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Safety Risk Assessment of Iranian Building Sites based on Construction Stage

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Abstract

To assist safety practitioners in the work of prioritizing preventative activities based on the stage of civil industry, it is necessary to identify the most common causes of accidents in the civil sector. Reports from official accident investigations are examined. For this aim, accidents are examined that were officially investigated by the Ministry of Cooperatives, Labour, and Social Welfare at the building sites of North of Iran (Mazandaran region) between 2013 and 2023. The percentage of causes in each of the several potential cause groups indicates a pattern of causation. There are notable correlations between the different cause categories and the phases of building and accident mechanisms. Depending on the accident's mechanism and the current building stage, there have been seen to be significant variances in accident causation. Prioritizing preventive measures to counter the most likely causes of each accident procedures and building stage should be done using these results.

Keywords: Risk evaluation approach, construction site accidents, classification, occurrence probability of system failure.

1. Introduction:

The European standard on health and safety at work, law 89/391/EEC, ensures that there are basic health and safety standards in place across Europe. However, Member States have the freedom to implement even stricter measures if they want to do so. In relation to building, there is a particular directive, Directive 92/57/EEC, which establishes specific posts (coordinators) and ad hoc safety plans. Directive 89/391/EEC [1] establishes the principle of risk evaluation as a challenging component and outlines the primary elements: identifying hazards, involving workers, implementing appropriate measures with the primary goal of eliminating risks at their origin, documenting findings, and regularly reassessing workplace

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hazards. Risk assessment is the primary proactive measure undertaken by safety professionals [2]. The given text is a list containing the elements 3 and 4. Building sites pose unique challenges due to their dynamic and transient working conditions [3]. Therefore, it is crucial to gather information on the primary factors contributing to accidents. We possess a valuable and informative resource in the shape of accident investigation reports [4]. After an accident, a thorough examination is conducted to assess and, if needed, reassess all precautionary and safeguarding actions [5]. Accident investigation is the method employed to ascertain the fundamental reasons behind accidents [6]. When analyzing accident investigations, it is crucial to consider two fundamental factors [7]. One approach is to examine accidents that can be properly compared and categorized together. It is crucial to thoroughly evaluate accidents that are as similar as possible [8]. A further concern is to encode the conditions and origins in a manner that allows for straightforward identification. The harmonized Phase III of European Statistics on Accidents at Work (ESAW) presented a standardized and straightforward evaluation system for categorizing work-related accidents. This system allows for easy comparison and accurate coding of accident situations. For this study, two factors, namely deviation and model of injury, were coded according to ESAW to determine accidents with similar processes [9].

Construction accidents have specific accident models that have been established. Haslam *et al.* [10] established a model that took into account several factors contributing to accidents. During the exploratory study, a significant percentage of the cases (about 50%) were attributed to human factors and workplace environment. The proposed model suggests that work teams and the workplace play a significant role in influencing outcomes, while immediate causes are primarily associated with equipment and materials. Based on literature reviews frequent type of construction accident which illustrated in Fig. 1. The structural failure and fall from the height were the most common civil site accident in the world.

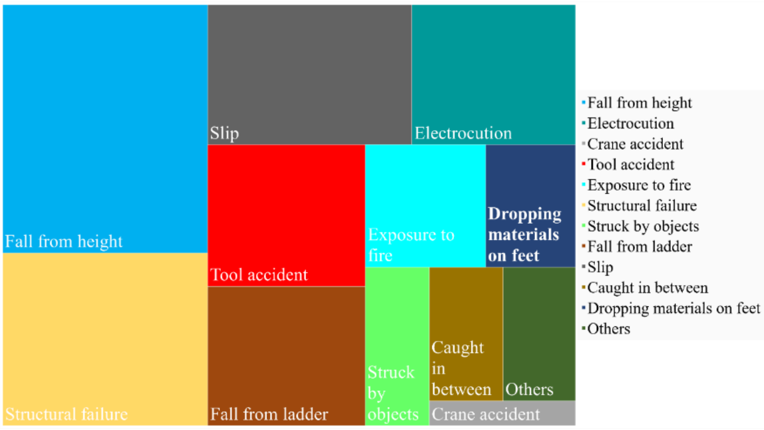

Fig. 1: Causes of civil site accidents

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A number of researchers have researched the causation of distinct accident scenarios, revealing that causation patterns are contingent upon the particular accident procedures and the task at hand. Chi *et al.* [11] conducted an analysis on the primary reasons for falls in construction, finding a significant incidence of occupational conditions. The primary cause is an "unguarded opening," which is found in 17% of the cases. The employed approach emphasized the correlation between accident scenarios and accident cases. In a recent study, Chi *et al.* [12] demonstrated that these causes can be examined in order to create graphical fault trees. Whitaker *et al.* [13] conducted an analysis of the data on scaffolding accidents and discovered that the majority of the cases were linked to faulty equipment. Additionally, less than 5% of the causes were attributed to human parameters. Arboleda and Abraham [14] examined the correlation between the underlying reasons and the method of communication in trenching incidents. A noteworthy point that may be made is that each accident mechanism has its unique pattern of causation. Hinze *et al.* [15] conducted an analysis of accidents caused by being struck, and discovered a significant number of incidents where protective systems were inadequate (14%), working techniques were subpar (13%), and training was insufficient (13%), among other contributing factors. Ale *et al.* [16] examined the predominant key incidents in building site accidents and the most common failures of safety barriers within the framework of the Workgroup Occupational Risk Model project (WORM). The aforementioned assessment also yielded an estimation of the occupational hazard level for each employment in the field of building sites. Leung *et al.* [17] found that the occurrence of injuries among civil site workers are directly influenced by the absence of goal setting. Furthermore, they concluded that insufficient safety equipment impacts both the physical and mental levels of stress.

Previous studies have highlighted the primary factors that contribute to accidents associated with various variables in the construction sector: Cheng *et al.* [18] revealed that there was a distinct causal relationship depending on whether the project was of a public or private nature. The primary issues encountered in public projects were the failure of employers to supply personal protective equipment (PPE) to workers, accounting for 28% of the problems, and the utilization of hazardous methods or procedures, which constituted 26% of the issues. The primary safety concerns in private projects were the employer's failure to provide Personal Protective Equipment (PPE) accounting for 50% of the issues, and unsafe working conditions making up 18% of the difficulties. The primary causes of accidents in public projects were the failure to adopt safeguards or ignore hazard warning signs (55%) and the incorrect use of personal protective equipment (30%). Within private projects, the most prevalent risky act (45%) was the incorrect utilization of Personal Protective Equipment (PPE). The study performed by Cheng *et al.* [19] examined the occurrence of legislation for different types of accidents in public and private projects in the construction sector. The study analyzed many independent variables such as project type and project jurisdiction. The findings indicated that specific sorts of accidents, such as falls, collapses, and others, were more prevalent in situations

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where specific combinations of variables were present. In their study, Hale *et al.* [20] identified a cluster of underlying issues that are linked to deficiencies in various areas, including planning, designing, procurement and installation. While the results of these studies vary in terms of geography and time, there is a significant consensus about the most common causes of accidents and how they differ depending on the specific accident scenarios and jobs being performed. Swuste *et al.* raised the topic of whether it is feasible to exert influence on safety in the construction industry. This pertains to the researchers' capacity to furnish valuable knowledge for safety practitioners [21]. According to Carrillo-Castrillo and Onieva [22], achieving this goal requires analyzing how safety planners perform their job and how safety management is implemented in the company.

Comparisons between researches are challenging due to the lack of a standardized categorization system for accident damages. A coding procedure is a tool that offers a hierarchical list of potential causes based on a causation model. By using the same coding system to study accidents, it becomes possible to analyze them using statistical methods. This system encompasses a wide range of causes, similar to other coding systems. An advantage of this method is its extensive utilization in Iran. This paper presents evidence for the significance of the construction stage in identifying the most likely reasons to combat by presenting a research that determines the causes of accidents in the building site on the basis of the mechanism of building's accidents in sites. The Fig. 2 presented the accidents on construction sites in North of Iran (Mazandaran region).

Fig. 2: Accidents on construction sites in North of Iran

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The aim of our research is centered on the examination of accident investigations conducted by public authorities and their possible contribution to the discovery and prioritization of preventative measures within the building sites. The data can be interpreted similarly to epidemiology, allowing for the identification of the most common causes. This information can then be used to prioritize the most efficient preventive measures, which is particularly beneficial for small and medium-sized construction enterprises. This study is grounded in the official enquiries conducted on accidents that occurred in the building sites in North of Iran throughout the past decade.

2. Technical challenges

The selection of the accident causation model and study approach is crucial. The chosen model and method should offer a solid foundation for studying accidents in the buildings industry. Both the bow-tie model and the fault tree method are suitable for analysis to demonstrate the primary causes and relationships that result in a particular accident. The bow-tie model describes the accident by illustrating the causal pathway that leads from a hazard to its effects, with a center event in between [23]. The potential central occurrences are determined by utilizing the two factors that specify the accident procedures: deviation and mode of harm [24]. The fault tree technique is a widely used approach for investigating accidents by identifying the causal channels that led to the accident. It focuses on identifying the root causes that led to the proximate causes of the accident [24]. Accident evaluations determine both immediate and underlying causes for each barrier breached in the bow-tie approach. [25].

It is crucial to identify the primary causes and their correlation with the accident's mechanism, which is the combination of deviation and mode of contact. This is significant because safety practitioners in Europe conduct risk assessments in construction as a part of the prevention plan mandated by European directives. Thus, it is essential for safety professionals to be aware of the primary factors that are likely to cause accidents at each stage of the building process and for each specific work. This knowledge enables them to prioritize the implementation of the most efficient preventative measures. Risk assessment is conducted using a procedure that is similar to the one used for analyzing accident mechanisms, but it is done in advance to prevent accidents from occurring. The optimal approach to risk assessment involves considering past accidents, particularly those that have occurred more frequently. This methodology has been previously employed to develop decision support systems [24]. Moreover, as the construction progresses through several stages of implementation and encounters varied working situations, the aforementioned risk assessment becomes increasingly effective when it closely aligns with the parameters of each stage. Understanding the correlation between the primary factors and various stages will aid in enhancing the effectiveness of prevention strategies. By examining the causes of accidents at each stage and

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the mechanisms involved, it is feasible to suggest preventive or protective actions that are highly likely to help ensure safety in North of Iran at present.

The aim of this study is to determine the correlation between the most common causes of accidents in construction and two significant factors: the building stages and the accident mechanisms. To accomplish this goal, accidents are examined that were officially investigated by the Ministry of Cooperatives, Labour, and Social Welfare at the building sites of North of Iran (Mazandaran region) between 2013 and 2023.

3. Materials and methods

This study focused on selecting accidents that took place at construction sites in North of Iran (Mazandaran region) between 2013 and 2023. To identify an accident at a construction site, we utilized the ESAW standard code for Working Environment. Codes ranging from 020 to 029 in ESAW are specifically designated for building sites. This research focuses exclusively on accidents that occur at construction sites, which are the working environments of construction companies. It does not consider incidents that happen in other working environments or accidents that are not related to construction firms.

3.1 Accident notifications

In Iran, accident notifications are gathered electronically using Official Workplace Incident Notification Forms. All incidents that lead to a work absence of at least 1 day must be reported. Accidents can be categorized based on their severity, which can range from minor to severe or even resulting in death. The accident is categorized as either slight or severe based on the severity of the injuries and the anticipated duration of recuperation, using medical criteria. Only accident data from cases that were both notified and formally examined are included in this research. This is because only in these cases can data on the reasons of the accident be obtained from safety officers. The official workplace incident notification forms reviewed all accident notifications. This study exclusively considers accident notifications in the construction sector to determine the overall number of accidents for each accident mechanism. The investigated attempts examine the correlation via the different phases of construction and the tasks performed at construction sites in North of Iran (Mazandaran region) from 2013 to 2023, as well as the underlying factors that have been uncovered.

The Iranian Labor Authority (ILA) determines whether to initiate an official accident inquiry after receiving the accident notification, based on the accident's characteristics and severity. Usually, traffic accidents and non-traumatic fatalities, such as strokes or heart attacks, are exempt from examination. Also, letter of No. 447 of safety management in construction sites which presented by executive technical system office of the Iranian president’s planning and strategic supervision was identified cases and conditions of construction accidents and damages. However, most significant accidents, which are defined as those with a recovery period exceeding 15 days or resulting in permanent impairment, are investigated.

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From 2013 to 2023, a total of 859 accidents that occurred in a working environment and fell within the codes 020 to 029 in the ILA were officially examined. This number is significant enough to warrant the use of statistical methods [26]. All accidents in this study were examined by safety officers. The investigations are conducted in accordance with internal protocols, and an official comprehensive investigation report is submitted. Safety officials participate in training sessions focused on the fault tree method, which is a methodology used for investigation purposes [27]. The Occupational Health and Safety Institute in Iran, known as the Iran Construction Engineering Organization (ICEO), has advocated for implementing a nationwide codification system for the causes listed in official accident investigation reports. The purpose of this system is to simplify the statistical analysis process [27].

3.2. Methodologies

The presented approach used a cross-sectional research design [28]. The statistical study of the relationship via categorical variables is conducted using the contingency table approach. Fig. 3 presented the research methodology of this study.

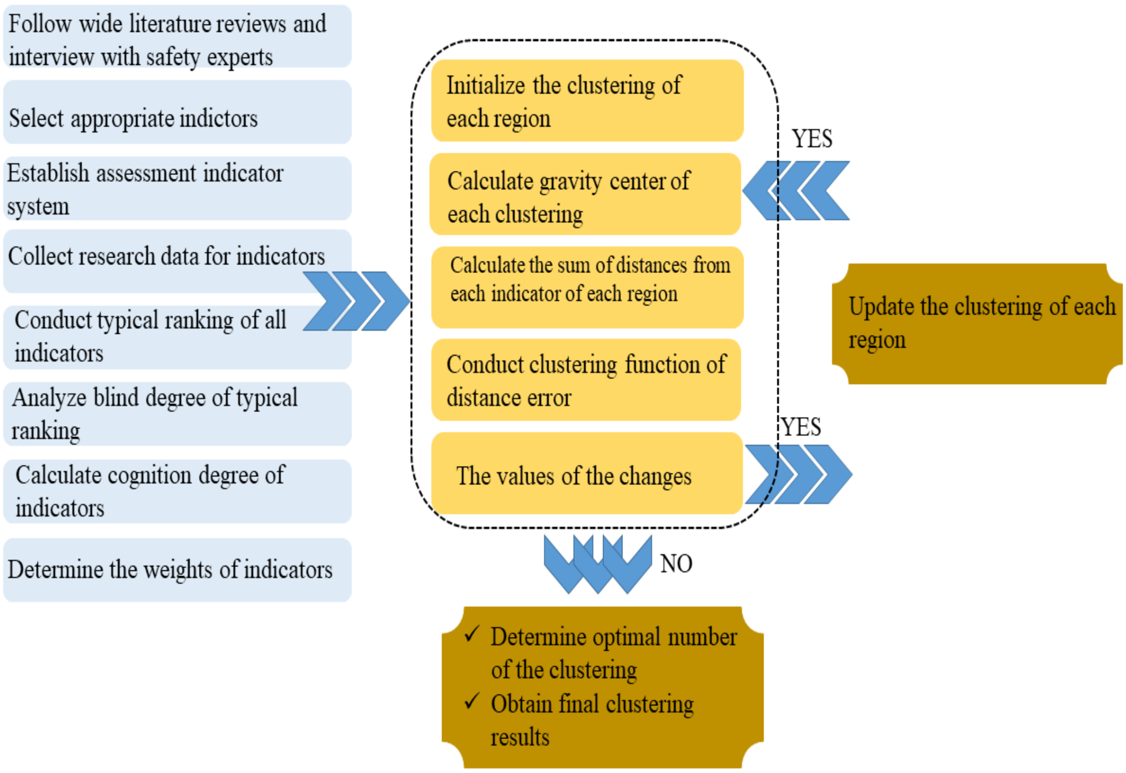

Fig. 3: Flowchart of this research methodology

This method allows for the examination of the interconnection between two variables and facilitates the identification of any interactions between them. When it comes to

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prevention, it is more advantageous to analyze the correlations between two categorical variables at the cell level in statistical analysis. At the cellular level, we may identify the associations between different categories. This is a more valuable measure than the total association between the contingency table of the two variables. Statistical analysis was conducted at the cell level to analyze the associations between each pair of categories. The tests used the φ coefficient test [30]. For each cell, a contingency table was constructed, with a value of '1' indicating a true association and a value of '0' indicating a false association. The accident pattern is determined using the combination of causal factors that contribute to the occurrence of the accident. The term "type of cause" refers to the many groupings or subgroups of causes within the coding pattern. To determine the cause of an accident, we established a criterion that if at least one cause falls under a specific kind of cause, then that type of cause is considered part of the overall causation pattern. This method used for the identification of several causes within the same type. Thus, the causation pattern is determined by the specific sorts of causes, with at least one cause being specified [30].

The simplified accident system is derived by considering all active cause types collectively. The causation pattern consists of four digits: the first digit indicates the presence of an active cause, the second digit indicates the presence of a work organization cause, the third digit indicates the presence of a safety management cause, and the fourth digit indicates the presence of a personal factors cause. An analysis was conducted on the contingency table that examined the relationship between subgroups (SG) of causes and the stage in the construction process. The stages that are taken into account are: Demolition (SG_1), Land Preparation (SG_2), Excavation (SG_3), Foundations (SG_4), Piping (SG_5), Trenching (SG_6), Structures (SG_7), External Walls (SG_8), Roofs (SG_9), Partition Walls (SG_{10}), Installations (SG_{11}), Finishing (SG_{12}), and Pavements (SG_{13}). An analysis was conducted on the contingency table that examined the relationship between subgroups of causes and accident procedure. The accident pattern is determined by analyzing the variables of Deviation and Contact [30]. For instance, if the accident deviation is classified as Slipping - Stumbling and falling - Fall of persons, which belongs to group five in ESAW, and the mode of injury is classified as Struck by object in motion, collision with, which belongs to group four in ESAW, the accident mechanism is coded as 54 (with the first digit representing the deviation and the second digit representing the mode of injury). Based on the fault tree analysis and the bow-tie model analyzed the 10 most common accident mechanisms. Each of them has over 30 cases, which is deemed sufficient for this purpose [31, 32]. The software utilized was SPSS version 22. Statistical results are deemed significant when the p-value$\leq$0.05.

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4. Results and discussion

About 2700 cases were discovered in the analysis of 838 accident investigations. Out of the total 52 accidents, a main cause could not be established in 6% of them. The accident investigation reports analyzed indicate that latent causes account for 43% of the primary main cause (MS) presented in Table 1. Furthermore, when considering all causes, latent causes make up 65% of the total reported in Table 2. The primary reasons consist of two main groups: MS 1, which accounts for 20% and relates to working conditions, and MS 6, which accounts for 21% and pertains to work organization. Within these groups, the most common subgroups are MS 11, which represents 15% and refers to workplace design, and MS 61, which represents 21% and pertains to work method. Table 1 shows that in fatal incidents, about one-third of the cases can be attributed to MS 1 – workplace circumstances (34%) and more precisely MS 11 – workplace design (31%). In terms of the categories and subcategories of all causes, the percentage of MS 1 - workplace conditions (13%) and specifically MS 11 - workplace design (10%) reasons are lower compared to the main causes. However, the percentage of MS 6 - work organization (28%) causes is larger. The primary causes at the four-digit codification level, as shown in Fig. 3, are as follows: No.6102 - inadequate work method (10%), No.7206 - lack of training (5%), No.4203 - lack of overall protection measures to avoid falls from a height (4%), and No.8106 - failure to utilize personal protective equipment (PPE) (4%). The primary causes identified were No.6102 - insufficient work methodology (11%), No.4203 - absence of comprehensive fall prevention systems (8%), and No.6110 - inadequate supervision (5%).

Concerning the simplified causation pattern (CP), 56% of the cases exhibit this pattern. In all instances, there was at least one reason identified as MS 6 - work. 40% of the organization experienced at least one classified cause. MS7 refers to safety management, and it is present in 33% of the situations. At least one cause was classed as MS 8, specifically the human factor as reported in Fig. 4.

Table1: Classification of causes marked as main cause in accident investigation reports.

Type of main cause	Slight		Severe		Fatal		Total	
	n	%	n	%	n	%	n	%
MS 1 – workplace conditions	18	14	123	19	24	34	165	20
MS 11 – workplace design	12	9	94	15	22	31	128	15
MS 12 – housekeeping	4	3	25	4	1	1	30	4
MS 13 – physical agents	1	1	1	0	0	0	2	0
MS 2 – service and protection facilities	0	0	7	1	1	1	8	1
MS 21 – service and protection facilities: design, installation and maintenance	0	0	2	0	1	1	3	0

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MS 22 – service and protection facilities: protective devices	1	1	5	1	0	0	5	1
MS 3 – machinery	6	5	49	8	9	13	64	8
MS 31 – machinery: design, installation and maintenance	6	5	33	5	2	3	41	5
MS 32 – machinery: protective devices	0	0	16	2	9	13	23	3
MS 4 – other work equipment	8	6	103	16	10	14	120	14
MS 41 – other work equipment: design, installation and maintenance	5	4	42	7	4	6	51	6
MS 42 – other work equipment: protective devices	2	2	58	9	5	7	65	8
MS 43 – other work equipment: signage and information	0	0	3	0	1	1	4	0
MS 5 – materials and agents	2	2	14	2	0	0	16	2
MS 51 – storage and handling of materials	2	2	8	1	0	0	10	1
MS 52 – chemical agents	0	0	6	1	0	0	6	1
MS 6 – work organization	26	20	145	22	8	11	179	21
MS 61 – work method	25	20	99	15	4	6	128	15
MS 62 – carrying out tasks	0	0	8	1	2	3	10	1
MS 63 – task training or information	0	0	10	2	1	1	11	1
MS 64 – equipment and material selection	0	0	25	4	0	0	25	3
MS 7 – safety system	16	13	45	7	2	3	63	7
MS 71 – safety management	5	4	9	1	0	0	14	2
MS 72 – safety activities	11	9	36	6	2	3	49	6
MS 8 – personal factors	17	13	96	15	9	13	98	12
MS 81 – behaviour	0	0	77	12	9	13	2	0
MS 82 – intrinsic factors	5	4	2	0	0	0	22	3
MS 9 – other causes	10	8	15	2	0	0	25	3
No principal cause	24	19	19	3	4	6	47	6
Number of accidents investigated	127	100	645	100	70	100	842	100

Table2: Classification of all causes identified in accident investigation reports.

	Slight		Severe		Fatal		Total	
Type of main cause	n	%	n	%	n	%	n	%
MS 1 – workplace conditions	37	9	267	13	40	18	344	13
MS 11 – workplace design	23	6	196	10	36	16	255	10
MS 12 – housekeeping	11	3	57	3	3	1	71	3

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MS 13 – physical agents	1	0	2	0	0	0	3	0
MS 2 – service and protection facilities	3	1	18	1	3	1	24	1
MS 21 – service and protection facilities: design, installation and maintenance	0	0	4	0	3	1	7	0
MS 22 – service and protection facilities: protective devices	1	0	12	1	0	0	13	0
MS 3 – machinery	16	4	140	7	29	13	185	7
MS 31 – machinery: design, installation and maintenance	10	2	91	5	12	5	113	4
MS 32 – machinery: protective devices	6	1	49	2	17	8	72	3
MS 4 – other work equipment	38	9	241	12	25	13	308	12
MS 41 – other work equipment: design, installation and maintenance	14	3	96	5	8	4	118	5
MS 42 – other work equipment: protective devices	13	3	99	5	8	4	120	5
MS 43 – other work equipment: signage and information	4	1	10	1	6	3	20	1
MS 5 – materials and agents	4	1	46	2	1	0	51	2
MS 51 – storage and handling of materials	4	1	36	2	1	0	41	2
MS 52 – chemical agents	0	0	10	1	0	0	10	0
MS 6 – work organization	132	33	552	28	52	24	736	28
MS 61 – work method	89	22	331	17	28	13	448	17
MS 62 – carrying out tasks	7	2	37	2	4	2	48	2
MS 63 – task training or information	20	5	87	4	15	7	122	5
MS 64 – equipment and material selection	13	3	78	4	2	1	93	4
MS 7 – safety system	108	27	360	18	39	18	507	19
MS 71 – safety management	27	7	115	6	29	13	171	7
MS 72 – safety activities	81	20	245	12	10	5	336	13
MS 8 – personal factors	51	13	293	15	25	11	369	14
MS 81 – behaviour	36	9	204	10	20	9	260	10
MS 82 – intrinsic factors	0	0	4	0	0	0	4	0
MS 9 – other causes	13	3	67	3	5	2	85	3
Total number of causes	402	100	1984	100	219	100	2605	0

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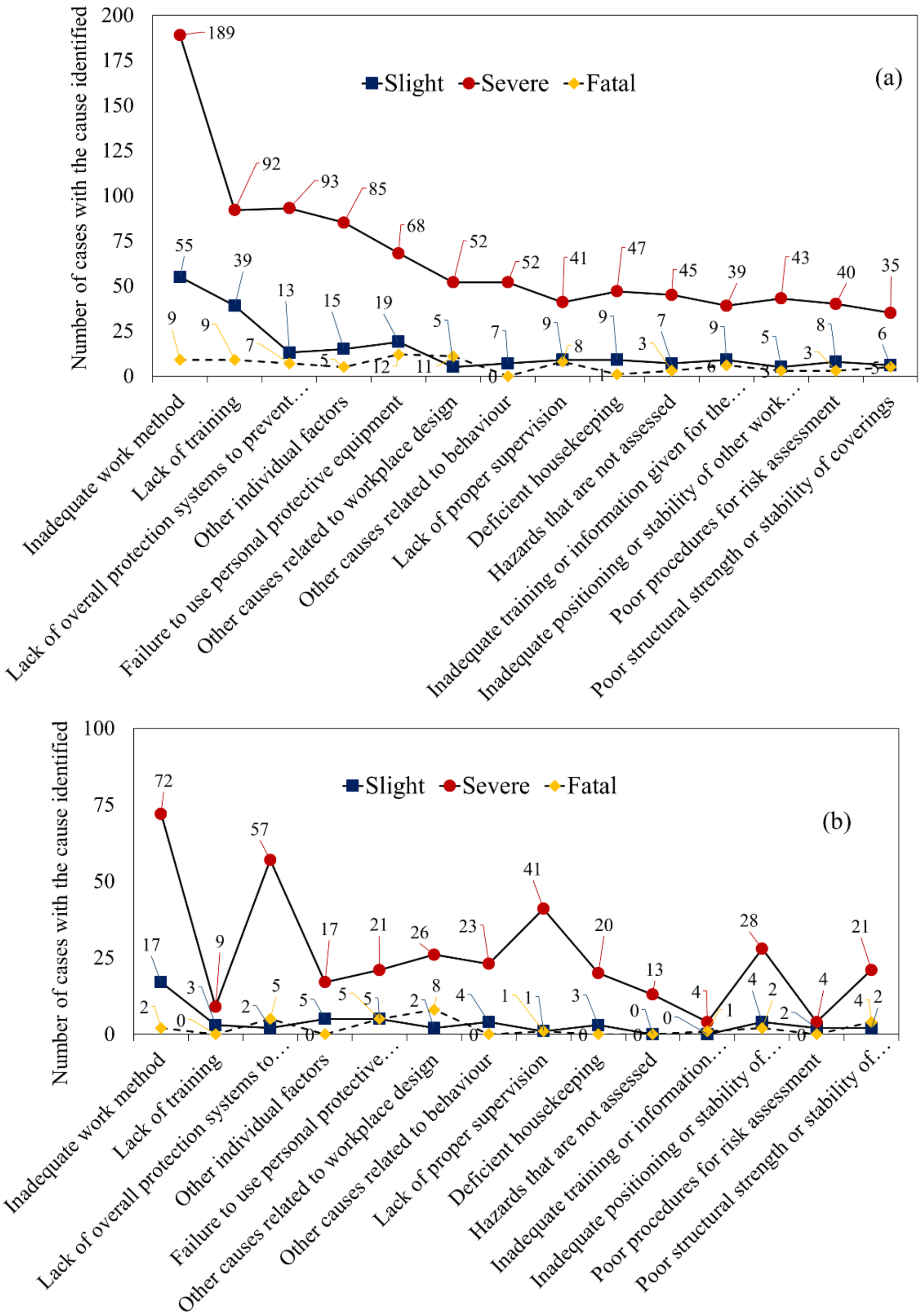

Fig. 3: Most frequent causes identified in the accidents investigated; (a): Number of cases with the cause identified, (b): Number of cases with identified as main cause

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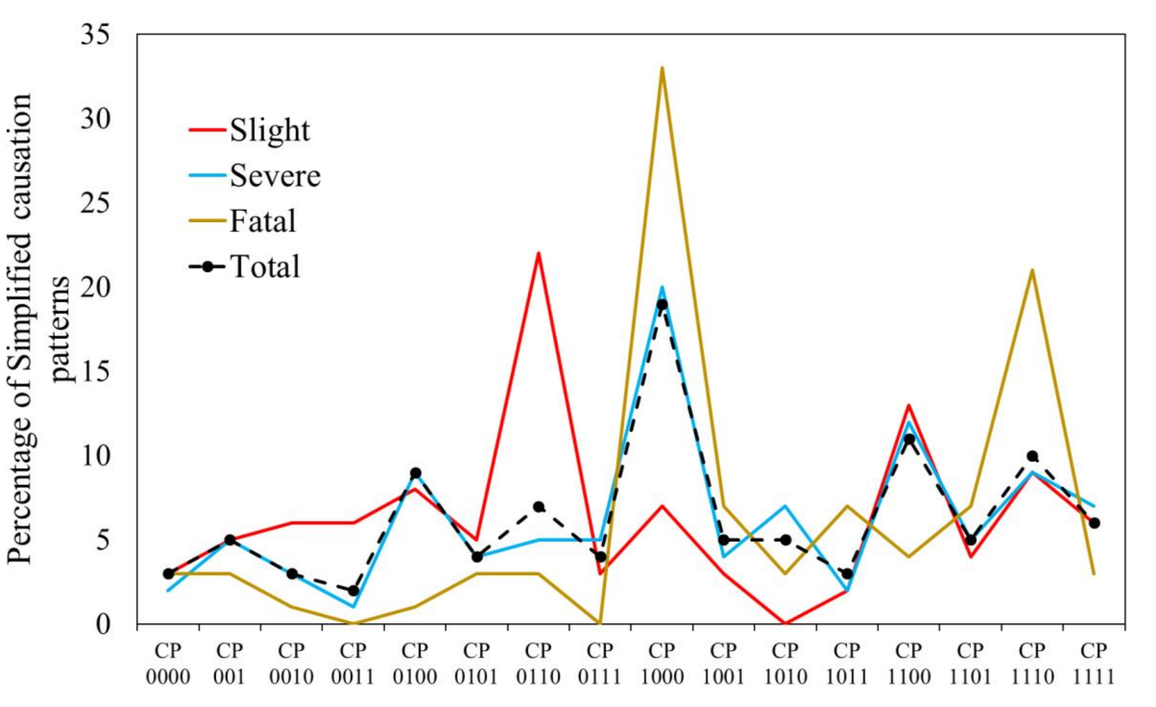

Fig. 4: Percentage of Simplified causation patterns (CP)

The most common causes of minor accidents are related to work organization and safety management, specifically groups MS 6 and MS 7, accounting for 22% of these incidents. The predominant pattern for serious (20%) and fatal accidents (33%) consists solely of active causes from groups one to five. The occurrence of fatal accidents is often associated with active causes, particularly MS 6 - work organization and MS 7 - safety management, which account for 21% of such accidents. Table 3 contains an analysis of the contingency table that shows the relationship between the stage of construction when accidents occurred and the subgroup of reasons. The φ coefficient revealed noteworthy correlations between accident mechanisms and the type of causes.

The following connections are considered significant, as they involve more than five cases: The S1 stage involves demolition, which is associated with safety management (MS 71). The S2 stage involves land preparation, which is linked to training and information (MS 63). The S3 stage involves excavation, which is influenced by workplace layout (MS 11). The SG_9 stage involves roofs, which are affected by other work equipment such as protective devices (MS 42) and machinery design, installation, and maintenance (MS 31), as well as poor performance in safety activities (MS 72). A review of the contingency table between the accident mechanism and the type of cause is presented in Table 4. The φ coefficient revealed significant connections between accident mechanisms and specific subgroups of causes. This study relies on identifying correlations between the causes determined in official accident investigations and

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the accident situation, such as the accident mechanism or the steps of construction at which the accident occurs.

Many small and medium-sized firms in the building industry do not have enough accidents to conduct a comprehensive risk assessment. The given input is a list containing the elements 5 and 6. Hence, in terms of public policy, it is imperative for official accident assessment to offer an initial assessment of the most probable factors contributing to accidents. By utilizing this information, safety practitioners can develop more efficient prevention strategies in accordance with Directive 92/57/EEC [1].

This study offers valuable insights connecting the primary factors contributing to an accident with the most probable causes. Construction site damages evaluation serves to bridge the gap via risk evaluation and identified preventative action by revealing the patterns of accidents. It is important to remember that each building site in the sector is inherently unpredictable.

Table 3: The differential causation varies depending on the stage of construction.

	Stages												
Subgroup of causes marked	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13
MS 11 – workplace design	4	6	6*	8	2	6	42	0	9	8	8	35	3
MS 12 – housekeeping	2	2	1	3	1	1	16	3	2	1	3	12	0
MS 13 – physical agents	0	0	0	1#	0	0	0	0	0	0	0	0	0
MS 21 – service and protection facilities: design, installation and maintenance	0	0	1#	0	0	0	1	3#	0	0	0	1	0
MS 22 – service and protection facilities: protective devices	0	0	0	1	0	1	0	4#	1	0	0	3	0
MS 31 – machinery: design, installation and maintenance	2	5	3	1	0	1	19	7	9*	2	5	13	3
MS 32 – machinery: protective devices	1	4*	0	3	1	0	11	7	5	1	1	16	0
MS 41 – other work equipment: design,	1	3	1	3	0	3	17	10	7	2	6	19	2

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installation and maintenance													
MS 42 – other work equipment: protective devices	3	2	0	3	0	5	20	14	11#	5	2	19	1
MS 43 – other work equipment: signage and information	0	2*	0	1	0	0	4	2	1	0	0	1	0
MS 51 – storage and handling of materials	0	0	0	0	0	2	8	5	2	0	2	5	0
MS 52 – chemical agents	0	0	0	0	0	0	3	0	0	0	0	1	3
MS 61 – work method	9	8	3	12	4	6	55	14	19	15	18	59	6
MS 62 – carrying out tasks	1	1	2	0	0	2	5	1	1	2	1	7	0
MS 63 – task training or information	2	6*	1	3	0	0	15	8	5	3	8	23	5
MS 64 – equipment and material selection	3	2	0	3	1	2	12	6	5	6	9*	15	0
MS 71 – safety management	7#	5	0	6	2	3	21	6	5	8	5	23	0
MS 72 – safety activities	8	7	4	9	2	7	35	18	22#	9	10	50	5
MS 81 – behaviour	3	7	1	3	1	5	29	22	16*	13	7	32	4
MS 82 – intrinsic factors	0	0	0	0	0	1	0	0	0	0	1	0	0
Total number of causes	15	21	11	26	8	25	161	73	39	34	41	152	7

Note: There is a statistically significant coefficient with a p-value less than 0.05.

Additionally, there is a statistically significant coefficient with a p-value≤0.01. Lastly, there is a statistically significant coefficient with a p-value less than 0.001. A Construction stages are denoted as SG_x. The following codes are utilized: S1 refers to the process of demolishing existing structures. SG_2 involves preparing the site for construction. S3 involves excavating the ground. S4 focuses on building the foundations. SG_5 involves installing pipe systems. SG_6 refers to the process of digging trenches. SG_7 involves constructing the main structures. SG_8 focuses on building the external walls. S_9 involves constructing the roofs. S_{10} refers to the construction of partition walls. SG_{11} involves installing various systems and

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utilities. SG_{12} focuses on the finishing touches of the construction. SG_{13} involves constructing pavements.

Previous research on this subject has demonstrated that the primary causes of serious and deadly accidents are often attributed to the conditions present in the workplace. Simultaneously, there is a significant occurrence of causes associated with safety management and safety activities across all types of accidents, particularly minor incidents. The most common causes identified are insufficient work methods, poor training, absence of comprehensive protection measures to avoid falls from heights, individual factors, and failure to utilize personal protective equipment (PPE). The result is consistent with researches carried out in china, turkey and Europe [33-35].

Workplace environment and machinery malfunctions are common factors contributing to accidents during the excavation process. The percentage of cases in excavation with workplace circumstances as the cause is 26%, whereas the average percentage throughout all stages is 10%. Carrying performing duties in the excavation stage accounts for a greater proportion in 9% of instances, while the average for all stages is 2%. Equipment selection causes in the installations stage account for 10% of cases, while the average for all stages is 5%.

Regarding causes linked to machinery and equipment in subgroups 31, 32, 41, 42, and 43, the largest proportions are observed in the stages of soil preparation (27%), external walls (31%), and roofing (28%). It is imperative to determine the most commonly used equipment in each phase and devise suitable procedures for conducting checks and inspections.

The most often identified subcategories of causes in all stages are work technique (17%), safety management (6.9%), and safety actions (13.5%). Nevertheless, the distribution is not evenly spread out. The work technique accounts for a greater share of pipes, specifically 29%. Safety management, on the other hand, is more prevalent in demolition (16%) and piping (15%). Safety activities are more common in roofs (19%) and demolition (16%). It is important to acknowledge that comparing this study with others is challenging due to variations in investigation methods, cause codification pattern, and investigator training. However, the study examined accidents that were investigated using a consistent and controlled process, with the same investigation approach, codification pattern, and trained researchers.

Table 4: The differential causation of the most common accident mechanisms.

	Accident mechanism[a]								
Subgroup of causes marked	M33	M34	M36	M43	M44	M45	M46	M53	M66
MS 11 – workplace design	104#	9	12	6	3	3	12	88#	7
MS 12 – housekeeping	26	3	2	0	2	2	3	23	5
MS 13 – physical agents	1	0	0	0	0	0	0	1	0

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MS 21 – service and protection facilities: design, installation and maintenance	1	0	0	0	0	0	0	0	1
MS 22 – service and protection facilities: protective devices	3	0	1	0	0	0	0	1	0
MS 31 – machinery: design, installation and maintenance	39	1	10+	3	3	7	8	31	1
MS 32 – machinery: protective devices	22	0	4	2	3	8#	3	19	2
MS 41 – other work equipment: design, installation and maintenance	48	4	7	5	3	3	7	36	3
MS 42 – other work equipment: protective devices	61#	4	4	3	0	0	3	49#	7
MS 43 – other work equipment: signage and information	6	0	2	1	1	1	3*	5	2
MS 51 – storage and handling of materials	11	4	1	1	2	5+	1	9	0
MS 52 – chemical agents	2	0	0	0	0	0	0	1	0
MS 61 – work method	108	28+	18	14	18*	13	24	75	12
MS 62 – carrying out tasks	23	2	4	0	1	1	1	18	1
MS 63 – task training or information	43	6	2	5	6	0	6	36	5
MS 64 – equipment and material selection	42*	3	4	4	4	5	4	34*	2
MS 71 – safety management	49	7	8	9*	6	5	8	37	4
MS 72 – safety activities	100	15	13	11	9	11	15	74	4
MS 81 – behaviour	78	12	11	6	5	12	6	67	9
MS 82 – intrinsic factors	G1	0	1*	0	0	0	0	1	0
Total number of causes	70	44	37	27	30	35	33	256	30

Note: There is a statistically significant coefficient with a p-value≤.0.05.

Additionally, a statistically significant coefficient with a p-value≤0.01 was conducted. Lastly, there is a statistically significant coefficient with a p-value less than 0.001. The relationship between mechanisms and M_{xy} may be expressed as Mechanisms = M_{xy}. Mechanisms in ESAW-III are identified by a capital letter M, followed by the first digit of the deviation code and the first digit of the mode of injury code. Deviation codes (first digit): 1 = deviation caused by electrical malfunctions, explosions, or fires; 2 = deviation resulting

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from overflow, overturning, leakage, flow, vaporization, or emission; 3 = material agent failure, such as breakage, bursting, splitting, slipping, fall, or collapse; 4 = complete or partial loss of control over a machine, means of transport, handling equipment, handed tool, object, or animal; 5 = incidents involving slipping, stumbling, and falling of individuals; 6 represents body movement without any physical strain, typically resulting in an external injury. On the other hand, 7 represents body movement performed under or with physical stress, which usually leads to an interior injury. Lastly, 8 encompasses experiences such as shock, fright, violence, aggression, menace, and presence. The second digit of the mode of injury codes. 1 = exposure to electrical voltage, extreme temperatures, or hazardous substances; 2 = submerged, buried, or enveloped; 3 = horizontal or vertical impact with a stationary object; 4 = struck by a moving object or involved in a collision; 5 = contact with sharp, pointed, rough, or coarse surfaces; 6 = trapped or crushed; 7 = physical or mental strain; 8 = bitten or kicked.

Consequently, it is feasible to identify the most probable causes for each stage of building. Nevertheless, this identification is limited to a single point in time and does not pertain to the particular circumstances and measures taken to ensure safety. Hence, the findings are valuable for public policies to pinpoint the predominant factors at each phase of development, and for enterprises as reminders of the primary potential safety lapses to verify. The primary outcome of this research project is the awareness of the most significant correlations between accident mechanisms and certain categories of causes. Within these linkages, certain subsets of causes are more prone to appear in the causal pattern of particular combinations of deviation and form of contact (accident mechanisms).

- Slips and falls are linked to causes related to safety management and protective devices, as previous studies have already identified. On the other hand, accidents involving breakage, bursting, splitting, slipping, falling, or collapsing of material agents are associated with causes related to workplace layout, equipment selection, and protective devices.
- Accidents involving being struck by contacts are strongly correlated with reasons related to work methods, as demonstrated by prior research.
- Interactions with sharp, pointed, rough, and coarse objects, while losing control, are linked to factors connected with protective equipment, as has also been observed in the industrial industry.

5. Conclusions

The findings obtained from this research are really valuable. The risk assessment can only offer a list of potential dangers in order of importance, but it does not provide any guidance on which preventative actions should be prioritized based on the research findings. Towards presenting an innovative risk evaluation to classify the construction site accidents in North of

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Iran (Mazandaran region), the risk approach employed in this study involves examining the correlation between the phase of the construction process and the specific cause found. However, the material that has been reviewed has not included or made available this significant factor. Future research should prioritize the examination of accident occurrences in the construction sector by taking into account the stage of the building. Taking into account the different phases of the building procedure implementation can assist engineers, architects, and contractors in predicting the potential workplace conditions that may arise during the project. The methodology employed in the research can pinpoint the most probable causes, guiding safety practitioners to implement suitable measures at each construction stage and for every accident types. Furthermore, from a public administration perspective, these findings can be utilized to highlight the most common causes of each accident mechanism in the construction industry. Civil researchers, designers and managers can utilize these findings to strategize preventive actions tailored to each building construction steps.

References

1- Council Directive 89/391/EEC of 12 June 1989 on the introduction of measures to encourage improvements in the safety and health of workers at work. OJ. 1989;L183:1–8
2- Gupta, A. K., Pardheev, C. G. V. S., Choudhuri, S., Das, S., Garg, A., & Maiti, J. (2022). A novel classification approach based on context connotative network (CCNet): A case of construction site accidents. Expert Systems with Applications, 202, 117281.
3- Hamid, A. R. A., Abd Majid, M. Z., & Singh, B. (2008). Causes of accidents at construction sites. Malaysian journal of civil engineering, 20(2).
4- Yilmaz, F. (2015). Monitoring and analysis of construction site accidents by using accidents analysis management system in Turkey. Journal of sustainable development, 8(2), 57.
5- Gholizadeh, P., & Esmaeili, B. (2016, May). Applying classification trees to analyze electrical contractors' accidents. In Construction Research Congress 2016 (pp. 2699-2708).
6- Rijo George, M., Nalluri, M. R., & Anand, K. B. (2022). Severity Prediction of Construction Site Accidents Using Simple and Ensemble Decision Trees. In Proceedings of SECON'21: Structural Engineering and Construction Management (pp. 599-608). Springer International Publishing.
7- Chen, N., Zhang, Z., & Chen, A. (2024). Comprehensive evaluation of classification: an empirical study on consequence prediction of construction accidents in China. Construction Innovation.
8- Gürcanli, G. E., & Müngen, U. (2013). Analysis of construction accidents in Turkey and responsible parties. Industrial health, 51(6), 581-595.

Power System Technology
ISSN:1000-3673
Received: 16-01-2024 Revised: 12-02-2024 Accepted: 07-03-2024

9- European Commission. European statistics on accidents atwork (ESAW) – methodology (ed. 2001). Luxembourg: Office for Official Publications of the European Communities; 2002.
10- Haslam RA, Hide SA, Gibb AGF, et al. Contributing factors in construction accidents. Appl Ergon. 2005;36(4):401–415. doi:10.1016/j.apergo.2004.12.002.
11- Chi C-F, Chang T-C, Ting H-I. Accident patterns and prevention measures for fatal occupational falls in the construction industry. Appl Ergon. 2005;36(4):391–400. doi:10.1016/j.apergo.2004.09.011.
12- Chi CF, Lin SZ, Dewi RS. Graphical fault tree analysis for fatal falls in the construction industry. Saf Sci. 2014;72:359–369.
13- Whitaker SM, Graves RJ, James M, et al. Safety with access scaffolds: development of a prototype decision aid based on accident analysis. J Saf Res. 2003;34(3):249–261. doi:10.1016/S0022-4375(03)00025-2.
14- Arboleda CA, Abraham DM. Fatalities in trenching operations – analysis using models of accident causation. J Constr Eng Manag. 2004;130(2):273–280. doi:10.1061/(ASCE)0733-9364(2004)130:2(273).
15- Hinze J, Huang X, Terry L. The nature of struck-by accidents. J Constr Eng Manag. 2005;131(2):262–268. doi:10.1061/(ASCE)0733-9364(2005)131:2(262).
16- Ale BJM, Bellamy LJ, Baksteenc H, et al. Accidents in the construction industry in the Netherlands: an analysis of accident reports using Storybuilder. Reliab Eng Syst Saf. 2008;93(10):1523–1533. doi:10.1016/j.ress.2007.09.004.
17- Leung M-Y, Chan IYS, Yu J. Preventing construction worker injury incidents through the management of personal stress and organizational stressors. Accid Anal Prev. 2012;48:156–166. doi:10.1016/j.aap.2011.03.017.
18- Cheng C-W, Lin C-C, Leu S-S. Use of association rules to explore cause–effect relationships in occupational accidents in the Taiwan construction industry. Saf Sci. 2010;48(4):436–444. doi:10.1016/j.ssci.2009.12.005.
19- Cheng C-W, Leu S-S, Cheng Y-M, et al. Applying data mining techniques to explore factors contributing to occupational injuries in Taiwan's construction industry. Accid Anal Prev. 2012;48:214–222. doi:doi:10.1016/j.aap.2011. 04.014.
20- Hale A, Walker D, Walters N, et al. Developing the understanding of underlying causes of construction fatal accidents. Saf Sci. 2012;50(10):2020–2027. doi:10.1016/ j.ssci.2012.01.018.
21- Swuste P, Frijters A, Guldenmund F. Is it possible to influence safety in the building sector? A literature review extending from 1980 until the present. Saf Sci. 2012;50(5):1333–1343. doi:10.1016/j.ssci.2011.12.036.
22- Carrillo-Castrillo JA, Onieva L. Framework for the use of official occupational accident investigations as a learning tool: analysis of a public programme for accident investigation

Power System Technology
ISSN:1000-3673
Received: 16-01-2024 Revised: 12-02-2024 Accepted: 07-03-2024

in the manufacturing sector. Int J Risk Assess Manag. 2014;17(3):212–232. doi:10.1504/IJRAM.2014. 062775.
23- Jacinto C, Soares CG. The added value of the new ESAW/Eurostat variables in accident analysis in the mining and quarrying industry. Saf Sci. 2008;39(6):632–644.
24- Jacinto C, Canoa M, Guedes Soares C. Workplace and organisational factors in accident analysis within the food industry. Saf Sci. 2009;47(5):626–635. doi:10.1016/j.ssci. 2008.08.002.
25- Jacinto MC, Aspinwall E. A survey on occupational accidents' reporting and registration systems in the European Union. Saf Sci. 2004;42(10):933–960. doi:10.1016/j.ssci. 2004.07.002.
26- Kjellén U. Prevention of accidents through experience feedback. London: Taylor & Francis; 2010
27- Alkaissy, M., Arashpour, M., Golafshani, E. M., Hosseini, M. R., Khanmohammadi, S., Bai, Y., & Feng, H. (2023). Enhancing construction safety: Machine learning-based classification of injury types. *Safety science*, *162*, 106102.
28- Robson LS, Shannon HS, Goldenhar LM, et al. Guide to valuating the effectiveness of strategies for preventing work injuries: how to show whether a safety intervention really works. Cincinnati (OH): National Institute for Occupational Safety and Health; 2001.
29- Markowski, A. S., & Kotynia, A. (2011). "Bow-tie" model in layer of protection analysis. *Process Safety and Environmental Protection*, *89*(4), 205-213.
30- Wierenga, P. C., Lie-A-Huen, L., de Rooij, S. E., Klazinga, N. S., Guchelaar, H. J., & Smorenburg, S. M. (2009). Application of the Bow-Tie model in medication safety risk analysis: consecutive experience in two hospitals in the Netherlands. Drug safety, 32, 663-673.
31- Ruijters, E., & Stoelinga, M. (2015). Fault tree analysis: A survey of the state-of-the-art in modeling, analysis and tools. Computer science review, 15, 29-62.
32- Ericson, C. A., & Ll, C. (1999, August). Fault tree analysis. In System Safety Conference, Orlando, Florida (Vol. 1, pp. 1-9).
33- Chen, N., Zhang, Z., & Chen, A. (2024). Comprehensive evaluation of classification: an empirical study on consequence prediction of construction accidents in China. Construction Innovation.
34- Müngen, U., & Gürcanli, G. E. (2005). Fatal traffic accidents in the Turkish construction industry. Safety science, 43(5-6), 299-322.
35- Lombardi, M., Fargnoli, M., & Parise, G. (2019). Risk profiling from the European statistics on accidents at work (ESAW) accidents′ databases: A case study in construction sites. International journal of environmental research and public health, 16(23), 4748.