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CIVIL ENGINEERING

Quantitative and qualitative analysis of hazardous events in the construction sector: causes, classification, and implications

Zuzanna WOŹNIAK* and **Bożena HOŁA**

Wrocław University of Science and Technology, Faculty of Civil Engineering, Poland

Abstract. In most countries worldwide, the construction industry is recognized as one of the sectors with an exceptionally high incidence of accidents. The inherent complexity of construction processes, coupled with the variability of implementation conditions, engenders a multitude of disruptions. These disruptions pose a threat to the life and health of construction employees and can give rise to hazardous events, including accidents and near-misses. The research focuses on identifying direct and indirect causes of hazardous events, intending to determine which factors have the greatest impact on their occurrence. A comprehensive dataset was systematically analyzed, comprising 754 recorded accidents at work (A) and 1717 near-miss events (NM). The research was conducted based on a model of the course of a hazardous event that was developed for the purposes of this study. A categorization system was devised, encompassing eight categories of direct causes and 12 categories of indirect causes. The significance of causes was assessed through the utilization of Pareto-Lorenz analysis and ABC methodology. The most significant factors contributing to occupational accidents were identified: inadequate work organization, improper use of materials by employees, and failure to adhere to instructions. The most significant factors contributing to the occurrence of near misses were identified: improper use of material by an employee, inadequate organization of the workstation, and failure to adhere to instructions.

Keywords: construction; accident at work; near misses; causes.

1. INTRODUCTION

The construction and assembly of products is of pivotal significance to both the global and domestic economy. In 2023, the total value of construction output in Poland amounted to PLN 3.28 million [1]. However, it is important to note that the implementation of construction works is often accompanied by numerous disruptions, which can result in dangerous events.

In most countries worldwide, the construction industry is recognized as being particularly susceptible to accidents [2, 3]. It is estimated that, on a global scale, one fatal accident occurs every ten minutes in the construction sector [4]. The U.S. Bureau of Labor Statistics has reported that in 2020, there were 1008 fatal injuries in the construction sector in the United States [5]. According to data from the Central Statistical Office (GUS), 3597 individuals sustained injuries in connection with an accident in the Polish construction industry in 2023, including 39 fatalities [6].

The high complexity of construction processes and the variability of implementation conditions contribute to disruptions in their course, which may pose a threat to the life and health of employees and lead to dangerous events such as accidents at work or near-miss events [7, 8]. An accident at work is defined as a sudden event caused by an external factor related to work performed, during which the employee suffers an injury [9]. A near miss is defined as a sudden event related to work, during which the employee could have sustained an injury if the circumstances had been different [10]. Consequently, sustaining an injury is a determining factor in distinguishing between an accident and a near miss [11]. Hazardous occurrences during construction investments present a substantial problem for construction companies and the broader community. The consequences of such events extend beyond the realm of employee injuries, encompassing work stoppages that can precipitate delays in the execution of strategic infrastructure and housing investments, in addition to the accrual of supplementary expenses and reductions in productivity [12, 13]. In 2023, the total number of working hours lost due to accidents in the Polish construction industry amounted to 2741 hours [6], which is equivalent to 342.6 working days. The estimated material losses caused by accidents at work in 2023 are estimated to be PLN 3283.4 thousand [6]. Material losses represent merely a fraction of the expenses that society incurs in the context of accidents at work. The psychological consequences of accidents must not be disregarded. It is a widely documented fact that individuals who have sustained injuries, along with their families, frequently encounter profound post-traumatic stress, a condition that can result in the onset of emotional disorders, depression, or post-traumatic stress disorder. This has a detrimental effect on their ability to function in day-to-day life.

A significant aspect related to accidents in construction is also the additional burden on the healthcare system. The necessity to admit injured parties to the hospital, to undertake long-term

*e-mail: zuzanna.wozniak@pwr.edu.pl

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rehabilitation, and to provide psychological support for both victims and their families generates significant social and economic costs.

In conclusion, it is imperative to acknowledge the profound ramifications of accidents and near misses in the construction sector. These incidents have far-reaching consequences for those directly involved, as well as for the broader societal context. Downtime in the implementation of investments affects the quality of residents' lives, places additional strain on the healthcare system, and has a significant impact on the mental state of both the injured and their families.

Hazardous events are the result of a multitude of causes occurring in different configurations. Within the framework of a causal analysis, it is possible to distinguish between the immediate cause of an event, which resulted in the injury, and antecedent causes, which are referred to as indirect.

The scientific objective of the research is:

a) to identify direct and indirect causes of accidents at work (A) and near misses (NM),
b) to determine which of the identified causes have the greatest impact on generating dangerous events.

The novelty of the conducted research consists of:

a) identifying direct and indirect causes of near misses in construction,
b) grouping the causes into especially important, important, and insignificant,
c) conducting a comparative qualitative and quantitative analysis of the causes of accidents at work and near misses.

The identification of these causes is fundamental to determining preventive measures and implementing effective safety management systems on construction sites to minimize the risk of such events. The analysis employed a combination of Pareto-Lorenz analysis and ABC methodology to assess the significance of the individual causes identified.

2. LITERATURE REVIEW

The etiology of occupational accidents has been the subject of extensive research by numerous scholars [14, 15]. A considerable amount of attention has been dedicated to the study of accident mechanisms and the construction of cause-and-effect models to illustrate this phenomenon [16]. A review of occupational accidents reveals the presence of recurring categories of incidents, including falls from heights [17, 18], being struck by objects [2], and others. The frequency and consequences of these events underscore the necessity for systematic prevention and control measures. For example, in [19] and [20], the causes of falls from construction scaffolding were analyzed. The risk of such incidents can be attributed to a combination of technical, organizational, and human factors [18, 19].

A range of methodologies is employed in the investigation of the causes of occupational accidents and near misses. These include both qualitative and quantitative approaches [20, 21]. Popular techniques include root cause identification, human error analysis, diagrammatic methods [22], as well as systemic approaches that assess risk at the entire project level [17]. The utilization of such tools facilitates a more profound comprehension of the mechanisms that precipitate accidents, thereby enabling the implementation of suitable preventive measures. However, near-miss incidents have received comparatively little attention in the extant literature, despite being recognized as potential precursors to occupational accidents [23].

A review of the extant literature on the subject revealed a paucity of research concerning the direct and indirect causes of near misses. To date, the direct and indirect causes of these events remain to be defined, as does the significance of their impact on the occurrence of the events in question. The relationship between the causes of accidents at work and near misses has not been defined either.

It is widely accepted that near misses are precursors of accidents, and therefore, it can be assumed that the structure of causes of near misses should be similar to the structure of causes of accidents at work. The absence of compelling empirical evidence substantiating the aforementioned assertion underscores the imperative to address the prevailing research deficit in this domain. The knowledge gained about them is necessary for better management of occupational safety.

3. RESEARCH METHODOLOGY

The research methodology is presented in the form of a block diagram in Fig. 1.

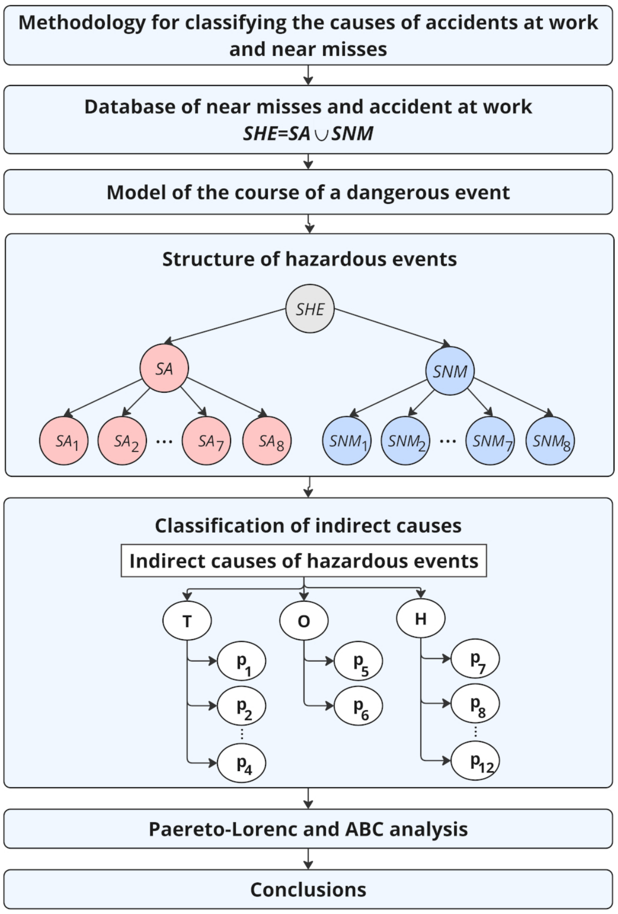

Fig. 1. Research methodology

3.1. Database

The set of analyzed events includes incidents recorded in the company implementing construction investments in Poland and abroad in the years 2015–2023. The investments implemented included residential buildings, public utility buildings, roads, railways, and other infrastructure. The analyzed database is available at the repository [24]. The set consists of 2471 hazardous events, including 754 accidents at work (A) and 1717 near misses (NM). It can thus be concluded that the set of all dangerous events is the sum of the set of accidents (SA) and the set of near misses (SNM).

$$\Omega = SHE = SA \cup SNM, \tag{1}$$

where $\Omega = SHE$ – set of all events, SA – set of accidents, SNM – set of near-misses.

3.2. Model of the course of a hazardous event

The development of an event progression model was undertaken for the purpose of analyzing hazardous occurrences, as demonstrated in Fig. 2.

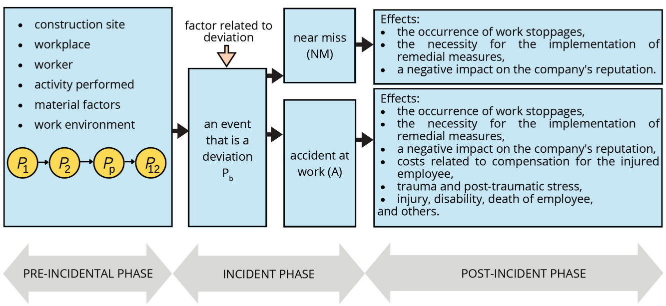

Fig. 2. Hazardous event development model

The process of incubation, as it is termed, refers to the gradual accumulation of risk factors in the work environment. This accumulation may, in the longer term, result in an accident at work or a near miss. This process is characterized by the accumulation of improper technical conditions (T), organizational errors (O), and human behaviors (H) that are not adequately identified and eliminated at an early stage. The development of a hazardous event can be conceptualized through the identification of three distinct phases: the phase preceding the hazardous event, the so-called pre-incident phase; the incident phase; and the post-incident phase.

The pre-incident phase encompasses the elements of the work process that pertain to the employee and the task they are performing at the time of the event. These elements act as catalysts for the indirect generation of hazardous occurrences. These include construction sites, places of work, employees, the activities performed by employees, material factors, and work environments. In this phase, disruptions to the effective functioning of the work process may occur, which pose a threat to employees. A hazard is defined as a specific situation related to the work process characterized by such a system or state of "T", "O", and "H" factors of this process, the consequence of which may be a dangerous event, i.e., an accident or a near-miss event. The factors and circumstances that influence the activation of a hazard, and thus the potential for a dangerous event, are termed the causes of the event. It is imperative to recognize that each dangerous event is the result of a multitude of factors occurring in varied configurations. Within the framework of a causal chain, it is possible to distinguish between the immediate cause of a hazardous event (P_b) and antecedent causes that are classified as indirect (P_p).

The incident phase is distinguished from the pre-incident phase by an event, defined as a deviation from the standard state (thereby being inconsistent with the appropriate course of the work process). The aforementioned phenomenon constitutes the immediate catalyst for the occurrence of the incident, including, for example, a descent from a considerable height or a physical impact with a machine. This phase is invariably associated with a material factor, which is defined as an object, machine, tool, element of the natural environment, or other object used by the injured party at the time of the accident [25]. The occurrence of dangerous events is subdivided into two categories: accidents at work and near misses.

In the post-incident phase, the primary focus is on the management of the consequences of dangerous events. In the context of an accident at work, the relevant data encompasses the number of injured parties, the nature of their injuries, the location of the injuries, the impact on their ability to work, any material losses incurred, and the loss of working time. The source of the injury is identified as a material factor, defined as the contact that caused the injury. Conversely, in the context of a near miss, the source of the event is also a material factor, yet it does not result in injury. This finding suggests that an accident at work and a near miss are occurrences that take place in analogous circumstances and are attributable to the same underlying causes.

3.3. Structure of hazardous events – direct causes

Following a thorough analysis of the hazardous events documented in the database, eight categories of events constituting a deviation from the normal state were identified in the sets of accidents at work and near-miss events.

The set of occupational accidents (SA) is the sum of elements $A_{i,k}$ ($i = 1, \ldots, 8$; $k = 1, \ldots, K$)

$$SA = \sum_{i=1}^{8} \sum_{k=1}^{K} A_{i,k} \,. \tag{2}$$

The set of near misses (SNM) is the sum of elements $NM_{i,l}$ ($i = 1, \ldots, 8$; $l = 1, \ldots, L$)

$$SNM = \sum_{i=1}^{8} \sum_{l=1}^{L} NM_{i,l} \,, \tag{3}$$

where I – the number of categories of occupational accidents, the number of categories of near misses, K – the number of items in set SA_i, L – the number of items in set SNM_i.

Consequently, the comprehensive data set is the aggregate of the set of occupational accidents and near-miss events

$$SHE = \sum_{i=1}^{8} SA_i \cup \sum_{i=1}^{8} SNM_i \,, \tag{4}$$

where SA_1, SNM_1 – a set of events classified as a direct cause – being hit by objects, SA_2, SNM_2 – a set of events classified as direct cause – being run over by a vehicle/being hit by a vehicle, SA_3, SNM_3 – a set of events classified as direct cause – work environment, SA_4, SNM_4 – a set of events classified as direct cause – fall of a person, SA_5, SNM_5 – a set of events classified as direct cause – electricity, SA_6, SNM_6 – a set of events classified as direct cause – fire/explosion/finding of unexploded munition, SA_7, SNM_7 – a set of events classified as direct cause – collapse/burial/being trapped, SA_8, SNM_8 – a set of events classified as a direct cause – contact with moving machine parts.

A comprehensive analysis of the proximate causes of occupational accidents indicates that they constitute merely the proverbial tip of the iceberg. The identification of indirect causes facilitates the discernment of systemic issues and the implementation of preventive measures. Consequently, this comprehensive approach facilitates not only the reduction of accidents but also the enhancement of organizational functionality in its entirety.

3.4. Classification of indirect causes

The TOH method [18] was employed for the classification of indirect causes of accidents and near misses. The method operates under the assumption that each accident or near miss is attributable to three distinct categories of cause: technical (T), organizational (O), and human (H). It can thus be concluded that the set of all indirect causes P_p, of accidents is the sum of causes classified into three distinct subsets

$$P_p = T \cup O \cup H \,. \tag{5}$$

Table 1 presents the main categories of indirect causes, as derived from the statistical card of accidents at work [25], with the specification of the technical, organizational, and human groups. The comprehensive inventory of detailed descriptions of indirect causes can be accessed in the repository [26].

The belonging of the cause P_p to the subsets T, O and H can be described by the formulas

$$T = \sum_{p=1}^{4} P_p \,, \tag{6}$$

$$O = \sum_{p=5}^{6} P_p \,, \tag{7}$$

$$H = \sum_{p=7}^{12} P_p \,. \tag{8}$$

3.5. Pareto-Lorenz analysis and ABC classification

The objective of this study is to determine the classes of causes with the greatest impact on the generation of hazardous events in construction. To this end, the Pareto-Lorenz analysis and the ABC classification are proposed as a means of systematizing and evaluating the causes of occupational accidents and near misses [18, 19]. The Pareto-Lorenz curve is a tool for the graphical analysis of the distribution and degree of concentration of the phenomena under study [27]. The process under discussion enables the isolation of those elements that exert the greatest influence on the structure of the analyzed population. To generate the curve, the identified causes were ordered according to decreasing frequency of occurrence, and then their cumulative percentages were calculated. On this basis, a graph was constructed, with the horizontal axis representing the cumulative percentage of the analyzed causes, and the vertical axis representing the cumulative share of causes. The employment

Table 1
Indirect causes of dangerous events

Group of causes	Symbol P_p	Class of indirect causes of dangerous events
Technical (T)	P_1	Design defects or improper technical and ergonomic solutions of the material factor
	P_2	Improper performance of the material factor
	P_3	Material defects of the material factor
	P_4	Improper exploitation of the material factor
Organizational (O)	P_5	Improper work organization
	P_6	Improper organization of the workstation
Human (H)	P_7	Improper use of a material factor by an employee
	P_8	Failure to use or improper use of protective equipment by an employee
	P_9	Failure to comply with instructions and occupational health and safety regulations and rules
	P_{10}	The psychophysical condition of an employee that does not ensure safe performance of work, caused by fatigue, sudden illness, and nervousness, among other things
	P_{11}	Incorrect behavior of an employee caused by ignorance of occupational health and safety regulations and principles, disregard of hazards, and inappropriate pace of work, among other things
	P_{12}	An event beyond the control of the employer or employee, the action of third parties, or animals

of the ABC methodology enabled the identification of causes to be categorized into groups according to their significance, thereby providing the foundation for the formulation of recommendations for preventive actions [19, 20]. The procedure for the analysis is as follows:

- Determining the number of intermediate causes (P_p, $p = 1, \dots, 12$) in individual classes in the analyzed event groups A_i and NM_i ($i = 1, \dots, 8$).
- Organizing the sequence of pairs of numbers (P_p, a_p) that describe the analyzed causes in descending order. The position of the pair in the ordered sequence is determined by the number a_p of occurrences of the attribute P_p in the subset T, O or H according to the rule

$$\text{If } a_{p+1} \geq a_p, \text{ then } P_{p+1} < P_p . \tag{9}$$

- Determination of the percentage share a_p of the occurrences of the cause P_p in the sum of all the causes examined.
- Determination of the percentage of the cumulative sum of the subsequent causes.

To classify the causes according to the degree of their influence on the occurrence of a dangerous event, the ABC analysis [28], known in economics and easy to use, was used. The ABC analysis was developed from Vilfredo Pareto's law, also referred to as the 80–20 rule or Pareto principle. As delineated by the ABC method, it is imperative to categorize the causes from the SA and SNM sets into three distinct subgroups. The following assumption was made:

- A set of highly significant indirect causes (marked A) was identified, which constitutes 80% of all the causes that influenced the initiation of the dangerous event.
- A set of significant indirect causes (marked B) was identified, which constitutes 15% of all causes that influenced the initiation of the dangerous event.
- A set of insignificant causes (marked C) was identified, which constitutes 5% of all identified causes that influenced the initiation of the dangerous event.

4. RESULTS

4.1. Direct causes of hazardous events

The direct causes of accidents at work are illustrated in Fig. 3, while the direct causes of near-miss incidents are demonstrated in Fig. 4.

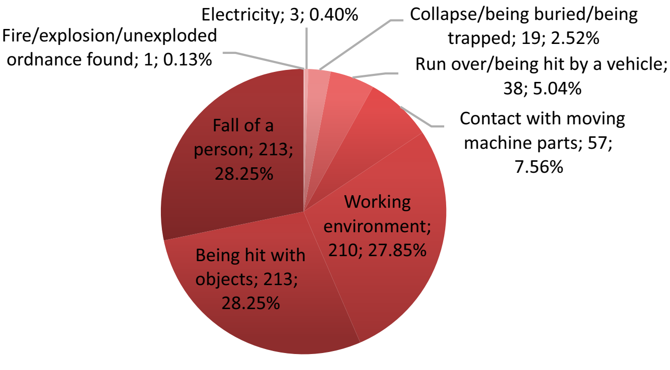

Fig. 3. Direct causes of accidents at work that occurred in the years 2015–2023 in a selected construction company

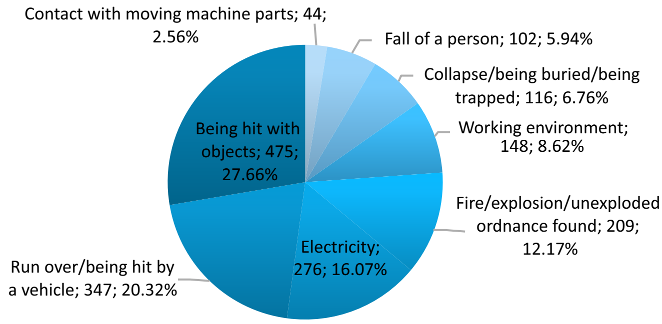

Fig. 4. Direct causes of near-miss incidents that occurred in the years 2015–2023 in a selected construction company

The most prevalent direct causes of accidents at work in the analyzed database were identified as Fall of a person (28.25% A) and Being hit with objects (28.25% A). A further noteworthy category is that of the working environment (27.85% A), which also exerts a noteworthy influence on the number of accidents at work. Smaller number of accidents at work are attributable to other categories, such as Contact with moving machine parts (7.56% A), Run over/being hit by a vehicle (5.04% A), Collapse/being buried/being trapped (2.52% A), Electricity (0.40% A) and Fire/explosion/unexploded ordnance (0.13%).

The most prevalent direct cause of near misses was identified as the category Being hit with objects, accounting for 27.66% of near misses. The second most prevalent cause was identified as being run over/being hit by a vehicle (20.21% NM). The subsequent primary causes, in terms of frequency of occurrence, were as follows: electricity (16.07% NM), fire/explosion/unexploded ordnance (12.17% NM), working environment (8.62% NM), collapse/being buried/being trapped (6.76% NM) and fall of a person (5.94% NM). The least common direct cause was identified as contact with moving machine parts, accounting for 2.56% of cases (NM).

4.2. Indirect causes

The role of indirect causes in elucidating the mechanisms that can lead to accidents is paramount, as it facilitates the implementation of effective preventive measures. As illustrated in Fig. 5, the indirect causes of accidents were arranged by the adopted classification system. As demonstrated in Fig. 6, the findings of the Pareto-Lorenz analysis and the ABC classification for indirect causes of accidents at work are presented.

As illustrated in Fig. 7, the indirect causes of near-miss events were arranged in accordance with the adopted classification system. As illustrated in Fig. 8, the results of the Pareto-Lorenz analysis and the ABC classification for indirect causes of near misses are presented. Table 2 presents a classification of indirect causes of accidents at work and near misses into highly significant, significant, and insignificant.

In both types of hazardous events (A, NM) an identical set of causes classified as especially important was found. This group of causes includes improper work organization (P_5), improper use of a material factor by an employee (P_7), failure to comply with instructions and occupational health and safety regulations

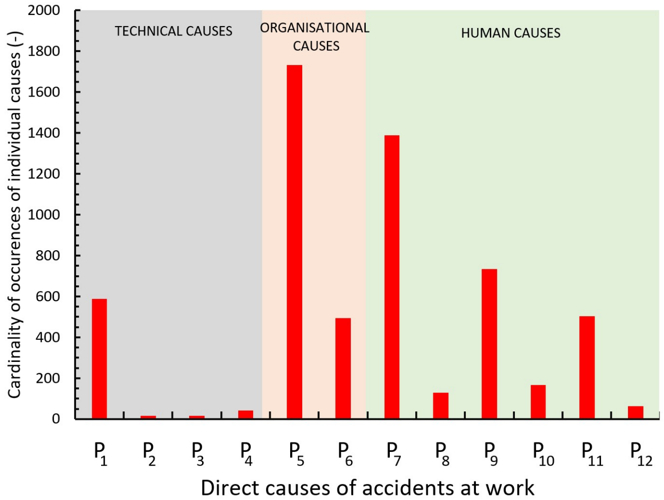

Fig. 5. Indirect causes of accidents at work from 2015 to 2023 from a selected construction company

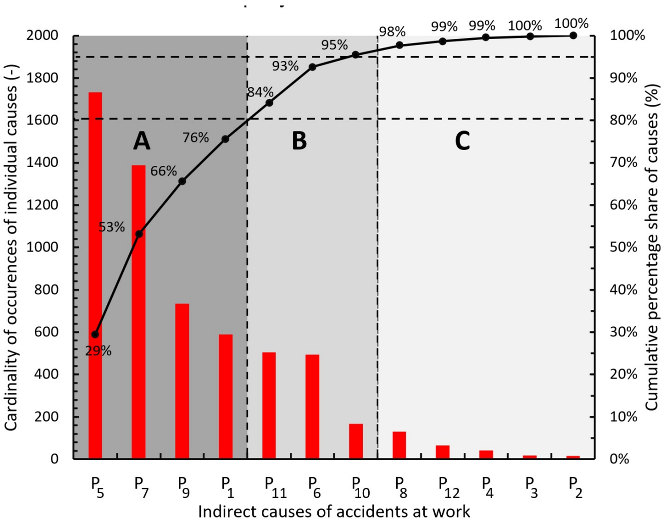

Fig. 6. Pareto-Lorenc chart of indirect causes of accidents at work from 2015 to 2023 from a selected construction company

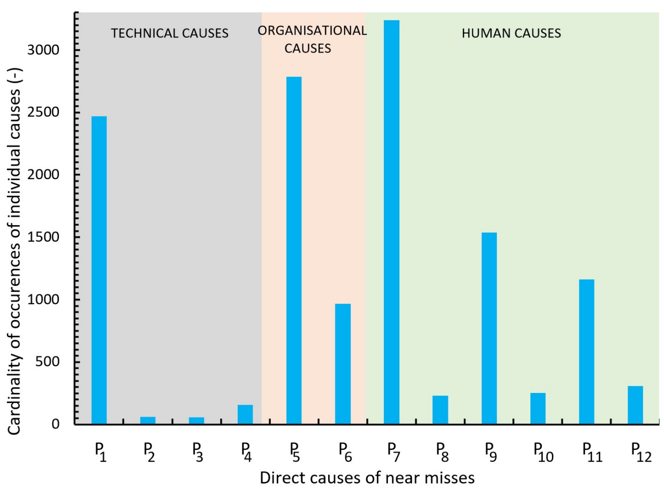

Fig. 7. Indirect causes of near misses from the years 2015–2023 from the selected construction company

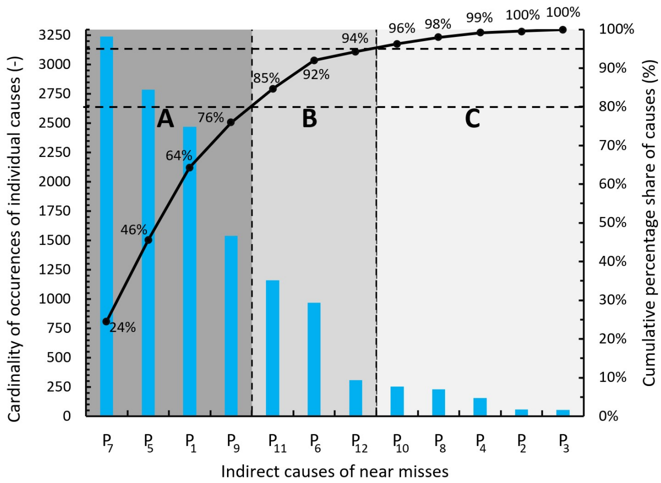

Fig. 8. Pareto-Lorenc chart of indirect causes of near misses from 2015 to 2023 from a selected construction company

Table 2

Assignment of indirect causes to significance groups and their percentage share in the group of dangerous events

Cause severity group	A		NM	
	Cause indirect	Percentage of cause in group A (%)	Cause indirect	Percentage of cause in group NM (%)
A	P_5	29.48	P_7	24.49
	P_7	23.64	P_5	21.06
	P_9	12.49	P_1	18.69
	P_1	10.03	P_9	11.64
B	P_{11}	8.58	P_{11}	8.79
	P_6	8.39	P_6	7.31
	P_{10}	2.83	P_{12}	2.32
C	P_8	2.21	P_{10}	1.91
	P_{12}	1.09	P_8	1.75
	P_4	0.71	P_4	1.18
	P_3	0.29	P_2	0.45
	P_2	0.26	P_3	0.42

and rules (P_9), and design defects or improper technical and ergonomic solutions of the material factor (P_1).

In both cases, the most significant factors pertain to the organization of work and the employee's behavior. However, the relative proportions of these factors vary.

The following were classified as significant causes:

1. In type A events: incorrect behavior of the employee (P_{11}), incorrect organization of the workstation (P_6), and the employee's psychophysical condition, not ensuring safe performance of work caused by fatigue, sudden illness, and nervousness (P_{10}), among others.
2. In NM events: incorrect behavior of the employee (P_{11}), incorrect organization of the workstation (P_6), an event be-

yond the control of the employer or employee, actions of third parties or animals (P_{12}).

The remaining causes not listed above accounted for a total of 5% of all identified indirect causes and had a minor impact on the generation of accidents.

4.3. Consequences of hazardous events in construction

The definition of an accident at work is the occurrence of physical harm to the injured parties. Figure 9 presents a detailed analysis of injuries sustained in the context of accidents at work, categorized according to the specific anatomical region affected.

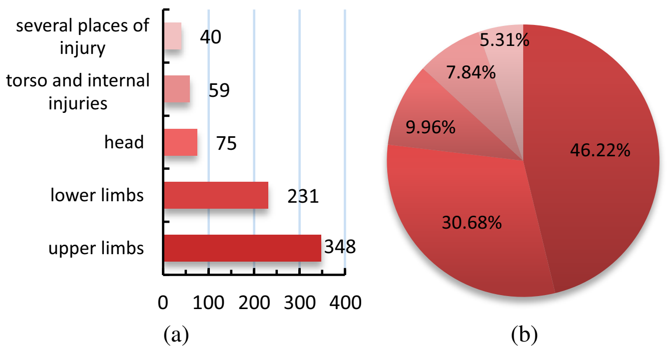

Fig. 9. (a) Number of injuries, (b) percentage share of individual injuries sustained due to accidents at work in a selected construction company in the years 2015–2023

In the aftermath of a near-miss incident, the consequences manifest in various forms, including the suspension of construction work, financial costs associated with the restoration of construction equipment, and a detrimental impact on the company's reputation. These repercussions exert a substantial influence on the trajectory of investment processes and the broader societal context.

The most prevalent injuries were to the upper limbs, which were documented 348 times, constituting 46.22% of injuries. The subsequent injury was to the lower limbs, with a score of 231, constituting 30.68% of accidents at work. The incidence of injuries to the trunk and internal injuries, head, and several sites of injury concurrently was the least recorded. The consequences of accidents at work are manifold. They include, but are not limited to, interruption of construction works, costs related to compensation and treatment of injured persons, pain and suffering of injured persons and their families, as well as negative impact on the company's reputation [12, 13]. Unfortunately, the estimation of these effects is an incredibly challenging task.

5. DISCUSSION

The adopted classification of direct and indirect causes of accidents at work is consistent with the classification proposed by the European Statistical Office of the European Union (EUROSTAT) and used in other countries of the world. Therefore, it is possible to compare the obtained results with the results of studies conducted by other researchers. In the studied set of *SA*, among the most common direct causes of accidents at work were being hit by objects (28.25%), a fall of a person (28.25%), and the work environment (27.85%). In the case of being hit by objects, a comparable result of 25.74% was obtained in the study conducted by Chi and Han [29]. Another direct cause of the work accidents studied was a fall of a person, which constituted 28.25% of group A events. For comparison, according to OSHA data, human fall is the dominant type of fatal accident, constituting as much as 44% of all construction accidents [29].

The direct cause of "work environment", accounting for 27.85% of all causes of accidents at work, encompasses contact with sharp, rough, or abrasive objects, contact with hazardous substances that may lead to irritation, and health problems such as epilepsy or a heart attack.

Within the SNM set, the most prevalent direct cause, accounting for 27.66% of events, aligning with the SA set, was being struck by objects. The second most prevalent direct cause was being run/being hit by a vehicle, which accounted for 20.21% of events in this group. The third most prevalent direct cause was electricity, accounting for 16.07% of events.

The basis for effective prevention and the establishment of a sustainable system for safeguarding the health and well-being of employees is indirect. In the studied set of SA and SNM, the following factors were identified as the most significant causes of accidents at work: improper work organization (P_5), improper use of a material factor by an employee (P_8), failure to comply with instructions and occupational health and safety regulations and rules (P_9), design defects and improper technical and ergonomic solutions (P_1). The causes classified as class A were identified in 80% of the accidents examined at work.

Inappropriate work organization, as a critical indirect cause, was also pointed out in the studies [20] concerning accidents at work on construction scaffolding. Data from the Central Statistical Office for 2023 [6] indicate that the most common indirect cause of accidents at work was the employee's improper behavior, followed by the employee's improper use of a material factor. The findings of this study demonstrate that effective work organization, the utilization of appropriate materials, and the role of employee misconduct are pivotal in ensuring work safety. A concerted focus on these factors within health and safety training, as well as preventive measures, will undoubtedly contribute to a significant reduction in the number of accidents.

The study of accidents at work revealed a predominance of upper limb injuries. This phenomenon is associated with the class of indirect causes, including the lack or improper selection of personal protective equipment, improper organization of the workstation, and the failure to use or improper use of protective equipment by employees. This is since the hands are most exposed to contact with tools and heavy materials. For comparison, the Central Statistical Office data from 2023 was examined, revealing that 41% of all injuries in Polish construction were sustained by the upper limbs, while the lower limbs accounted for 35% [6]. The high frequency of lower limb injuries may result from hazards related to moving in dangerous or uneven places, inappropriate passages, or the presence of unnecessary objects. These are one of the groups of improper organization of the workstation.

6. CONCLUSIONS

The consequences of dangerous events are far-reaching, impacting not only construction workers but also members of the public, including residents and users of public spaces. The potential consequences of such incidents are significant, encompassing aspects of health, society, and economics. This underscores the necessity for systematic research and the development of effective preventive strategies.

As part of this analysis, a study was conducted on the causes of accidents at work in one of the Polish construction companies. Among the accidents at work, the significant direct causes were improper work organization, improper use of a material factor by an employee, failure to follow instructions and occupational health and safety regulations and principles, design defects, and improper technical and ergonomic solutions. In the case of near misses, the group of significant causes includes improper use of a material factor by an employee, improper work organization, design defects or improper technical and ergonomic solutions of the material factor, failure to follow instructions, and occupational health and safety regulations and principles. The research results demonstrated a comparable structure of causes in the categories of highly significant, significant, and insignificant causes in the sets of accidents at work and near-miss events.

The registered accidents at work resulted in 348 upper limb injuries, 231 lower limb injuries, and other head, trunk, and internal injuries, as well as several injury sites. These numbers clearly emphasize the need for further research into these types of incidents. Their effects have not only an individual dimension, but also an organizational and social one, which makes them a key area of analysis in the context of occupational safety in construction.

The findings of the study indicate the necessity to assign priority to preventive actions, which should concentrate on enhancing work organization, eradicating errors pertaining to the management of material factors, and augmenting the efficacy of supervision over compliance with health and safety regulations. The results can also provide a basis for developing tools supporting decisions on training, internal audits, and allocation of inspection resources. The implementation of recommendations based on a key cause analysis has the potential to contribute to a significant reduction in the number of accidents and to improve the overall level of safety on construction sites.

7. RESEARCH LIMITATIONS AND DIRECTIONS FOR FUTURE RESEARCH

Notwithstanding the results obtained, which are of considerable application value, it is imperative to indicate the significant limitations of the study. The analysis was conducted based on data from an organization operating in a specific cultural, legal, and organizational context. Such conditions have the potential to impact on the structure and nature of the identified causes of events. It is imperative to consider the local operational and institutional conditions when generalizing conclusions.

The proposed research methodology has the potential to be adapted to other economic sectors by modifying the classification of causes and considering local conditions. The method has the potential to be integrated with digital systems and can support the creation of predictive safety management tools in various work environments.

The authors' future research directions include the analysis of the possibilities of real-time safety monitoring on construction sites and the development of predictive models enabling early detection of potential threats. The implementation of such solutions has the potential to contribute to an improvement in the state of occupational safety by means of the implementation of preventive measures during periods of increased probability of occurrence of dangerous events.

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