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Risk Analysis on the Causes of Safety Accident at Construction Site in Korea using Eigenvector

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Abstract: In this study, the causes of safety accident in construction site were derived and the risk of the causes of safety accidents was analyzed. First, the causes of safety accident at the construction site in Korea from 2016-2018 were analyzed to identify the causes of safety accident. The causes of safety accident were classified into 4M technique (Man, Machine, Media and Management) which is safety management technique. The risk of man, machine, media and management was analyzed using the eigenvector method and the risk of the causes of safety accident was analyzed. Using the risk of man, machine, media and management and the risk of the causes of safety accident, the final risk of the causes of safety accident was calculated. The risk of safety accident due to breaches of safety regulations or guidelines', 'inappropriate communication with worker's, 'inadequate construction method plans', 'lack of training and education of personnel' and 'inadequate recognition and evaluation of site hazards' was analyzed to be high. All of the causes of safety accident with high-risk were analyzed as belonging to management. Therefore, safety management activities in terms of management are necessary to prevent safety accidents. In addition, by improving safety management activities for the causes of safety accident with high-risk, the effectiveness of safety management activities can be improved and safety accident can be prevented.

Key words: Construction safety, safety management, cause of safety accident, risk, media and management, eigenvector

INTRODUCTION

Background and purpose of the study: In 2018, the number of safety accidents caused by industrial accidents in Korea is 25,649 in construction, 25,333 in manufacturing, 4,237 in transportation, warehousing and communication service, 1,897 in mining, 1,124 in forestry and 87 in electricity and gas water supply. The number of safety accident victims in the construction industry is the largest. The number of safety accidents that occurred at the construction site in Korea over the past 3 years increased to 23,669 in 2016, 25,132 in 2017 and 25,649 in 2018. In addition, among the safety accidents in Korea in 2018, the number of deaths by industry was 579 in construction, 433 in manufacturing, 121 in transportation, warehousing and communication service, 457 in mining, 16 in forestry and 4 in electricity and gas water supply (MEL., 2019). As such, the death toll in the construction industry is more than 35.9%. Safety accident occurring at the construction site is caused by complex causes throughout the entire process of ordering, design and construction. Also in recent years, the causes of safety accident have been diversified due to the introduction of advanced construction methods, diversification of process and workplace conditions and changes in the characteristics of workers. Due to such changes of the construction environment, activities for predicting and preventing safety accident occurring at the construction site are becoming more difficult. Safety management refers to management technique to prevent accidents by anticipating risk factors in advance. It is involved in the entire process of the construction project (Park, 2010). It is important to develop a safety management system that will be highly effective in reducing workplace disasters. The safety management system should rely simply on experienced management and post management but it should also be able to prevent accidents by eliminating harmful factors and risks by identifying potential risks (Seo, 2013). Therefore, it is necessary to estimate the risks of identified risk factors during work and to establish countermeasures for improvement of those risks, so as to achieve effective safety management (Matthews and Ageros, 2008). However, safety management in the construction site focusing on examples of accidents and preventive measures as well as risk assessment about potential accidents has not yet been implemented (Paek and Cho, 2015). In this study, the causes of safety accident in the construction site were derived and the risk of the causes of safety accident was analyzed. Through this, it is intended to provide basic data that can be used to establish a safety accident prevention plan in the construction site.

Scope and method of study: The scope of this study is to derive the causes of safety accident occurring at the construction site and to derive the risk of the causes of each safety accident. The methods and procedures of this study are as follows.

Analyze the causes of safety accident occurring at the construction site. The causes of safety accident were classified into 4 items of 4M technique (Man, Machine, Media and Management) according to their characteristics. Design the risk analysis model using eigenvectors. Calculate the risk of the 4M items and the risk of the causes of safety accident. Then, the final risk is calculated using the risk of the 4M item and the risk of the causes of safety accident. Identify the causes of safety accident that require centralized management according to the degree of risk. And summarize the result of the study.

MATERIALS AND METHODS

Risk analysis model

Composition of 4M items and causes of safety accident: Risk analysis identifies the causes of safety accident that may occur in the work for risk analysis. Measures are taken to minimize the likelihood that the causes of safety accident can develop into an accident. The 4M technique used for risk analysis classifies the causes of safety accident into four items, man, machine, management and media as shown in Table 1 (MEL., 2019). The causes of safety accident corresponding to human risk that lead to unsafe behavior of workers correspond to man. The causes of safety accident corresponding to the physical risk that causes unsafe condition correspond to machine. The causes of safety accident corresponding to the administrative flaws that cause the accident correspond to management. The causes of safety accident corresponding to the working environment such as noise, dust and harmful substances correspond to media.

As a result of analyzing safety accident data at the construction site from 2016-2018 provided by the construction safety management information system operated by the Korean government, there are 49 causes of safety accident occurred at the construction site from 2016-2018 as shown in Table 2.

Commissioned by four experts in the field of construction safety, 49 causes of safety accident in Table 1 were classified into 4M items according to their characteristics. A plurality of 4M items can be selected according to the characteristics of the cause of safety accident and a 4M item having a large number of selections was determined as the final 4M item.

As shown in Table 3, 25 causes of safety accident corresponding to management were the most. Next, 10 causes of safety accident correspond to man. It was analyzed that 7 causes of safety accident corresponded to media and 6 causes of safety accident corresponded to machine. 'Inappropriate use of personal protective equipment (A30)' was judged by experts 2, 3 and 4 as the cause of safety accident for man. And expert 1 judged 'Inappropriate use of personal protective equipment (A30)' as the cause of safety accident for two 4M items, Man and Management. Hence, 'Inappropriate use of personal protective equipment (A30)' is classified as the cause of safety accident for man with a large number of choices. 'Operation of defective machinery, equipment and tools (A41)' was judged by experts A, C and D as the cause of safety accident for machine. Expert B judged 'Operation of defective machinery, equipment and tools (A41)' as the cause of safety accident for management. Thus, 'Operation of defective machinery, equipment and tools (A41)' is classified as the cause of safety accident for machine with a large number of choices. Table 3 shows data classified by 4M items according to the characteristics of causes of safety accident.

Table 1: Characteristics of 4M items

4M items	Contents
Man	Human risk assessment that generates the unsafe behavior
Machine	Physical risk assessment that generates the unsafe condition
Management	Evaluation defects administrative to generate the accident
Media	Workplace assessment noise, dust and toxic substances

Design of risk analysis model: A risk analysis model was designed for the causes of safety accident occurring at 4M items and construction sites. The eigenvector method was used to design the risk analysis model.

The eigenvector method uses the characteristics of pairwise comparison matrix and eigenvector (Saaty and Hu, 1998). In this study, the eigenvector corresponding to the maximum value among the eigen values of the pairwise comparison matrix was used as the risk. Analyze the relative risk between items from the defined pairwise comparison matrix. Then, the eigenvector for each item is calculated (Fig. 1).

The eigenvector of the items in row i and column j of pairwise comparison matrix can be calculated by dividing the pairwise comparison value in row i and column j by all pairwise comparison values in column j. The risk can be calculated by arithmetically averaging the eigenvector of calculated row i. Therefore, the eigenvector of item k located in row i and column j is defined as in Eq. 1. The formula of risk calculation is defined as Eq. 2:

$$E_{ij} = \frac{W_{ij}}{\sum_{j=1}^{n} W_j} \quad (1)$$

$$R_k = \frac{\sum_{i=1}^{n} E_{ij}}{N} \quad (2)$$

Table 2: Causes of safety accident occurred at the construction site (2016~2018)

Accident codes	Causes of safety accident
A01	Performing work in unsafe positions
A02	Performing work with inadequate communication between supervisors and workers
A03	Creation of alternative design without consideration of construction method or construction procedure
A04	Failure to assess adverse effects on work caused by deterioration due to weather conditions
A05	Performing work in judgment mistakes, underestimation and overestimation
A06	Improper maintenance of machinery, equipment and tools
A07	Inadequate communication with workers
A08	Inadequate conditions above ground and underground
A09	Inadequate topography
A10	Inappropriate control of underground utilities
A11	Inappropriate control of working system
A12	Inappropriate control of workplace environment (light, noise, temperature, humidity, air, etc.)
A13	Inappropriate design of entry structures
A14	Inappropriate entry and exit from workplace
A15	Inappropriate environmental management of workplace
A16	Inappropriate installation plan for safety facilities
A17	Inappropriate instructions from managers to construction workers
A18	Inappropriate loading and handling of materials
A19	Inappropriate maintenance of temporary structure
A20	Inappropriate management of hazardous chemicals or toxic substances
A21	Inappropriate method statement
A22	Inappropriate plan for machinery and equipment use
A23	Inappropriate plan for site deployment such as manpower, machinery, equipment, etc.
A24	Inappropriate recognition and assessment of on-site risk factors
A25	Inappropriate site deployment of manpower, machinery, equipment, etc.
A26	Inappropriate structural design for installation of machinery, equipment, etc.
A27	Inappropriate structural design of temporary structure
A28	Inappropriate use of machinery and equipment while in operation
A29	Inappropriate use of machinery, equipment and tools
A30	Inappropriate use of personal protective equipment
A31	Inappropriate use of safety facilities or personal protective equipment
A32	Inappropriate use of working tools
A33	Inappropriate work plan
A34	Instability of temporary structure
A35	Lack of experience designing projects
A36	Lack of training and education on manpower needs
A37	Lack of understanding of designer's methods and procedures
A38	Omission of standard safety work procedures
A39	Operating a construction site with inappropriate work procedures
A40	Operation of an inappropriate temporary structure
A41	Operation of defective machinery, equipment and tools
A42	Performing work while lacking proficiency in the task
A43	Performing work in a state of non-compliance with safety regulations
A44	Performing work with physical disabilities
A45	Unfavorable climate conditions
A46	Unsafe behavior by workers
A47	Unsafe work behavior
A48	Unsafe work conditions caused by inadequate or missing safety facilities
A49	Violation of safety regulations and guidelines

Table 3: Causes of safety accident by 4M items

4M items/Accident code	Causes of safety accident
Man	
A01	Performing work in unsafe positions
A05	Performing work in judgment mistakes, underestimation and overestimation
A30	Inappropriate use of personal protective equipment
A38	Omission of standard safety work procedures
A42	Performing work while lacking proficiency in the task
A43	Performing work in a state of non-compliance with safety regulations
A44	Performing work with physical disabilities
A46	Unsafe behavior by workers
A47	Unsafe work behavior
A48	Unsafe work conditions caused by inadequate or missing safety facilities
Machine	
A06	Improper maintenance of machinery, equipment and tools
A22	Inappropriate plan for machinery and equipment use
A26	Inappropriate structural design for installation of machinery, equipment, etc.

Table 3: Continue

4M items/Accident code	Causes of safety accident
A28	Inappropriate use of machinery and equipment while in operation
A29	Inappropriate use of machinery, equipment and tools
A41	Operation of defective machinery, equipment and tools
Management	
A02	Performing work with inadequate communication between supervisors and workers
A04	Failure to assess adverse effects on work caused by deterioration due to weather conditions
A07	Inadequate communication with workers
A10	Inappropriate control of underground utilities
A11	Inappropriate control of working system
A13	Inappropriate design of entry structures
A14	Inappropriate entry and exit from workplace
A15	Inappropriate environmental management of workplace
A16	Inappropriate installation plan for safety facilities
A17	Inappropriate instructions from managers to construction workers
A18	Inappropriate loading and handling of materials
A19	Inappropriate maintenance of temporary structure
A21	Inappropriate method statement
A23	Inappropriate plan for site deployment such as manpower, machinery, equipment etc.
A24	Inappropriate recognition and assessment of on-site risk factors
A25	Inappropriate site deployment of manpower, machinery, equipment etc.
A27	Inappropriate structural design of temporary structure
A31	Inappropriate use of safety facilities or personal protective equipment
A32	Inappropriate use of working tools
A33	Inappropriate work plan
A34	Instability of temporary structure
A35	Lack of experience designing projects
A36	Lack of training and education on manpower needs
A39	Operating a construction site with inappropriate work procedures
A40	Operation of an inappropriate temporary structure
A49	Violation of safety regulations and guidelines
Media	
A03	Creation of alternative design without consideration of construction method or construction procedure
A08	Inadequate conditions above ground and underground
A09	Inadequate topography
A12	Inappropriate control of workplace environment (light, noise, temperature, humidity, air, etc.)
A20	Inappropriate management of hazardous chemicals or toxic substances
A37	Lack of understanding of designer's methods and procedures
A45	Unfavorable climate conditions

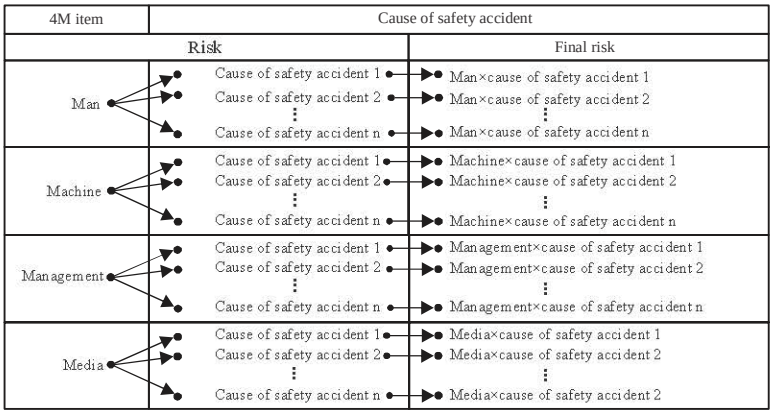

Fig. 1: Final risk calculation method

Where:

R_k : The risk of item k

N : The size of the pairwise comparison matrix (the number of items in pairwise comparison)

E_{ij} : The eigenvector of row i and column j

E : The eigenvector of the pairwise comparison matrix

R : The risk, w is the pairwise comparison value

k : The item, j is the column vector

I : The row vector

Define 4M items in the upper class and 49 causes of safety accident in the lower class. Analyze the risk of 4M

items and 49 causes of safety accident. First, compare the relative risk between 4M items using a two-point scale (risk = 2, equal risk = 1, inverse of the given value if the opposite). Next, compare the relative risk between the causes of safety accident by 4M items using a two-point scale (risk = 2, equal risk = 1, inverse of the given value if the opposite). Then, the final risk by causes of safety accident is calculated by multiplying the risk of the 4M item in the upper class by the risk of the causes of safety accident in the lower class. Figure 1 illustrates the final risk calculation method.

RESULTS AND DISCUSSION

Risk analysis

Risk analysis of 4M items: Four experts in the field of construction safety were commissioned to compare the relative risk between the 4M items Table 4. The eigenvector of 4M items were substituted into Eq. 2 to calculate the risk of 4M items Table 5. The risk of management was analyzed to be the highest with 1.63. The risk of man was 0.96, the risk of machine was 0.82 and the risk of media was 0.69. Table 4 shows the eigenvector calculated by the pairwise comparison of the risk of 4M items. Table 5 shows the risk of 4M items calculated using the eigenvector in Table 4.

Risk analysis of the causes of safety accident by 4M items: Risk of the causes of safety accidents of each 4M item was analyzed.

Risk of the causes of safety accident in man: The risk of A47 is the highest with 1.34. Next, the risk of A48 is 1.26, the risk of A30 is 1.25, the risk of A43 is 1.1, the risk of A38 is 1.09, the risk of A46 is 1.05, the risk of A01 is 0.85, the risk of A05 is 0.78, the risk of A42 is 0.73 and the risk of A44 was 0.56.

Table 6 shows the eigenvector calculated by comparing the degree of risk of the causes of safety accident belonging to man. Table 7 shows the risk of the causes of safety accident belonging to man calculated using the eigenvector of Table 6.

Risk of the causes of safety accident in machine: The risks of A28 and A29 are the highest with 1.32. Next, the risk of A41 was 1.21, the risk of A22 was 0.77, the risk of A02 was 0.70 and the risk of A26 was 0.66. The following Table 8 is the eigenvector calculated by the pairwise comparison of the risk of the causes of safety accident in machine.

Table 9 shows the risk of the causes of safety accident belonging to machine calculated using the eigenvector in Table 8.

Table 4: Pairwise comparison and eigenvector of 4M items

	Man	Machine	Management	Media
Man	1.0	1.0	0.5	2.0
Machine	1.0	1.0	0.5	1.0
Management	2.0	2.0	1.0	2.0
Media	0.5	1.0	0.5	1.0
Eigenvector (E)	4.5	5.0	2.5	6.0

Table 5: Risk calculation data of 4M items

Variables	Man	Machine	Management	Media	Risk (R)
Man	0.22	0.20	0.20	0.33	0.96
Machine	0.25	0.20	0.20	0.17	0.82
Management	0.50	0.40	0.40	0.33	1.63
Media	0.22	0.20	0.20	0.33	0.96

Table 6: Pairwise comparison and eigenvector of the causes of safety accident in man

Accident codes	A01	A05	A30	A38	A42	A43	A44	A46	A47	A48
A01	1.0	1.0	0.5	0.5	1.0	1.0	2.0	1.0	0.5	1.0
A05	1.0	1.0	0.5	1.0	1.0	0.5	2.0	1.0	0.5	0.5
A30	2.0	2.0	1.0	1.0	2.0	1.0	2.0	1.0	1.0	1.0
A38	2.0	1.0	1.0	1.0	2.0	1.0	1.0	2.0	0.5	0.5
A42	1.0	1.0	0.5	0.5	1.0	1.0	2.0	0.5	0.5	0.5
A43	1.0	2.0	1.0	1.0	1.0	1.0	2.0	1.0	1.0	1.0
A44	0.5	0.5	0.5	1.0	0.5	0.5	1.0	0.5	0.5	0.5
A46	1.0	1.0	1.0	0.5	2.0	1.0	2.0	1.0	1.0	1.0
A47	2.0	2.0	1.0	2.0	2.0	1.0	2.0	1.0	1.0	1.0
A48	1.0	2.0	1.0	2.0	2.0	1.0	2.0	1.0	1.0	1.0
Eigenvector (E)	12.5	13.5	8.0	10.5	14.5	9.0	18.0	10.0	7.5	8.0

Table 7: Risk calculation data of the causes of safety accident in man

Accident codes	A01	A05	A30	A38	A42	A43	A44	A46	A47	A48	Risk (R)
A01	0.08	0.07	0.06	0.05	0.07	0.11	0.11	0.10	0.07	0.13	0.85
A05	0.08	0.07	0.06	0.10	0.07	0.06	0.11	0.10	0.07	0.06	0.78
A30	0.16	0.15	0.13	0.10	0.14	0.11	0.11	0.10	0.13	0.13	1.25
A38	0.16	0.07	0.13	0.10	0.14	0.11	0.06	0.20	0.07	0.06	1.09
A42	0.08	0.07	0.06	0.05	0.07	0.11	0.11	0.05	0.07	0.06	0.73
A43	0.08	0.15	0.13	0.10	0.07	0.11	0.11	0.10	0.13	0.13	1.10
A44	0.04	0.04	0.06	0.10	0.03	0.06	0.06	0.05	0.07	0.06	0.56
A46	0.08	0.07	0.13	0.05	0.14	0.11	0.11	0.10	0.13	0.13	1.05
A47	0.16	0.15	0.13	0.19	0.14	0.11	0.11	0.10	0.13	0.13	1.34
A48	0.08	0.15	0.13	0.19	0.14	0.11	0.11	0.10	0.13	0.13	1.26

Table 8: Pairwise comparison and eigenvector of the causes of safety accident in machine

Accident codes	A06	A22	A26	A28	A29	A41
A06	1.0	0.5	1.0	0.5	0.5	1.0
A22	2.0	1.0	1.0	0.5	0.5	0.5
A26	1.0	1.0	1.0	0.5	0.5	0.5
A28	2.0	2.0	2.0	1.0	1.0	1.0
A29	2.0	2.0	2.0	1.0	1.0	1.0
A41	1.0	2.0	2.0	1.0	1.0	1.0
Eigenvector (E)	9.0	8.5	9.0	4.5	4.5	5.0

Table 9: Risk calculation data of the causes of safety accident in machine

Accident codes	A06	A22	A26	A28	A29	A41	Risk (R)
A02	0.11	0.06	0.11	0.11	0.11	0.20	0.70
A22	0.22	0.12	0.11	0.11	0.11	0.10	0.77
A26	0.11	0.12	0.11	0.11	0.11	0.10	0.66
A28	0.22	0.24	0.22	0.22	0.22	0.20	1.32
A29	0.22	0.24	0.22	0.22	0.22	0.20	1.32
A41	0.11	0.24	0.22	0.22	0.22	0.20	1.21

Table 10: Pairwise comparison and eigenvector of the causes of safety accident in management

Accident codes	A02	A04	A07	A10	A11	A13	A14	A15	A16	A17	A18	A19	A21	A23	A24	A25	A27	A31	A32	A33	A34	A35	A36	A39	A40	A49
A02	1.0	2.0	1.0	2.0	1.0	2.0	2.0	1.0	1.0	0.5	1.0	1.0	0.5	0.5	1.0	0.5	0.5	0.5	2.0	0.5	2.0	1.0	0.5	1.0	0.5	0.5
A04	0.5	1.0	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1.0	0.5	0.5	0.5	0.5
A07	1.0	2.0	1.0	2.0	2.0	2.0	1.0	1.0	1.0	2.0	2.0	2.0	2.0	1.0	2.0	2.0	2.0	1.0	2.0	2.0	2.0	1.0	2.0	1.0	2.0	1.0
A10	0.5	2.0	0.5	1.0	1.0	1.0	0.5	0.5	0.5	0.5	1.0	1.0	0.5	0.5	0.5	1.0	1.0	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
A11	1.0	2.0	0.5	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.5	1.0	1.0	1.0	1.0	1.0
A13	0.5	2.0	0.5	1.0	1.0	1.0	0.5	0.5	0.5	0.5	0.5	1.0	0.5	0.5	0.5	0.5	1.0	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
A14	0.5	2.0	0.5	2.0	1.0	2.0	1.0	1.0	0.5	0.5	1.0	0.5	0.5	0.5	0.5	0.5	0.5	1.0	0.5	0.5	1.0	2.0	0.5	1.0	1.0	0.5
A15	1.0	2.0	1.0	2.0	1.0	2.0	1.0	1.0	1.0	1.0	1.0	1.0	0.5	1.0	0.5	1.0	2.0	0.5	2.0	0.5	1.0	1.0	0.5	1.0	1.0	0.5
A16	1.0	2.0	1.0	2.0	1.0	2.0	2.0	1.0	1.0	1.0	2.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	2.0	1.0	2.0	2.0	1.0	1.0	1.0	0.5
A17	2.0	2.0	1.0	2.0	1.0	2.0	2.0	1.0	1.0	1.0	2.0	2.0	1.0	1.0	1.0	1.0	1.0	1.0	2.0	1.0	2.0	1.0	0.5	1.0	1.0	0.5
A18	1.0	2.0	0.5	1.0	1.0	2.0	1.0	1.0	0.5	0.5	1.0	0.5	0.5	1.0	0.5	1.0	1.0	0.5	2.0	0.5	1.0	0.5	0.5	0.5	1.0	0.5
A19	1.0	2.0	0.5	1.0	1.0	1.0	2.0	1.0	1.0	0.5	2.0	1.0	0.5	0.5	0.5	0.5	1.0	0.5	1.0	0.5	1.0	0.5	0.5	0.5	1.0	0.5
A21	2.0	2.0	0.5	2.0	1.0	2.0	2.0	2.0	1.0	1.0	2.0	2.0	1.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	1.0	1.0	1.0	2.0	0.5
A23	2.0	2.0	1.0	2.0	1.0	2.0	2.0	1.0	1.0	1.0	1.0	2.0	0.5	1.0	0.5	1.0	1.0	1.0	1.0	2.0	1.0	1.0	0.5	0.5	1.0	0.5
A24	1.0	2.0	0.5	2.0	1.0	2.0	2.0	2.0	1.0	1.0	2.0	2.0	0.5	2.0	1.0	2.0	2.0	2.0	2.0	1.0	2.0	1.0	1.0	1.0	2.0	1.0
A25	2.0	2.0	0.5	1.0	1.0	2.0	2.0	1.0	1.0	1.0	1.0	2.0	0.5	1.0	0.5	1.0	0.5	1.0	0.5	1.0	1.0	0.5	0.5	2.0	1.0	0.2
A27	2.0	2.0	0.5	1.0	1.0	1.0	2.0	0.5	1.0	1.0	1.0	1.0	0.5	1.0	0.5	2.0	1.0	2.0	2.0	1.0	2.0	1.0	1.0	2.0	1.0	0.5
A31	2.0	2.0	0.5	2.0	1.0	2.0	1.0	2.0	1.0	1.0	2.0	2.0	0.5	1.0	0.5	1.0	0.5	1.0	1.0	0.5	1.0	1.0	0.5	0.5	1.0	0.5
A32	0.5	2.0	0.5	2.0	1.0	2.0	2.0	0.5	0.5	0.5	0.5	1.0	0.5	1.0	0.5	2.0	0.5	1.0	1.0	1.0	1.0	1.0	0.5	0.5	1.0	0.5
A33	2.0	2.0	0.5	2.0	1.0	2.0	2.0	2.0	1.0	1.0	2.0	2.0	0.5	0.5	1.0	1.0	1.0	2.0	1.0	1.0	1.0	1.0	0.5	1.0	1.0	0.5
A34	0.5	2.0	0.5	2.0	2.0	2.0	1.0	1.0	0.5	0.5	1.0	1.0	0.5	1.0	0.5	1.0	0.5	1.0	1.0	1.0	1.0	0.5	0.5	0.5	1.0	0.5
A35	1.0	1.0	1.0	2.0	1.0	2.0	0.5	1.0	0.5	1.0	2.0	2.0	1.0	1.0	1.0	2.0	1.0	1.0	1.0	1.0	2.0	1.0	0.5	1.0	1.0	0.5
A36	2.0	2.0	0.5	2.0	1.0	2.0	2.0	2.0	1.0	2.0	2.0	2.0	1.0	2.0	1.0	2.0	1.0	2.0	2.0	2.0	2.0	2.0	1.0	1.0	2.0	0.5
A39	1.0	2.0	1.0	2.0	1.0	2.0	1.0	1.0	1.0	1.0	2.0	2.0	1.0	2.0	1.0	0.5	0.5	2.0	2.0	1.0	2.0	1.0	1.0	1.0	2.0	0.5
A40	2.0	2.0	0.5	2.0	1.0	2.0	1.0	1.0	1.0	1.0	1.0	1.0	0.5	1.0	0.5	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.5	0.5	1.0	0.5
A49	2.0	2.0	1.0	2.0	1.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	1.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	1.0
E	33.0	50.0	17.5	43.5	27.5	45.5	37.0	29.5	23.0	24.5	36.5	36.5	19.5	27.5	21.0	31.0	27.0	29.5	35.5	26.5	35.0	27.0	19.5	24.0	30.0	14.7

E: Eigenvector

Risk of the causes of safety accident in management: The risk of A49 is the highest with 1.7. Next, the risk of A07 is 1.5, the risk of A21 is 1.42, the risk of A36 is 1.41, the risk of A24 is 1.31, the risk of A39 is 1.16, the risk of A16 and A17 is 1.13, the risk of A27 and A33 is 1.07, the risk of A35 is 1.02, the risk of A23 is 1.01, the risk of A15 and A31 is 0.94, the risk of A11 is 0.93, the risk of A25 is 0.91, the risk of A02 and A40 is 0.89, the risk of A32 is 0.81, the risk of A34 is 0.80, the risk of A14 and A19 is 0.76, the risk of A18 is 0.75, the risk of A10 is 0.61, the risk of A13 is 0.58 and the risk of A04 is 0.51.

The following Table 10 is the eigenvector calculated by the pairwise comparison of the risk of the causes of safety accident in management. Table 11 shows the risk of the causes of safety accident belonging to management calculated using the eigenvector in Table 10.

Risk of the causes of safety accident in media: The risk of A37 is the highest with 1.54. Next, the risk of A03 is 0.37, the risk of A20 is 1.26, the risk of A12 is 0.96 and the risk of A08, A09 and A45 is 0.64. The following Table 12 is the eigenvector calculated by the pairwise comparison of the risk of the causes of safety accident in media. Table 13 shows the risk of the causes of safety accident belonging to media calculated using the eigenvector in Table 12.

Final risk calculation: The final risk for each cause of safety accident was calculated by multiplying the risk of the 4M item in the upper class by the risk of the cause of safety accident in the lower class. The risk of A49 in management is the highest with 2.77. Next, the risk of A07 is 2.45, the risk of A21 is 2.31 and the risk of A36 is 2.30. The risk of A08, A09 and A45 belonging to media was the lowest with 0.43.

Table 11: Risk calculation data of the causes of safety accident in management

Codes	A02	A04	A07	A10	A11	A13	A14	A15	A16	A17	A18	A19	A21	A23	A24	A25	A27	A31	A32	A33	A34	A35	A36	A39	A40	A49	R
A02	0.03	0.04	0.06	0.05	0.04	0.04	0.05	0.03	0.04	0.02	0.03	0.03	0.03	0.02	0.05	0.02	0.02	0.02	0.06	0.02	0.06	0.04	0.03	0.04	0.02	0.03	0.89
A04	0.02	0.02	0.03	0.01	0.02	0.01	0.01	0.02	0.02	0.02	0.01	0.01	0.03	0.02	0.02	0.02	0.02	0.02	0.01	0.02	0.01	0.04	0.03	0.02	0.02	0.03	0.51
A07	0.03	0.04	0.06	0.05	0.07	0.04	0.03	0.03	0.04	0.08	0.05	0.05	0.10	0.04	0.10	0.06	0.07	0.03	0.06	0.08	0.06	0.04	0.10	0.04	0.07	0.07	1.50
A10	0.02	0.04	0.03	0.02	0.04	0.02	0.01	0.02	0.02	0.02	0.03	0.03	0.03	0.02	0.02	0.03	0.04	0.02	0.01	0.02	0.01	0.02	0.03	0.02	0.02	0.03	0.61
A11	0.03	0.04	0.03	0.02	0.04	0.02	0.03	0.03	0.04	0.04	0.03	0.03	0.05	0.04	0.05	0.03	0.04	0.03	0.03	0.04	0.01	0.04	0.05	0.04	0.03	0.07	0.93
A13	0.02	0.04	0.03	0.02	0.04	0.02	0.01	0.02	0.02	0.02	0.01	0.03	0.03	0.02	0.02	0.02	0.04	0.02	0.01	0.02	0.01	0.02	0.03	0.02	0.02	0.03	0.58
A14	0.02	0.04	0.03	0.05	0.04	0.04	0.03	0.03	0.02	0.02	0.03	0.01	0.03	0.02	0.02	0.02	0.02	0.03	0.01	0.02	0.03	0.07	0.03	0.04	0.03	0.03	0.76
A15	0.03	0.04	0.06	0.05	0.04	0.04	0.03	0.03	0.04	0.04	0.03	0.03	0.03	0.04	0.02	0.03	0.07	0.02	0.06	0.02	0.03	0.04	0.03	0.04	0.03	0.03	0.94
A16	0.03	0.04	0.06	0.05	0.04	0.04	0.05	0.03	0.04	0.04	0.05	0.03	0.05	0.04	0.05	0.03	0.04	0.03	0.06	0.04	0.06	0.07	0.05	0.04	0.03	0.03	1.13
A17	0.06	0.04	0.06	0.05	0.04	0.04	0.05	0.03	0.04	0.04	0.05	0.05	0.05	0.04	0.05	0.03	0.04	0.03	0.06	0.04	0.06	0.04	0.03	0.04	0.03	0.03	1.13
A18	0.03	0.04	0.03	0.02	0.04	0.04	0.03	0.03	0.02	0.02	0.03	0.01	0.03	0.04	0.02	0.03	0.04	0.02	0.06	0.02	0.03	0.02	0.03	0.02	0.03	0.03	0.75
A19	0.03	0.04	0.03	0.02	0.04	0.02	0.05	0.03	0.04	0.02	0.05	0.03	0.03	0.02	0.02	0.02	0.04	0.02	0.03	0.02	0.03	0.02	0.03	0.02	0.03	0.03	0.76
A21	0.06	0.04	0.03	0.05	0.04	0.04	0.05	0.07	0.04	0.04	0.05	0.05	0.05	0.07	0.10	0.06	0.07	0.07	0.06	0.08	0.06	0.04	0.05	0.04	0.07	0.03	1.42
A23	0.06	0.04	0.06	0.05	0.04	0.04	0.05	0.03	0.04	0.04	0.03	0.05	0.03	0.04	0.02	0.03	0.04	0.03	0.03	0.08	0.03	0.04	0.03	0.02	0.03	0.03	1.01
A24	0.03	0.04	0.03	0.05	0.04	0.04	0.05	0.07	0.04	0.04	0.05	0.05	0.03	0.07	0.05	0.06	0.07	0.07	0.06	0.04	0.06	0.04	0.05	0.04	0.07	0.07	1.31
A25	0.06	0.04	0.03	0.02	0.04	0.04	0.05	0.03	0.04	0.04	0.03	0.05	0.03	0.04	0.02	0.03	0.02	0.03	0.01	0.04	0.03	0.02	0.03	0.08	0.03	0.01	0.91
A27	0.06	0.04	0.03	0.02	0.04	0.02	0.05	0.02	0.04	0.04	0.03	0.03	0.03	0.04	0.02	0.06	0.04	0.07	0.06	0.04	0.06	0.04	0.05	0.08	0.03	0.03	1.07
A31	0.06	0.04	0.03	0.05	0.04	0.04	0.03	0.07	0.04	0.04	0.05	0.05	0.03	0.04	0.02	0.03	0.02	0.03	0.03	0.02	0.03	0.04	0.03	0.02	0.03	0.03	0.94
A32	0.02	0.04	0.03	0.05	0.04	0.04	0.05	0.02	0.02	0.02	0.01	0.03	0.03	0.04	0.02	0.06	0.02	0.03	0.03	0.04	0.03	0.04	0.03	0.02	0.03	0.03	0.81
A33	0.06	0.04	0.03	0.05	0.04	0.04	0.05	0.07	0.04	0.04	0.05	0.05	0.03	0.02	0.05	0.03	0.04	0.07	0.03	0.04	0.03	0.04	0.03	0.04	0.03	0.03	1.07
A34	0.02	0.04	0.03	0.05	0.07	0.04	0.03	0.03	0.02	0.02	0.03	0.03	0.03	0.04	0.02	0.03	0.02	0.03	0.03	0.04	0.03	0.02	0.03	0.02	0.03	0.03	0.80
A35	0.03	0.02	0.06	0.05	0.04	0.04	0.01	0.03	0.02	0.04	0.05	0.05	0.05	0.04	0.05	0.06	0.04	0.03	0.03	0.04	0.06	0.04	0.03	0.04	0.03	0.03	1.02
A36	0.06	0.04	0.03	0.05	0.04	0.04	0.05	0.07	0.04	0.08	0.05	0.05	0.05	0.07	0.05	0.06	0.04	0.07	0.06	0.08	0.06	0.07	0.05	0.04	0.07	0.03	1.41
A39	0.03	0.04	0.06	0.05	0.04	0.04	0.03	0.03	0.04	0.04	0.05	0.05	0.05	0.07	0.05	0.02	0.02	0.07	0.06	0.04	0.06	0.04	0.05	0.04	0.07	0.03	1.16
A40	0.06	0.04	0.03	0.05	0.04	0.04	0.03	0.03	0.04	0.04	0.03	0.03	0.03	0.04	0.02	0.03	0.04	0.03	0.03	0.04	0.03	0.04	0.03	0.02	0.03	0.03	0.89
A49	0.06	0.04	0.06	0.05	0.04	0.04	0.05	0.07	0.09	0.08	0.05	0.05	0.10	0.07	0.05	0.06	0.07	0.07	0.06	0.08	0.06	0.07	0.10	0.08	0.07	0.07	1.70

R: Risk

Table 12: Pairwise comparison and eigenvector of the causes of safety accident in media

Accident codes	A03	A08	A09	A12	A20	A37	A45
A03	1.0	2.0	2.0	2.0	1.0	1.0	2.0
A08	0.5	1.0	1.0	0.5	0.5	0.5	1.0
A09	0.5	1.0	1.0	0.5	0.5	0.5	1.0
A12	0.5	2.0	2.0	1.0	0.5	0.5	2.0
A20	1.0	2.0	2.0	2.0	1.0	0.5	2.0
A37	1.0	2.0	2.0	2.0	2.0	1.0	2.0
A45	0.5	1.0	1.0	0.5	0.5	0.5	1.0
Eigenvector (E)	5.0	11.0	11.0	8.5	6.0	4.5	11.0

Table 13: Risk calculation data of the causes of safety accident in media

Accident codes	A03	A08	A09	A12	A20	A37	A45	Risk (R)
A03	0.20	0.18	0.18	0.24	0.17	0.22	0.18	1.37
A08	0.10	0.09	0.09	0.06	0.08	0.11	0.09	0.63
A09	0.10	0.09	0.09	0.06	0.08	0.11	0.09	0.63
A12	0.10	0.18	0.18	0.12	0.08	0.11	0.18	0.96
A20	0.20	0.18	0.18	0.24	0.17	0.11	0.18	1.26
A37	0.20	0.18	0.18	0.24	0.33	0.22	0.18	1.54
A45	0.10	0.09	0.09	0.06	0.08	0.11	0.09	0.63

Table 14: Final risk of the causes of safety accident

		Causes of safety accident	
4M items/Risk (A)	Accident codes	Risk (B)	Final risk (A×B)
Man (0.96)	A01	0.85	0.82
	A05	0.78	0.75
	A30	1.25	1.20
	A38	1.09	1.05
	A42	0.73	0.70
	A43	1.10	1.06
	A44	0.56	0.54
	A46	1.05	1.01
	A47	1.34	1.29
	A48	1.26	1.21
Machine (0.82)	A02	0.70	0.57
	A22	0.77	0.63
	A26	0.66	0.54
	A28	1.32	1.08
	A29	1.32	1.08
	A41	1.21	0.99
Management (1.63)	A02	0.89	1.45
	A04	0.51	0.83
	A07	1.50	2.45
	A10	0.61	0.99
	A11	0.93	1.52
	A13	0.58	0.95
	A14	0.76	1.24
	A15	0.94	1.53
	A16	1.13	1.84
	A17	1.13	1.84
	A18	0.75	1.22
	A19	0.76	1.24
	A21	1.42	2.31
	A23	1.01	1.65
	A24	1.31	2.14
	A25	0.91	1.48
	A27	1.07	1.74

Table 14: Continue

4M items/Risk (A)	Accident codes	Causes of safety accident	
		Risk (B)	Final risk (A×B)
	A31	0.94	1.53
	A32	0.81	1.32
	A33	1.07	1.74
	A34	0.80	1.30
	A35	1.02	1.66
	A36	1.41	2.30
	A39	1.16	1.89
	A40	0.89	1.45
	A49	1.70	2.77
Media (0.69)	A03	1.37	0.95
	A08	0.63	0.43
	A09	0.63	0.43
	A12	0.96	0.66
	A20	1.26	0.87
	A37	1.54	1.06
	A45	0.63	0.43

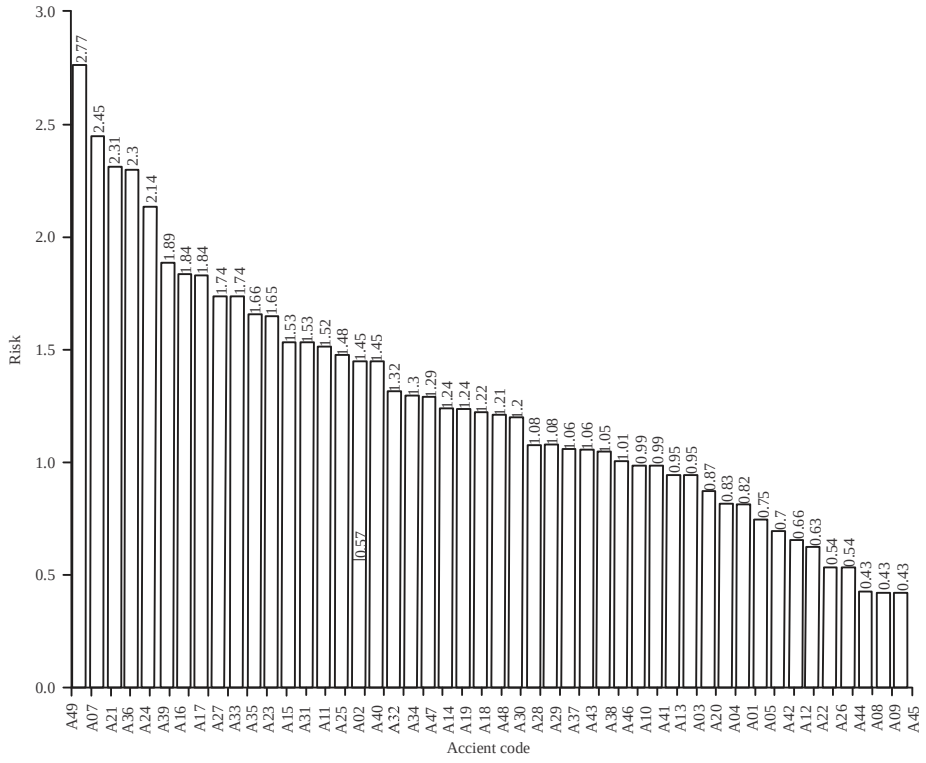

Fig. 2: A graph of the final risk of the causes of safety accident in order of high risk

The causes of safety accident with a final risk of <0.5 are A08, A09 and A45. The causes of safety accidents with a final risk of <0.5 accounted for 6.1% of all causes of safety accident. A10, A41, A13, A03, A20, A04, A01, A05, A42, A12, A22, A02, A26 and A44 are the causes of safety accident with a final risk of <0.5 and <1.0. The causes of safety accident with a final risk of 0.5 and <1.0 accounted for 28.6% of all causes of safety accident. Causes of safety accident with a final risk of 1.0 and <2.0 include A39, A16, A17, A27, A33, A35, A23, A15, A31, A11, A25, A02, A40, A32, A34, A47, A14, A19, A18, A48, A30, A28, A29, A37, A43, A38 and A46. The causes of safety accident with a final risk of >1.0 and <2.0 accounted for 55.1% of all causes of safety accident. The causes of safety accident with a final risk of level of 2.0 or higher are A49, A07, A21, A36 and A24. The causes of safety accident with a final risk of level of 2.0 or higher accounted for 10.2% of all causes of safety accident (Fig. 2).

CONCLUSION

Korea has carried out various activities to prevent safety accidents occurring at construction sites. However, despite the government and private safety accident prevention activities, 25,649 workers were injured in the

construction industry in 2018. In 2018, the number of casualties in the construction industry is the highest among industries. Such a high number of casualties represents a limitation on existing methods of preventing safety accidents. Therefore, a new approach to current safety accident prevention activities is needed (Kia and Park, 2014).

The purpose of this study was to analyze the risk of the causes of safety accidents in construction sites in order to enhance the effectiveness of safety management activities. The risk of safety accidents caused by 'Violation of safety regulations or guidelines (A49)', 'Inadequate communication with workers (A07)', 'Inappropriate method statement (A21)', 'Lack of training and education on manpower needs (A36)' and 'Inappropriate recognition and assessment of on-site risk factors (A24)' was analyzed to be high. On the other hand the risk of safety accidents due to 'Inadequate conditions above ground and underground (A08)', 'Inadequate topography (A09)' and 'Unfavorable climate conditions (A45)' was analyzed not to be high. 'Violation of safety regulations and guidelines (A49)', 'Inadequate communication with workers (A07)', 'Inappropriate method statement (A21)', 'Lack of training and education on manpower needs (A36)' and 'Inappropriate recognition and assessment of on-site risk factors (A24) with high final risk belong to management among 4M items. On the other hand, 'Inadequate conditions above ground and underground (A08)', 'Inadequate topography (A09)' and 'Unfavorable climate conditions (A45)' which are not at high final risk, belong to media among 4M items.

Therefore, in order to prevent safety accidents, it is necessary to upgrade safety management by additionally arranging safety management personnel and strengthening safety education in terms of management with the most high-risk items.

The results of this study can be used to adjust the timing, frequency and level of supervision according to the risk level of the causes of safety accident. In addition, centralized management of the causes of safety accident with high final risk can increase the efficiency of construction safety management.

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