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Analysis of Building Construction Jobsite Accident Scenarios Based on Big Data Association Analysis

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Abstract: Although there have been many studies related to construction site safety that have tried to reduce accidents, no significant improvement has been reported. Because of the complex nature of construction work processes, it is important to have a scenario-based worksite safety management system instead of reports such as safety guidelines and manuals. This study utilizes accumulated construction site accident big data, namely Construction Safety Management Integrated Information (CSI), to establish accident scenarios for different work types. To propose accident occurrence scenarios, the hazard profile managed by CSI and prior research analyses are employed for each work type and cause materials at the construction site. For accident occurrence association rules, we developed a framework based on Work Breakdown Structure–Risk Breakdown Structure (WBS-RBS) for reinforced concrete work, temporary work, and earthwork, considering 25,986 accident cases. Subsequently, association analysis was conducted to derive association rules for each work type. The accident occurrence scenarios were extracted by classifying work types (project type, activity type) and cause materials (object, location). The analysis generated 145 association rules, and 76 association rules for reinforced concrete work, temporary work, and earthwork work were extracted to derive accident scenarios, considering scenarios with high accident frequency. Furthermore, by establishing association rules between work processes, we derived accident types and occurrence rules frequently observed at construction sites. These rules formed the basis for constructing accident occurrence scenarios for each construction type based on WBS-RBS. These findings facilitate the development of appropriate safety management plans and effective accident countermeasures tailored to specific construction types and causes. The developed scenarios will help to improve construction site safety by providing useful information for safety managers and worker training.

Keywords: accident scenario; association analysis; construction safety; WBS-RBS framework

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1. Introduction

Social awareness of safety management at construction sites has increased in recent years. Numerous studies have focused on enhancing regulations and policies to mitigate construction-related fatalities [1]. Given the substantial property losses associated with accidents at construction sites, the importance of accident prevention and safety management has been underscored.

According to the 2021 Industrial Accident Analysis [2] released by the Korea Occupational Safety and Health Agency, there were 19,378,565 workers employed in all industries and 102,278 accidents occurred, of which 2080 were fatal. The fatality rate was 1.07 per 10,000 workers, and the fatality rate in the construction industry was 2.32. Figure 1 shows the number of workers and fatal accidents by industry, of which manufacturing accounted for 24.62% (512) of 3,959,780 workers, mining accounted for 16.78% (349) of 10,257 workers, and construction accounted for 26.49% (551) of 2,378,751 workers.

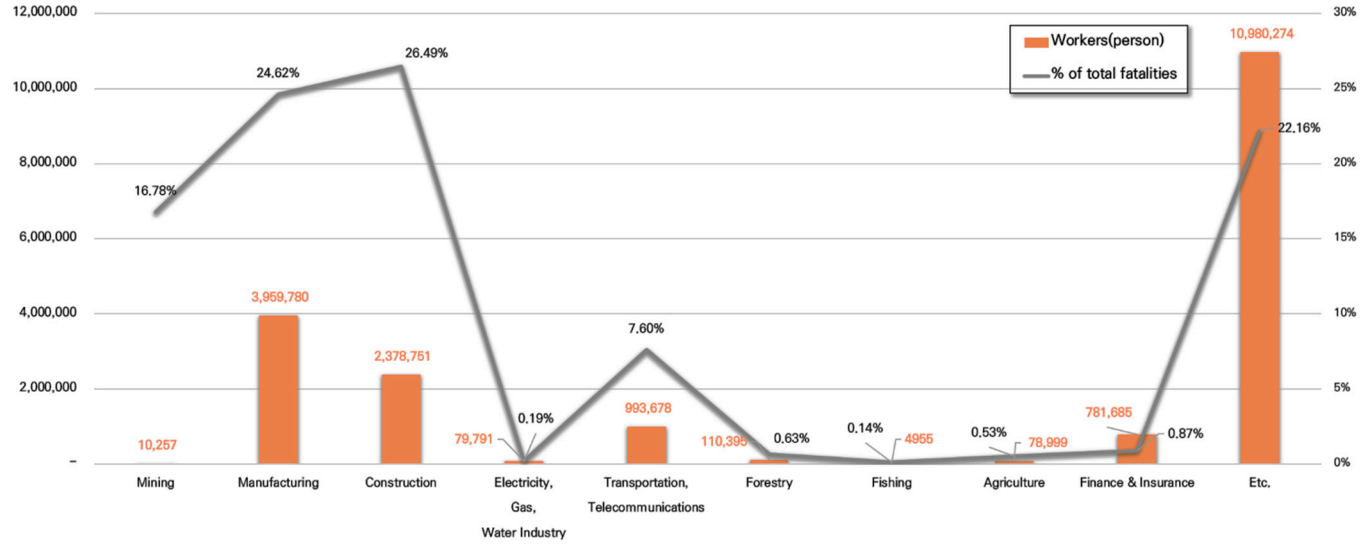

Figure 1. Industrial accidents in Korea, 2021. Source: Korea Occupational Safety and Health Administration, KOSHA.

To mitigate these construction accidents, legislative measures such as the Construction Industry Basic Act and the Serious Accident Punishment Act have been enacted. However, a shift is required from the existing fragmented site-centered safety management approach towards safety management that incorporates the technological advancements of the Fourth Industrial Revolution [3].

In this study, 55,910 cases were collected from the risk profile provided by the Korea Land Information Corporation [4]. Among them, 25,986 cases related to construction work were extracted through association analysis, and 145 association rules were derived. In addition, the association rules were based on the integrated framework of the Work Breakdown Structure–Risk Breakdown Structure (WBS-RBS) system, and the association rules between the type of construction work (large, medium, small), risk factors (object and place), and the type of accident through the construction work and risk factors were conceptualized for accident occurrence. Through this, we aimed to develop accident occurrence scenarios that are essential for establishing precise safety management plans for each type of work.

This study aims to establish risk factors and accident occurrence scenarios by utilizing risk factor profiles obtained from Construction Safety Management Integrated Information (CSI). These profiles categorize all potential risk factors at construction sites, identifying factors that jeopardize worker safety and providing valuable insights for formulating safety management plans.

Furthermore, we employed unsupervised learning techniques, specifically association analysis, to investigate risk associations among activity-specific processes in construction work. Association analysis is a powerful method for examining the association between accident-causing factors. Given that construction accidents result from a combination of multiple factors, understanding the relationships between these factors can offer crucial insights for more effective safety management. This, in turn, facilitates the development of detailed safety management plans tailored to each construction site type, based on the Work Breakdown Structure–Risk Breakdown Structure (WBS-RBS) framework.

2. Literature Review

We analyzed accidents considering building use and construction type. We classified nine facility groups and 34 building uses into 41 construction types and 20 accident types based on 5732 major accidents from 2007 to 2016. As a result, a framework integrating Level 5 WBS and Level 1 RBS was developed [5]. Ryu et al. employed the chi-square test on KOSHA data to verify the statistical significance of the data from apartment construction

sites. Only conditions with a p-value of 0.05 or lower were extracted to demonstrate the most frequent fall accidents and high fatality rates associated with aerial work. Based on the identified causes, measures were proposed for efficient accident prevention [6]. Ying et al., on the other hand, collected accident data in China spanning from 2015 to 2020. They developed a case-based reasoning (CBR)-based platform and accident scenarios for automated management of construction safety risks using rough set and K-NN algorithms [7].

While many studies have focused on the adoption of new technologies, others have empirically investigated the psychological factors that influence the intention to use these technologies or developed predictive models of people's knowledge-sharing behavior by incorporating the relationship between actual construction safety knowledge-sharing behavior and construction accident reduction into MLP feedforward neural networks [8].

Small-to-medium-sized construction site formwork, where many accidents occur, presents checks on risk factors and suggests a checklist for preventing accidents [9]. To reduce the accident rate at these sites, a risk assessment plan was suggested, along with the identification of issues pertaining to risk assessment at small construction sites. Furthermore, a risk assessment model was developed, emphasizing the need for the implementation of a prior work permit system [10].

Data mining techniques employed in safety incident studies in the construction industry vary based on data type, characteristics, and analysis objectives. To assess the impact of factors on outcome variables, supervised learning techniques like decision tree models, artificial neural networks, and discriminant analysis have been employed to analyze and quantify their influence. Previous studies on construction safety incidents have derived association rules using variables related to accident type, construction scale, process schedule, cause, work type, worker age, treatment period, employment period, incident occurrence time, and facilities [11]. Some studies have specifically analyzed construction fatalities and injuries caused by falling objects using association rules [6] and explored fatal accidents at small-scale construction sites. However, these existing studies have limitations in formulating practical safety management measures at construction sites due to the absence of detailed information on the construction industry or workers' specific work processes in the variables used [12].

Research on construction site accidents caused by falling objects through association rules has highlighted the significance of considering various factors beyond falling objects, including worker characteristics and construction type. Such comprehensive analysis is crucial in understanding the causes of accidents [12].

In addition, we analyzed occurrence patterns, work types, and interrelationships among causative factors based on limited data from professional construction workers. The results highlighted the high risk associated with reinforced concrete construction and earthwork construction. Notably, the data used in this study were specific to professional construction work, which limits the generalizability of the findings to overall construction sites [13].

To reduce accident rates at small- and medium-sized construction sites, we proposed a method for establishing risk assessment. Given that construction accidents are influenced by both worker characteristics and site-specific conditions, it is crucial to conduct a multifactor analysis of construction hazards [14].

The authors analyzed fatal accidents caused by weather conditions using association rules. However, it is important to acknowledge that fatal accidents caused by weather conditions are highly variable, and the proposed measures cannot directly control weather conditions [15].

Another study examined the correlation between worker characteristics and safety consciousness. The results presented insights into worker characteristics and consciousness levels, emphasizing the need for realistic and diverse safety education approaches [16].

This study aims to establish an overall construction safety plan by conducting an association analysis on accident types based on process progression to derive association rules between common factors and establishing accident scenarios by construction type for

accident types that occur as construction progresses, rather than focusing only on financial causes and accident types determined by the frequency of occurrence as in previous studies. In addition, the association analysis used in this study attempts to derive meaningful association rules that directly affect construction accidents by itemizing construction scale (large, medium, small) and accident cause (object, place) by accident type. By deriving association rules for process progress conditions that directly contribute to the occurrence of accidents at construction sites through construction accident big data, this study aims to facilitate safety management decision making by providing comprehensive accident occurrence patterns by construction type and generalizing effective countermeasures, rather than analyzing indirect risk factors and limited data on the construction industry in existing studies.

3. Research Method

This study was conducted as shown in Figure 2. First, previous studies on construction site accident factors and safety management frameworks were reviewed. Second, the accident dataset was constructed by extracting the construction type, accident occurrence objects, and accident types for the Work Breakdown Structure (WBS) [17] and Risk Breakdown Structure (RBS) system linkage framework. Third, 145 accident occurrence scenarios were constructed through association analysis by itemizing construction types and risk factors using the constructed WBS-RBS-based framework. Finally, safety checklists based on the Work Breakdown Structure–Risk Breakdown Structure (WBS-RBS) [18] framework were established based on the derived accident occurrence scenarios.

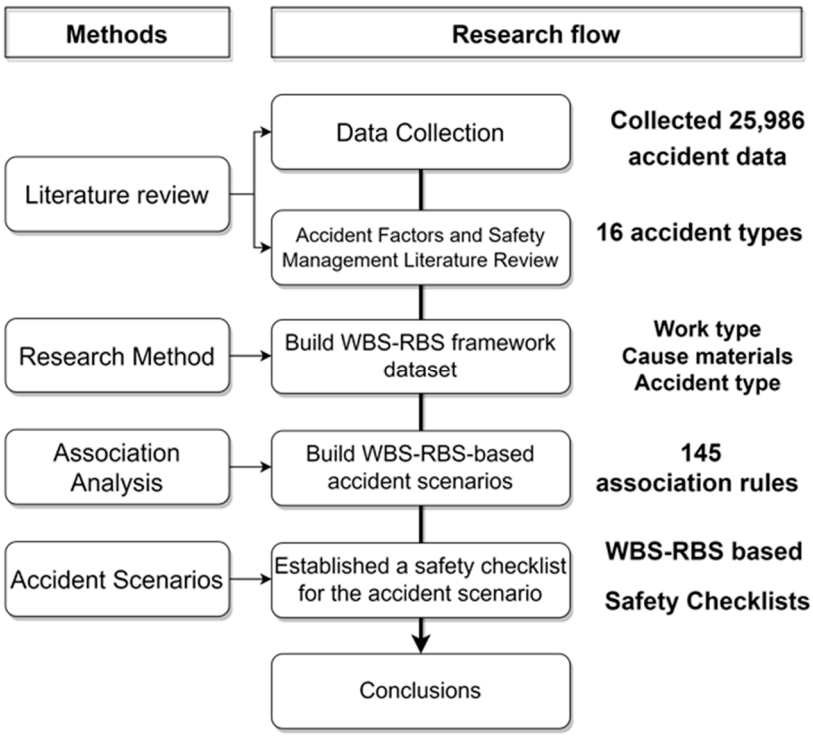

Figure 2. Research flow.

3.1. Establishment of Work Breakdown Structure–Risk Breakdown Structure Framework

Accident data on construction sites have been extensively accumulated. However, their usefulness has been limited owing to the lack of a well-organized and easily understandable safety information data system that is readily available and necessary in the field.

Therefore, a Work Breakdown Structure–Risk Breakdown Structure (WBS-RBS) system has been established by utilizing the accumulated big data on hazard profiles (Figure 3). This system allows practitioners on-site to easily comprehend and access historical accident

information based on scheduled work types and processes. To enhance the accessibility of accident information for different construction project types, we have reorganized the 19 major construction activity types based on the Work Breakdown Structure (WBS).

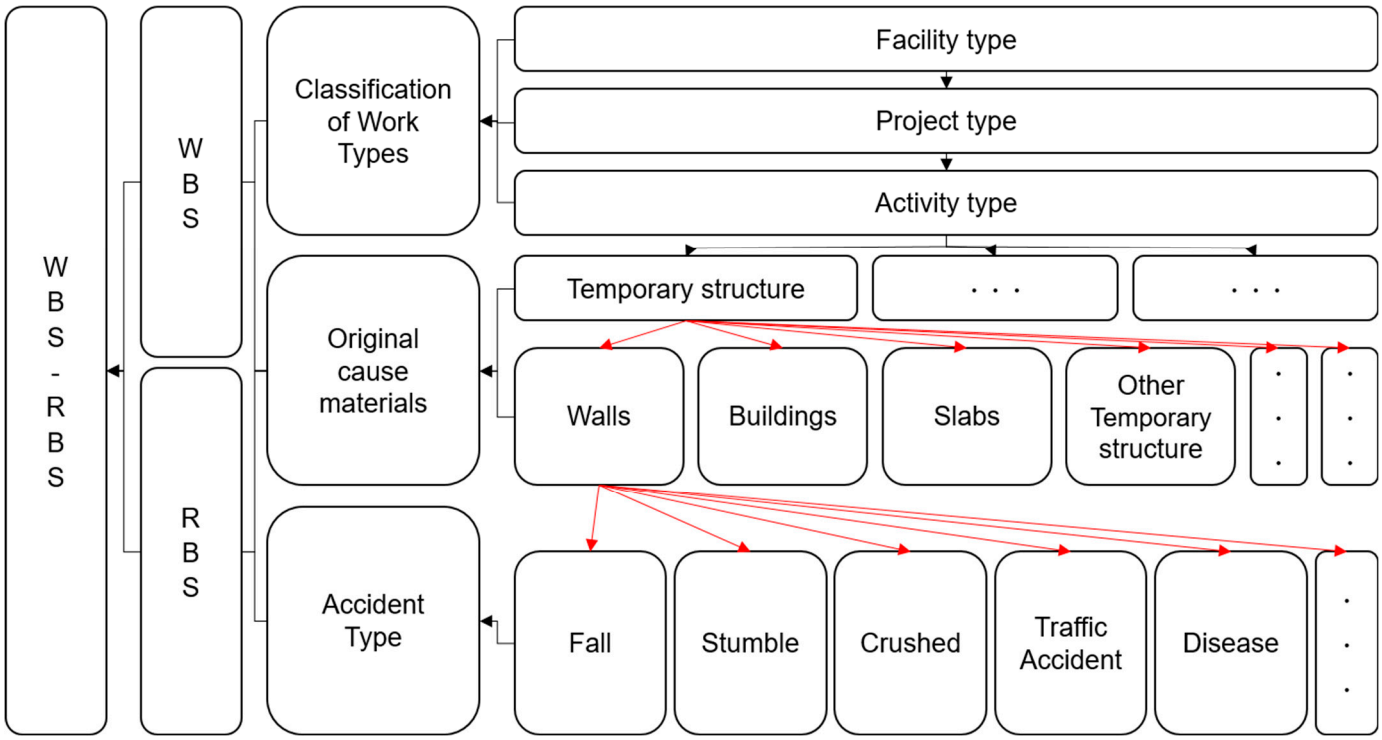

Figure 3. WBS-RBS framework.

A Risk Breakdown Structure (RBS) system has also been established to capture information related to accident location, object, and type. By linking the RBS matrix with the work-type WBS, we have developed the Work Breakdown Structure–Risk Breakdown Structure (WBS-RBS) system, which facilitates a clear understanding of accident details for each construction project type. We have classified project types to establish the Work Breakdown Structure (WBS) system and introduced a classification system to associate each accident with its underlying cause materials [19]. Moreover, we have implemented a data system to assess accident likelihood, severity, and countermeasures, providing a comprehensive framework for analyzing and addressing site accidents.

3.2. Association Analysis

In this study, we utilized association analysis, an unsupervised learning technique, to uncover associations between work processes and accident occurrences in construction sites. Association analysis, a data mining method, uncovers hidden patterns and relationships within a dataset, commonly referred to as "Market Basket Analysis" due to its origins in retail to understand item associations in customers' shopping carts [20].

These associations are crucial for building predictive models or identifying the relationships between cause and effect, particularly in situations where multiple factors are at play, such as construction sites. Factors on a construction site include work process hazards, worker training, working environment, and equipment conditions.

As a non-causal technique, association analysis reveals interrelationships among variables instead of establishing cause-and-effect relationships in chronological order. It differs from supervised learning methods used for prediction or classification [21].

The fundamental approach of association analysis is to identify frequently co-occurring itemsets and derive robust rules from them. The Apriori algorithm is employed to reduce the number of frequent itemsets by leveraging the principle that "if a set of items occurs

frequently, then all subsets of that set also occur frequently". We applied this algorithm to our designated dataset to discover and analyze association rules.

Furthermore, the assessment of association rules in the complete dataset involves three evaluation measures: support, confidence, and lift [16,18,21].

The Apriori algorithm used in this study selects all association rules that satisfy the support and confidence thresholds and searches for frequent items through multiple iterations; all frequent items can be calculated through K iterations [22]. Therefore, robust association rules for accident information by type can be obtained through the WBS-RBS framework.

Support denotes the proportion of overall incidents where hazard factors X and co-occur. It indicates the significance of the relationship rule between these hazard factors. The support value is determined based on the total count of hazard factors. $P(X \cap Y)$ represents the occurrence of the hazard factor that includes both X and Y, while N represents the total count of hazard factors.

This is shown in the following equation.

$$Support(X \rightarrow Y) = \frac{P(X \cap Y)}{N} \tag{1}$$

Confidence is the proportion of cases in the relationship where the hazard factor X is present, in which X and Y occur together. $P(X)$ represents the occurrence of the accident incident that includes factor X, while $P(X \cap Y)$ represents the probability of an accident occurring that includes both X and Y.

This is shown in the following equation.

$$Support(X \rightarrow Y) = \frac{P(X \cap Y)}{N} \tag{2}$$

Lift indicates the close relationship between the hazard factors X and Y. It indicates how much more likely the occurrence of X and Y together is compared to their individual probabilities. A lift value of 1 suggests no significant relationship between X and Y. A lift greater than 1 indicates a positive correlation, meaning that the occurrence of X increases the likelihood of Y. On the other hand, a lift value of less than 1 indicates a negative correlation. When the lift is equal to or greater than 1, it suggests that the presence of hazard factor X can lead to the occurrence of hazard factor Y.

This is shown in the following equation.

$$Lift(X \rightarrow Y) = \frac{P(X \cap Y)}{P(X) \cdot P(Y)} \tag{3}$$

4. Association Analysis and Results

In this study, a Work Breakdown Structure–Risk Breakdown Structure (WBS-RBS) framework is built to derive the main scenarios of accident occurrence of construction types in the process. Through this, we extract the rules of major construction types where accidents occur using association analysis to derive accident scenarios and types of accidents occurring at construction sites and prepare measures to deal with accidents by construction type.

STEP1. To build the Work Breakdown Structure–Risk Breakdown Structure (WBS-RBS) framework, we categorize the collected data into large, medium, and small WBS and build a classification of work in progress by construction type.

STEP2. Through the work classification built in STEP1, the Risk Breakdown Structure (RBS) is built by matching risk factors (objects and locations) associated with each type of work by type of work.

STEP3. The Work Breakdown Structure–Risk Breakdown Structure (WBS-RBS) framework built above is the work progress status for the process, and the built framework generates major accident occurrence rules for accident types through association analysis.

4.1. Data Processing

In this study, we collected hazard factor profile data by categorizing risk factors based on work type. We analyzed a total of 55,910 construction site accident case data collected by the Korea Land Transportation Safety Administration from 2020 to 2022. The collected data are divided into civil engineering, construction, industrial environmental facilities, and landscape facilities. In this study, we conducted a correlation analysis based on the accident cases for construction facilities and selected 25,986 cases related to construction projects for analysis. Table 1 presents the collected data, which includes work type classification, accident-occurring objects (object and location), and accident information for each work type.

Table 1. Variables description.

Variables		Factors
Work type	Project type (W01~37)	Architectural earthwork work, building components work, carpentry work, designated work, earthwork, electrical facilities work, floor finishing work, interior finishing work, landscaping work, masonry work, mechanical facilities work, metal work, painting work, piling work, reinforced concrete work, roofing and gutter work, steel frame work, tile and stone work, waterproof work, window and glass work
	Activity type (P01~40)	Assembly work, auxiliary and consolidation work, dismantling work, equipment work, excavation work, finishing work, formwork and carpentry, high scaffold work, inspection and testing work, installation work, lifting work, loading work, moving, painting work, pouring work, piling and anchoring work, salvage work, scaffolding work, stacking work, transportation work, welding work
Cause materials	Object (O01~09)	Components, construction machinery, construction materials, construction tools, facilities, temporary structure, soil and rock
	Location of object (OS01~114)	Bolts, buildings, ceiling panels, concrete pumps, cranes (mobile cranes, etc.), deck plates, drills, dump trucks, excavation slopes, fall prevention nets, ground, Aerial work platform, ladders, materials, openings, other temporary structures, piling and anchoring equipment, piping, prefabricated piles, prefabricated stairs, rebars, retaining walls, safety belts, safety facilities, scaffolding, scaffolding, slabs, slope protection, soil retention fences, special construction machinery, special scaffolding (e.g., gang forms), Steel pipe scaffolds, steel structural components, stone walls, system scaffolds, toe plates, tools, tower cranes, vapor barriers, wall structures, windows and doors, wire ropes, work platforms
Accident type (H01~16)		Amputation/stabbing, caught in between, collapse, electric shock, exposure to hazardous material, falling, fire/explosion, hit, pressed/overturned, slip down, struck by object

For our analysis, we selected variables commonly used in previous studies: work type (project type: W), work type (activity type: P), cause materials (object: O), cause materials (location of object: OS), and accident type (accident type: H). These variables are considered key factors influencing accidents.

4.2. Frequency Analysis of Accidents

In this study, we analyzed the relationship between work types and cause materials in the construction process. To accomplish this, we examined the frequency of construction accidents by utilizing hazard factor profiles derived from an accident occurrence framework. We reclassified the risk factor profile data and categorized the accident occurrence factors into work type (project type, activity type) and cause materials (object, location). The project type refers to various types of construction work. Additionally, we identified the 10 most frequent accident types out of a total of 17 categories for further analysis.

4.2.1. Project Type

Out of the 37 work types included in the hazard factor profile, we analyzed 22 work types, as indicated in Table 2. The analysis revealed that temporary work accounted for 21.4% of the accidents, reinforced concrete work accounted for 18.6%, and earthwork accounted for 12.4%. These three work types together constituted 52.4% of the total number of accident cases.

Table 2. Project type.

Project Type	Frequency (%)	Project Type	Frequency (%)
Temporary work	21.4%	Piling work	2.1%
Reinforced concrete work	18.6%	Window and glasswork	2.1%
Earthwork	12.4%	Electrical facilities work	1.4%
Building components work	7.6%	Interior finishing work	1.4%
Steel frame work	6.9%	Landscaping work	1.4%
Metalwork	6.2%	Tile and stonework	1.4%
Foundation work	3.4%	Carpentry work	1.4%
Waterproof work	3.4%	Drainage earthwork	0.7%
Other	2.8%	Mechanical facilities work	0.7%
Floor finishing work	2.1%	Painting work	0.7%
Masonry work	2.1%	Roofing and gutter work	0.7%

4.2.2. Activity Type

Activity types were identified based on the classification of work types, resulting in 22 tasks, as presented in Table 3. The analysis revealed that installation work, moving, pouring work, finishing work, and lifting work were the most prominent activity types, in that order. Remarkably, these five activities accounted for 54.5% of the total number of accident cases.

Table 3. Activity type.

Activity Type	Frequency (%)	Activity Type	Frequency (%)
Installation work	22.8%	Stacking work	3.4%
Moving	10.3%	Loading work	2.1%
Pouring work	8.3%	Other	2.1%
Finishing work	7.6%	Painting work	2.1%
Lifting work	5.5%	Salvage work	2.1%
Assembly work	4.8%	Drill work	2.1%
Excavation work	4.8%	Transportation work	2.1%
Piling and anchoring work	4.8%	Consolidation work	0.7%
Welding work	4.8%	Equipment work	0.7%
Formwork and carpentry	4.1%	High scaffold work	0.7%
Dismantling work	3.4%	Inspection and testing work	0.7%

4.2.3. Accident Cause Materials

According to the Korea Occupational Safety and Health Agency (KOSHA) Guidelines for Recording and Classifying Industrial Accidents (G-83-2016), causal materials refer to machines/devices and structures with energy sources (motion, location, heat, electricity, etc.) that directly cause or impact accidents involving objects/substances, people, or the environment [23].

Furthermore, within the hazard factor profile, accident cause materials are categorized as object or location. The objects are classified as presented in Table 4, and their dominance can be ranked as follows: temporary structure (32.4%), structure components (15.9%), construction machinery (15.2%), and construction materials (13.1%).

Table 4. Object.

Object	Frequency (%)	Object	Frequency (%)
Temporary structure	32.4%	Other	8.3%
Structure Components	15.9%	Facilities	7.6%
Construction machinery	15.2%	Soil and rock	5.5%
Construction materials	13.1%	Construction tools	2.1%

Locations of objects are classified as shown in Table 5. Accidents occur at various locations, such as buildings (7.6%), scaffolding (6.2%), and retaining facilities (5.5%).

Table 5. Location.

Location Object	Frequency (%)	Location Object	Frequency (%)
Structure	7.6%	Tools	1.4%
Scaffolding	6.2%	Tower cranes	1.4%
Soil retaining panel	6.2%	Bolts	0.7%
Deck plates	5.5%	Concrete pumps	0.7%
Excavation slopes	4.1%	Dump trucks	0.7%
Piling and anchoring equipment	4.1%	Fall prevention nets	0.7%
Scaffolding	4.1%	Ground	0.7%
Slabs	4.1%	Aerial work platform	0.7%
Wall structures	4.1%	Ladders	0.7%
Cranes (mobile cranes, etc.)	4.1%	Openings	0.7%
Drills	3.4%	Prefabricated stairs	0.7%
Materials	3.4%	Retaining walls	0.7%
Steel structural components	3.4%	Safety belts	0.7%
Work platforms	3.4%	Slope protection	0.7%
Other temporary structures	2.8%	Special construction machinery	0.7%
Steel pipe scaffolding	2.8%	Special scaffolding (e.g., gang forms)	0.7%
System scaffolds	2.8%	Stone walls	0.7%
Prefabricated piles	2.1%	Toe plate	0.7%
Rebars	2.1%	Vapor barriers	0.7%
Ceiling panels	1.4%	Windows and doors	0.7%
Piping	1.4%	Wire ropes	0.7%
Safety facilities	1.4%		

4.2.4. Accident Type

Accident types are classified as shown in Table 6 and are categorized into eight accident types that can be ranked in the order of frequency. Double crushing (40.0%), falling (38.6%), and being hit by an object (10.3%) collectively accounted for 88.9% of all the accident types.

Table 6. Accident type.

Accident Type	Frequency (%)	Accident Type	Frequency (%)
Crushed by an object	40.0%	Burns	2.1%
Falling	38.6%	Stumble	1.4%
Struck by object	10.3%	Collision	0.7%
Asphyxiation	6.2%	Others	0.7%

4.3. Analyze Incidents by Type

In this study, a work type-based accident occurrence framework was built by utilizing the types of work conducted during construction and the causal materials of the accident.

In addition, the proportion of the major types of construction work in the case data was 65.5% for reinforced concrete (W06) [24], temporary work (W01) [25], and earthwork (W17) [26], and the correlation analysis showed that reinforced concrete (W06), temporary work (W01), and earthwork (W17) accounted for 70.3% of the total types of construction

work (Figure 4). We used support, lift, and confidence as measures to evaluate the degree of relevance of the association rules [27].

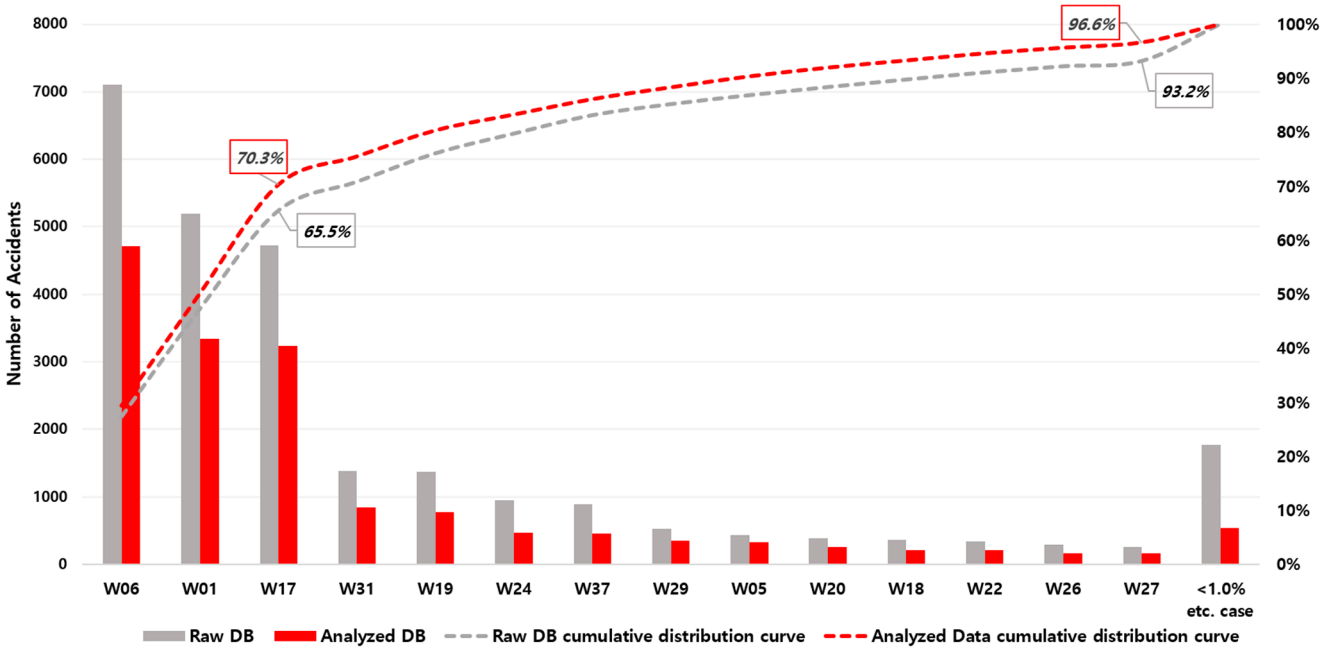

Figure 4. Pareto chart by work type.

When generating association rules, setting low levels of support and confidence may lead to an excessive number of difficult-to-interpret rules. Conversely, setting high levels of support and confidence may result in a lack of meaningful rules [28]. Additionally, a meaningful improvement in association rules is achieved when the value is 1.0 or higher [29].

Using a dataset of 25,986 cases, we analyzed and derived task type-based incident occurrence association rules by applying the metric of a lift level of 1 or higher with a support of 0.001 or higher. In general, in association rules, two items are said to be independent if they have an enhancement of 1, a positive association if it exceeds 1, and a negative association if it is less than 1. Therefore, if the value of the lift is zero, the two items are not related; if the value is negative, there is a negative association; and if it is positive, we can think of a just association [30]. We derived 145 association rules for 16,042 cases (61.7%) of the total data. These rules provided insights into the types of projects with high incident frequency.

4.3.1. Reinforced Concrete Work Accidents

For reinforced concrete work, we derived 27 rules that occur in the order of Left-Hand Side (LHS) to Right-Hand Side (RHS).

Left-Hand Side (LHS) refers to the labor pattern, and Right-Hand Side (RHS) refers to the accident type that occurs according to the labor pattern.

Figure 5 shows that Left-Hand Side (LHS) is an accident type and Right-Hand Side (RHS) is an accident type according to the work pattern, and the main types of accidents in reinforced concrete work are being crushed by objects (H01, 13 cases), falling (H02, 12 cases), tripping (H04, 1 case), and electric shock (H10, 1 case). Accidents in reinforced concrete work can occur during pouring, installation, and formwork. Among the causal substances, we derived a number of rules for temporary facilities and construction materials. We also categorized accident locations into 16 types and derived rules for locations of formwork, slabs, system supports, etc.

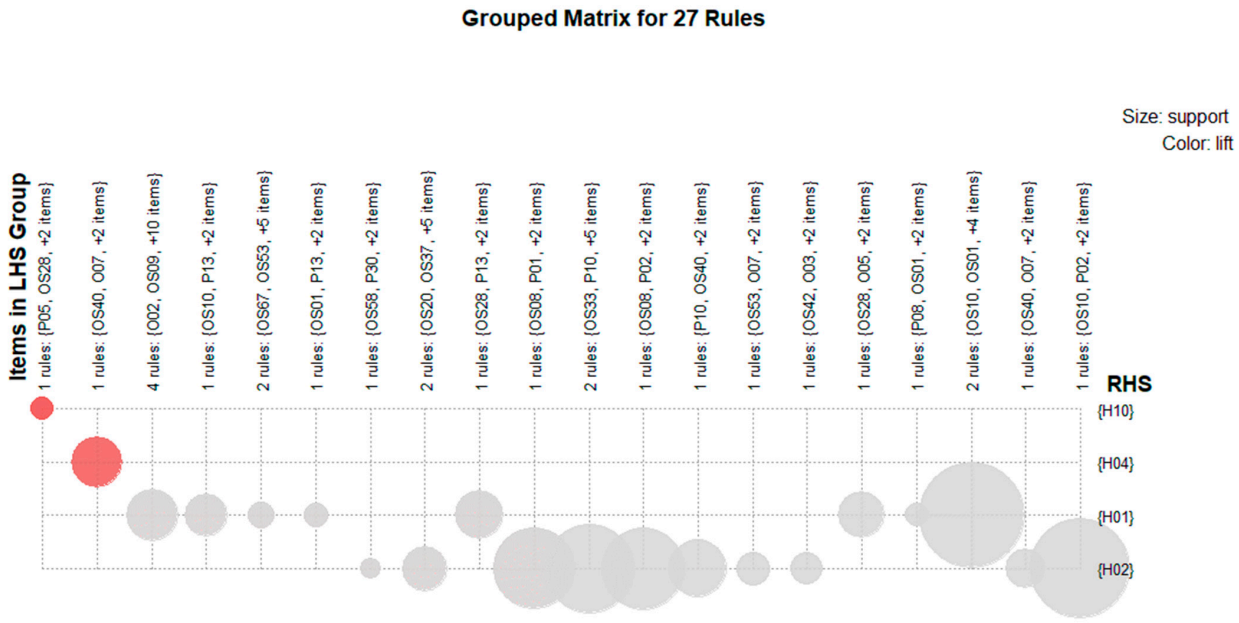

Figure 5. Association rules of reinforced concrete work accidents.

Considering Work Breakdown Structure–Risk Breakdown Structure (WBS-RBS)-based accident types, we generated rules with the highest support rate of 0.029 for reinforced concrete work (W06), pouring operations (P02), temporary facilities (O01), system supports (OS03), and crushed by object (H01), as shown in Table 7. Of the 27 association rules for reinforced concrete work, 13 are related to crushing accidents, with Lift of 1.56 or higher, showing a high correlation within the rule set. Twelve rules were derived for falling accidents in reinforced concrete work, with reinforced concrete work (W06), pouring (P02), temporary facilities (O01), formwork (OS1), and falling (H02) having the highest support of 0.025. Falling accidents can occur during pouring (P02) and erection (P01). The causative materials are temporary facilities (OS1), construction machinery (OS53), and construction materials (OS27). Also, based on the lift value, there is a correlation of more than 1.362 between the type of work in the set and the causative material.

Table 7. Association rules of reinforced concrete work.

Rule (LHS→RHS)	Support	Confidence	Lift
W06, P02, O01, OS3→H01	0.029	0.605	1.560
W06, P02, O01, OS1→H02	0.025	0.820	2.005
W06, P01, O01, OS3→H02	0.015	0.557	1.362
W06, P01, O01, OS16→H01	0.014	0.997	2.572
W06, P01, O01, OS4→H02	0.012	0.807	1.975
W06, P02, O01, OS4→H02	0.012	0.854	2.090
W06, P13, O03, OS53→H02	0.009	0.924	2.262
W06, P08, O01, OS44→H01	0.008	1.000	2.579
W06, P05, O05, OS27→H02	0.008	0.751	1.838
W06, P02, O05, OS27→H04	0.006	0.959	54.509
W06, P09, O02, OS18→H01	0.006	0.858	2.213
W06, P02, O02, OS18→H01	0.006	0.689	1.778
W06, P09, O01, OS3→H01	0.005	0.984	2.538
W06, P01, O05, OS27→H02	0.004	0.628	1.536
W06, P01, O05, OS90→H02	0.003	0.733	1.793

Table 7. *Cont.*

Rule (LHS→RHS)	Support	Confidence	Lift
W06, P02, O03, OS64→H02	0.003	0.731	1.790
W06, P02, O05, OS90→H01	0.003	0.971	2.503
W06, P06, O04, OS24→H01	0.003	1.000	2.579
W06, P01, O01, OS1→H01	0.003	0.598	1.543
W06, P09, O01, OS1→H01	0.002	0.953	2.459
W06, P10, O02, OS18→H10	0.002	0.929	60.630
W06, P09, O01, OS1→H01	0.002	0.623	1.607
W06, P04, O01, OS66→H01	0.001	0.972	2.507
W06, P02, O05, OS59→H02	0.001	0.941	2.303
W06, P09, O02, OS42→H01	0.001	1.000	2.579
W06, P13, O03, OS19→H02	0.001	1.000	2.447
W06, P05, O02, OS49→H02	0.001	0.818	2.002

4.3.2. Temporary Support Work Accidents

In the case of temporary work, we obtained 31 rules through correlation analysis out of the 145 association rules (Figure 6). The dominant accident types were falling (H02, 19 cases) and crushing (H01, 12 cases). For falling incidents in temporary construction, we classified detailed work types into 15 categories, involving various tasks such as installation work (P01), moving (P08), and pouring work (P02). Among the cause materials, most rules were derived from temporary facilities (temporary structures, O01). Additionally, accident locations were categorized into 16 types, with rules derived for scaffolding (OS17), soil retention fences (OS2), and other temporary facilities (other temporary structures, OS8).

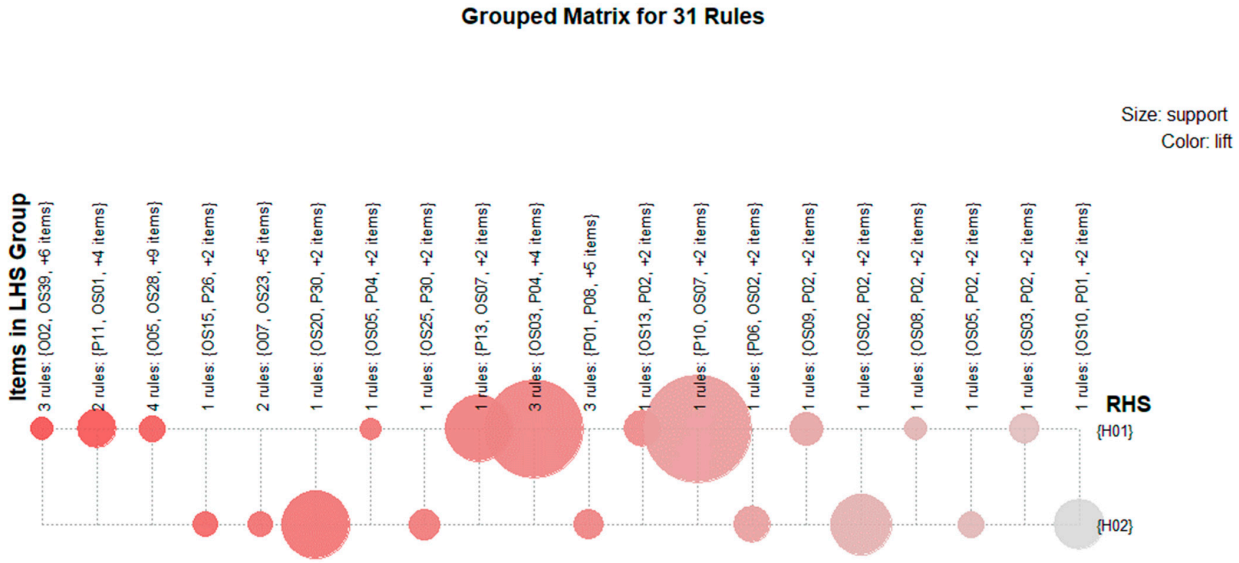

Figure 6. Association rules of temporary work accidents.

Regarding Work Breakdown Structure–Risk Breakdown Structure (WBS-RBS)-based association rules, the rule with the highest support rate of 0.031 was generated for temporary construction (W01), installation work (P01), temporary facility (O01), scaffolding (OS17), and falling (H02), as shown in Table 8. Out of the 31 association rules for temporary construction, 19 were specifically related to falling accidents, exhibiting a strong correlation within the rule set with a lift value of 1.67 or higher.

Temporary work (W01), drilling work (P15), construction machinery (O03), drilling machine (OS36), and crushing (H01) showed the highest lift value of 2.447 among the association rules related to crushing.

This indicates that the correlation between the work types and cause materials within this rule set was 2.447 times higher compared to other rules.

Table 8. Association rules of temporary work.

Rule (LHS→RHS)	Support	Confidence	Lift
W01, P01, O01, OS17→H02	0.031	0.857	2.209
W01, P05, O01, OS17→H02	0.014	0.742	1.915
W01, P13, O03, OS53→H01	0.008	0.955	2.336
W01, P09, O01, OS17→H02	0.008	0.871	2.247
W01, P01, O01, OS2→H01	0.007	0.693	1.696
W01, P02, O01, OS3→H01	0.005	0.592	1.448
W01, P08, O01, OS17→H02	0.005	0.862	2.222
W01, P30, O01, OS17→H02	0.005	0.992	2.557
W01, P01, O01, OS21→H02	0.003	0.835	2.153
W01, P11, O01, OS2→H01	0.003	0.766	1.874
W01, P05, O01, OS1→H02	0.003	0.987	2.546
W01, P01, O01, OS16→H02	0.003	0.699	1.803
W01, P07, O01, OS17→H02	0.003	0.973	2.508
W01, P02, O01, OS1→H01	0.003	0.893	2.186
W01, P13, O03, OS78→H01	0.003	0.930	2.275
W01, P16, O01, OS8→H01	0.002	0.968	2.369
W01, P01, O01, OS6→H02	0.002	0.621	1.602
W01, P02, O01, OS4→H01	0.002	0.906	2.218
W01, P06, O01, OS8→H02	0.002	0.962	2.482
W01, P04, O01, OS2→H01	0.002	0.895	2.189
W01, P01, O01, OS8→H01	0.002	0.667	1.631
W01, P15, O03, OS36→H01	0.002	1.000	2.447
W01, P01, O01, OS14→H02	0.002	0.976	2.516
W01, P01, O01, OS4→H02	0.001	0.648	1.672
W01, P09, O04, OS24→H02	0.001	1.000	2.579
W01, P12, O01, OS2→H02	0.001	1.000	2.579
W01, P08, O01, OS6→H02	0.001	0.857	2.211
W01, P08, O02, OS18→H02	0.001	0.968	2.496
W01, P08, O04, OS24→H02	0.001	1.000	2.579
W01, P08, O01, OS8→H02	0.001	0.900	2.321
W01, P24, O05, OS71→H01	0.001	0.963	2.356

4.3.3. Earthwork Accidents

Through our analysis, we derived 18 association rules for accident types: crushed by an object (H01, 12 cases), falling (H02, 4 cases), hit by an object (H05, 1 case), and burns (H09, 1 case) as shown in Figure 7. Regarding crushing incidents in construction earthwork, we categorized detailed work types into 10 categories, involving various tasks such as excavation work (P11), installation work (P01), and moving (P08). Association rules were derived from soil and rock (O07) and temporary facilities (other temporary structures, O02) among the cause materials. Additionally, accident locations were classified into 10 types, with rules derived for scaffolding (OS17), soil retention fences (OS2), and others (OS79). For the crushed-by-an-object type, the rule with the highest support rate of 0.041 was created for earthwork (W01), excavation work (P011), soil and rock (O07), excavation slope (OS67), and crushed by an object (H12). Out of the 18 association rules for earthworks, 12 were specifically related to the crushed by an object type, exhibiting a strong association between the factors within the rule set with a lift value of 1.73 or higher.

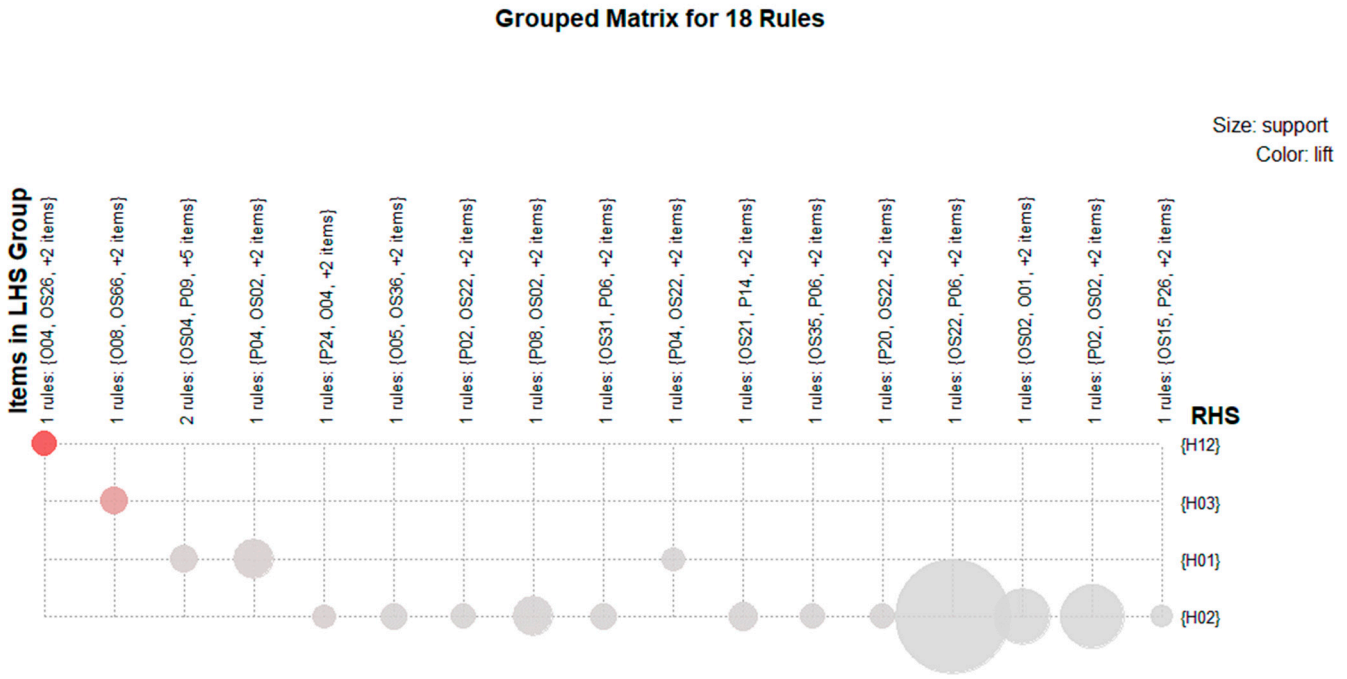

Figure 7. Association rules of earthwork accidents.

Additionally, we derived six cases as association rules for falling, being hit by an object, and burns. The association rule for earthwork (W01), excavation work (P011), other (OS79), and burns (H12) had a lift value of 31.1, indicating a higher likelihood of burns compared to other item sets, as shown in Table 9. Other incidents resulting from an insufficient inspection of obstructions during excavation work, such as gas pipes, include explosions and fire accidents. Furthermore, the association rule related to earthwork (W01), installation work (P01), construction tools (O06), tools (OS60), and being hit by an object (H05) had a lift value of 12.89. Being hit by an object caused by lifting work during installation exhibited a stronger correlation between factors than other rules.

Table 9. Association rules of architectural earthwork.

Rule (LHS→RHS)	Support	Confidence	Lift
W17, P11, O07, OS67→H01	0.041	0.816	1.996
W17, P01, O01, OS2→H01	0.019	0.742	1.816
W17, P11, O01, OS2→H01	0.016	0.752	1.840
W17, P04, O01, OS2→H01	0.008	0.961	2.351
W17, P08, O01, OS2→H02	0.008	0.991	2.556
W17, P12, O01, OS7→H02	0.004	1.000	2.579
W17, P14, O03, OS37→H01	0.004	0.930	2.276
W17, P01, O06, OS60→H05	0.003	1.000	12.890
W17, P29, O02, OS38→H01	0.003	0.971	2.377
W17, P11, O07, OS34→H01	0.002	0.955	2.336
W17, P04, O07, OS67→H02	0.002	1.000	2.579
W17, P11, O07, OS68→H01	0.002	0.924	2.262
W17, P01, O07, OS67→H01	0.002	0.968	2.368
W17, P27, O07, OS67→H01	0.002	0.918	2.246
W17, P11, O08, OS79→H09	0.002	0.610	31.102
W17, P08, O07, OS67→H02	0.002	0.885	2.282
W17, P33, O08, OS79→H01	0.001	1.000	2.447
W17, P15, O03, OS36→H01	0.001	0.711	1.739

Table 9. *Cont.*

Rule (LHS→RHS)	Support	Confidence	Lift
W17, P11, O07, OS67→H01	0.041	0.816	1.996
W17, P01, O01, OS2→H01	0.019	0.742	1.816
W17, P11, O01, OS2→H01	0.016	0.752	1.840
W17, P04, O01, OS2→H01	0.008	0.961	2.351
W17, P08, O01, OS2→H02	0.008	0.991	2.556
W17, P12, O01, OS7→H02	0.004	1.000	2.579
W17, P14, O03, OS37→H01	0.004	0.930	2.276
W17, P01, O06, OS60→H05	0.003	1.000	12.890
W17, P29, O02, OS38→H01	0.003	0.971	2.377
W17, P11, O07, OS34→H01	0.002	0.955	2.336
W17, P04, O07, OS67→H02	0.002	1.000	2.579
W17, P11, O07, OS68→H01	0.002	0.924	2.262
W17, P01, O07, OS67→H01	0.002	0.968	2.368

5. Conclusions

In this study, we utilized association analysis, an unsupervised learning method, to establish accident occurrence association rules between WBS-RBS-based construction work types and hazard factors in building projects. The objective was to provide valuable insights for workers and site safety managers in preparing appropriate hazard countermeasures at construction sites.

Using a dataset of 25,986 accident cases from building projects, we derived association rules for accident types in reinforced concrete work, temporary work, and earthwork, which are known for their high frequency of accidents. The goal was to provide useful insights for construction workers and site safety managers to prepare appropriate risk measures by establishing a WBS-RBS-based framework for detailed tasks and risk factors (objects and locations) involved in the execution of construction work. The key findings of our analysis are as follows:

1. For accidents related to reinforced concrete work, we identified 27 association rules with a support level of 0.001 or higher and a lift level of 1 or higher. Notably, we derived an association rule with the highest support (0.029) for the crushed-by-an-object type in the scenario of reinforced concrete work–pouring work–temporary facility–system support–crushed by an object. Additionally, we established an association rule scenario for the falling accident type in reinforced concrete work–pouring work–temporary facility–formwork–falling.
2. In the context of temporary work-related accidents, we derived 31 association rules with a support level of 0.001 or higher and a lift level of 1 or higher. Among these, 19 rules were created for the falling accident type, with the highest support (0.031) observed in the accident type of temporary work–installation work–temporary facility–scaffolding–falling.
3. For earthwork accidents, we obtained 12 association rules specifically related to the crushing of objects out of the total 18 association rules. Notably, the scenario of earthwork–excavation work–soil and bedrock–excavation slope–crushed by an object exhibited the highest support rate of 0.041.

Furthermore, we derived six association rules related to falling, being hit by an object, and burns. Among the rules related to burns, the association rule of earthwork–excavation work–other–burns had a lift value 31 times higher than other item sets. This scenario encompasses accidents caused by insufficient inspection of obstructions such as gas pipes during excavation work, including explosions and fire accidents resulting from excavation work. Additionally, the association rule associated with earthwork–installation work–construction tools–struck by object had a lift value of 12.89, indicating a stronger association among the factors than other rules.

Although we successfully identified meaningful rules through our study, it is important to note that creating rules with high support presents challenges in the construction industry. The complexity of work types and the extensive range of cause materials contribute to this difficulty. Nonetheless, by analyzing accident frequency, we can anticipate that work types with a high frequency of accidents will occur in high-frequency scenarios.

Therefore, one can effectively manage safety on construction sites by utilizing the accumulated data to build accident scenarios based on the Work Breakdown Structure–Risk Breakdown Structure (WBS-RBS) for each construction type.

Nevertheless, by analyzing the frequency of accidents, it can be expected that the scenarios with a high frequency of accidents will occur in the scenarios with a high frequency of work types. Therefore, it is possible to predict the types of accidents for each detailed work type and object that are carried out according to the work type, and it is possible to establish accident countermeasures for each work type. The high frequency of accidents means that the risk of accidents for that type of work is high, and active accident countermeasures and training of workers are needed in this area.

The limitation of this study is that it is difficult to set the minimum support level objectively. Therefore, future studies should further investigate the effect of changing the threshold of the minimum support map through sensitivity analysis. In addition, it is recommended that further analyses be conducted that include construction scale, process rate, and worker information rather than patterns based on construction type.

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