented in Figure 4, and is a directed graph:

$$G = \langle W, K \rangle , \quad (1)$$

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

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

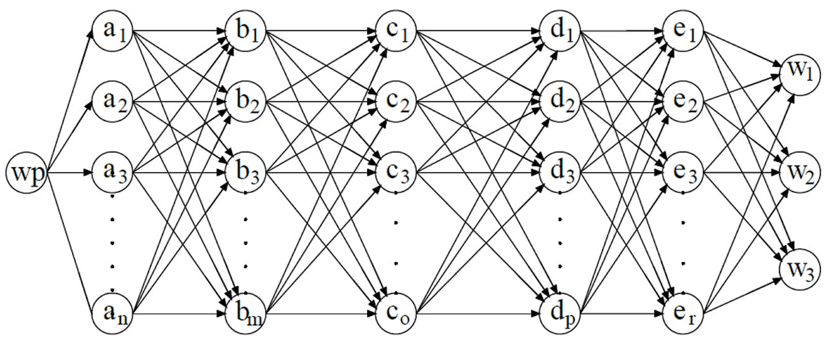

Fig. 4. Model applied for the analysis of accidents in the construction industry.

The W set 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 $WP = \{wp\}$,
2. work environment, $A = \{a_i, i = 1,..., n\}$,
3. work process, $B = \{b_j, j = 1,..., m\}$,
4. events being a deviation from the normal state, $C = \{c_k, k = 1,..., o\}$,
5. events causing an injury, $D = \{d_l, l = 1,..., p\}$,
6. kinds of injures, $E = \{e_q, q = 1,..., r\}$,

7. kinds of accidents, $W = \{w_S, s = 1,...,3\}$, where: 1 – lighter accidents, 2 – serious accidents, 3 – fatal accidents.

$$W = WP \cup A \cup B \cup C \cup D \cup E. \tag{3}$$

Relations between specific events are represented by directed edges (arcs of the graph). The graph arcs connect individual vertexes on a "round robin" rule which is a result of a possible theoretical implication of events. The sequence of vertexes and arcs creates an accident process which begins in the initiation phase in the initial node *wp*, and ends at the last node w_s which describes the type of an accident.

The analysis of a sufficiently large number of accident processes will allow the weights of specific arcs for the analysed set of accidents at work to be determined, and the most probable scenarios of accident developments in the construction industry to be defined.

4. Analysis of accidents a work

4.1. Case study

Using the model of the development of an accident situation presented in section 3.2 and based on the analysis of post-accident inspection reports drawn up in companies where accidents occurred by the National Labour Inspectorate, the course of dozens of accidents in the construction industry have been analyzed. In order to illustrate the methodology of accidents at work study, an exemplary analysis of an accident is presented.

The accident happened during the painting work in a renovated church building. After painting, employees began dismantling the scaffolding. Disassembled elements of the scaffolding were lowered on a rope to the floor. The victim on the disassembled scaffolding fell from a height of 8m due to the detachment of a grip which was holding the guard rail of the scaffolding and he hit the concrete floor.

The victim died on the way to hospital. Based on the description of the occurred accident situation the accident process was reconstructed and events were classified to appropriate groups, namely:

- work environment: a_2 – construction site,
- work process: b_7 – presence,
- events being a deviation from the normal state: c_4 – collapse of material agent, fall of persons to a lower level,
- events causing an injury: d_{10} – vertical impact with a stationary object,
- kinds of injures: e_8 – other injuries,
- kinds of accidents: w_3 – fatal accident.

In the above example, the active edges of the graph are as follows: wp - a_2, a_2 - b_7, b_7 - c_4, c_4 - d_{10}, d_{10} - e_8, e_8 - w_3.

4.2. The obtained statistical data

Data obtained from the analysis of individual accidents can be used to determine the weight values for each edge of the graph. The sequence of edges with the largest weight values designates the most probable scenario of accidents.

Table 1 shows the fragment of data obtained from the analysis of 40 accidents at work in the construction industry. Weight values given in the last row of the table are calculated with the use of the following formula:

$$\delta(w \to u) = \sum(w \to u)/n \tag{4}$$

where:

$\delta(w \to u)$ - weight of edge $w \to u$,
w - preceding vertex,
u - following vertex,

$\sum(w \to u)/n$ - the number of active edges of the $w \to u$ type in a n set of analyzed accidents,
n - the number of analyzed accidents at work.

Table 1. Fragment of a summary table of accidents at work.

L.p.	a_i-b_j edges				b_j-c_k edges				c_k-d_l edges				d_l-e_q edges				e_q-w_s edges		
	a_2-b_2	a_2-b_4	a_2-b_7	…	b_2-c_7	b_4-c_5	b_4-c_7	…	c_4-d_{10}	c_5-d_7	c_7-d_{10}	…	d_7-e_1	d_{10}-e_2	d_{10}-e_8	…	e_1-w_2	e_2-w_2	e_8-w_3
W1			×						×						×				×
W2		×					×				×		×						×
W3	×				×					×				×				×	
…																			
$\sum(w \to u)$	12	7	6		7	3	3		5	6	14		4	7	10		4	5	11
$\delta(k)$	0.33	0.18	0.15		0.18	0.08	0.08		0.13	0.15	0.35		0.10	0.18	0.25		0.10	0.13	0.28

Based on analysis of 40 fatal accidents at work in the construction industry it was concluded that the most probable scenario of accident events runs through the following events: a_2 – construction site, b_2 –working with hand-held tools, c_7 – slipping, stumbling, falling of persons, d_{10} – horizontal or vertical impact with or against a stationary object, e_8 – other injuries, w_3 – fatal accidents.

5. Conclusions

Carried out research enabled the formulation of the following conclusions:

1. Statistical data published by the Central Statistical Office, the National Labour Inspectorate and other state institutions give a general idea about accidents in the construction industry. On this basis, precise conclusions regarding preventive actions cannot be formulated.
2. Knowledge about the most probable scenarios of the development of accident situations in the construction industry is necessary to determine the scope and method of preventive actions. Based on a review of existing process models of accidents it was found that a model that can estimate such a probability has not yet been developed.
3. A new model of the development of an accident situation in the form of a directed graph was proposed to assess the probability of various scenarios of accident events. Research carried out on the model and with the use of an Excel spreadsheet will enable the most probable scenario of the development of an accident situation in the construction industry to be defined and on that basis the necessary preventive actions to be determined.

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