buildings

MDPI

Article

Quantitative Accident Risk Estimation for Infrastructure Facilities Based on Accident Case Analysis

Jeongung Lee and **Jaewook Jeong** *

Department of Safety Engineering, Seoul National University of Science and Technology, 232 Gongneung-ro, Nowon-gu, Seoul 01811, Republic of Korea; mantoasia@seoultech.ac.kr
* Correspondence: jaewook.jeong@seoultech.ac.kr; Tel.: +82-2-9706381

Abstract: The construction industry records higher accident rates than other industries, and thus, risk estimation is necessary to manage accident rates. Risk levels differ based on facility type and construction project size. In this sense, this study aims to calculate the quantitative accident risk level according to the construction project size per infrastructure facility type. To this end, the following five-step risk estimation was performed: (1) data collection and classification; (2) calculation of fatality rate based on construction cost; (3) calculation of fatal construction probability by construction cost classification; (4) reclassification of construction cost considering fatal construction probability; and (5) calculation of risk level by facility type and construction cost classification. As a result, the fatality rate per facility type was the highest in 'Dam' at 0.01024 (person/USD million). Additionally, the risk level according to the construction project size per facility type was the highest for 'Dam' (0.00403 person/USD million) for a construction of less than USD 0.77 million. The risk level presented in this study can be utilized as basic data in the design stage for safety management. Our results also indicate the necessity of preparing a separate construction cost classification for safety management.

Keywords: quantitative risk level; construction industry; Bayesian theorem; infrastructure facilities; construction project size

Citation: Lee, J.; Jeong, J. Quantitative Accident Risk Estimation for Infrastructure Facilities Based on Accident Case Analysis. *Buildings* **2024**, *14*, 1283. https://doi.org/10.3390/buildings14051283

Academic Editor: Osama Abudayyeh

Received: 20 March 2024
Revised: 24 April 2024
Accepted: 29 April 2024
Published: 1 May 2024

1. Introduction

The construction industry records higher accident rates than other industries [1–3]. According to the 'Industrial Accident Status Analysis in 2021' released by the Ministry of Employment and Labor of the Republic of Korea (MOEL), the number of fatalities in all industries in the Republic of Korea in 2021 was 2080. Among these, the number of fatalities in the construction industry was the highest at 551 [4]. In this regard, risk estimation is required to manage the high accident rate in the construction industry [5].

According to the Occupational Safety and Health Act (OSHA), business owners/employers must conduct a risk assessment by identifying work-related risks [6]. However, since conventional risk assessment is performed by combining the subjectively evaluated frequency and severity of accidents, it is impossible to estimate the precise risk levels [7], and an exact risk estimation requires the calculation of fatality rates. The Republic of Korea has currently estimated the fatality rate based on the number of construction workers and fatalities. To this end, the number of construction workers is calculated by the construction cost and the labor cost. However, the number of construction workers can change depending on the work type, service period, etc. Consequently, it is difficult to accurately estimate the number of construction workers in this manner [8,9]. Currently, Korean institutions are disclosing data on construction costs [10]. The disclosed data suggest precise construction costs based on diverse classifications. Therefore, when estimating the risk levels of construction accidents, it is reasonable to calculate fatality rates via construction costs rather than by estimating the number of construction workers [9].

Risk levels differ according to the facility type, construction project size, and work type in the construction industry [11–15]. Additionally, there is a difference in the accident frequency per construction project size, and the fatality rate is high in small-size construction [16]. Previous studies of risk levels mostly focus on building construction, and it is possible to confirm research outcomes for each of the diverse building types [17–19]. In addition to building construction, risk levels should be managed in other construction industry fields, such as infrastructure construction and industrial facilities. However, several infrastructure facility-related studies focus on single facilities, such as bridges and tunnels, and there is a lack of studies on general infrastructure facilities [8,15,20,21].

Consequently, this study aims to calculate the quantitative accident risk level according to the construction project size per infrastructure facility type based on construction costs. To this end, we collected and analyzed accident data and construction cost data per facility type and construction project size provided by Korean organizations.

2. Literature Review

In this study, we attempt to calculate the quantitative accident risk level according to the construction project size of infrastructure facilities. To this end, we analyzed previous studies related to the following three topics: (1) risk estimation in the construction industry; (2) calculation of accident rate; and (3) construction project size in risk management. Table 1 shows the summary of the targeted previous studies by topic.

Table 1. Contents of previous studies by topic.

Subject	Reference	Contents
Risk estimation in the construction industry	Baradan and Usmen, 2006 [17]	– Risk analysis was conducted according to the type of construction work based on frequency and severity. – Frequency was defined as accident probability, and severity was defined as the worker's income loss.
	Leu and Chang, 2013 [18]	– Risk assessment of steel building construction by combining fault tree analysis and the Bayesian network.
	Soh et al., 2023 [9]	– To evaluate the risk level considering the probability and financial cost of accidents by building type.
	Chi and Caldas, 2012 [22]	– Development of an automated safety assessment method for earthmoving and surface mining.
	Kim et al., 2016 [15]	– Proposal of an on-site safety assessment system for construction work according to location.
Calculation of the accident rate	Jo et al., 2017 [23]	– Accident probability calculated as the ratio of injured workers to total workers in the construction industry.
	Dong et al., 2014 [24]	– Calculation of the ratio of fatalities from falls to the total number of fatalities in residential construction.
	Chua and Goh, 2005 [25]	– Calculation of accident rate using the Poisson model and Bayesian approach.
	Tymvios and Gambatese, 2016 [26]	– Calculation of the fatality rate as the ratio of fatalities to total full-time workers in the construction industry.
	Nowobilski and Hoła, 2022 [27]	– Calculate the scaffolding-related accident probability by establishing the ratio between the number of scaffolds used and the number of scaffolding-related accidents in the study area.

Table 1. *Cont.*

Subject	Reference	Contents
Construction project size in risk management	Choi et al., 2020 [28]	– Analysis of season and employment size as the most significant factors in the possibility of fatal accidents.
	Gurcanli et al., 2015 [29]	– Define the size of a residential construction site by area and calculate the safety cost per unit area through a risk assessment and construction schedule.
	Arquillos et al., 2012 [30]	– Derive different variables, such as age, size of company, and place of accident, in relation to accidents.
	Lu et al., 2016 [31]	– Investigate the impact on safety performance through safety investment according to project characteristics such as type, size, cost, etc.
	Yim et al., 2015 [32]	– The construction size is proportional to the construction cost. – Development of a construction cost prediction model by construction size.
	Yi, 2015 [33]	– Define construction scale as construction cost, and analyze compliance with occupational safety and health management expenses by construction size.

First, we analyzed previous studies on risk estimation in the construction industry. Risk is calculated based on subjective criteria in traditional risk assessment [7]. Baradan and Usmen [17] studied quantitative risk assessment using accident probability and worker's income loss per work type in building construction. Leu and Chang [18] suggested a risk assessment model to derive accident probabilities based on the Bayesian network of steel construction projects. Soh et al. [9] calculated the risk level per building type according to accident probability and accident cost and classified them into groups of similar risk levels. In addition, several previous studies related to risk estimation in the construction industry showed risk level-related research outcomes using the number of workers and frequency of accidents in the statistical aspect.

Second, we analyzed previous studies on the calculation of accident rates. Jo et al. [23] calculated the ratios of fatalities or injuries to total construction workers to evaluate the characteristics of construction accidents. Dong et al. [24] calculated the ratio of fatalities from falls to total fatalities in residential construction to confirm the trend of fatalities from falls. Chua and Goh [25] calculated accident rates via the Poisson model and Bayesian approach to statistically interpret the occurrence of construction accidents. Tymvios and Gambatese [26] aimed to measure the evaluation of prevention through design in the U.S. construction industry and calculated the ratio of fatalities to total full-time workers in the construction industry as the fatality rate. Nowobilski and Hoła [27] calculated the accident probability based on the number and ratio of scaffolding-related industrial accidents, which are determined empirically to estimate the probability of building scaffolding accidents.

Finally, we analyzed previous studies on construction project size in risk management. Choi et al. [28] identified that the factors most influencing the likelihood of a fatal accident were season and employment size. Gurcanli et al. [29] conducted a risk assessment of residential construction sites and defined small- or medium-scale residential projects via a unit construction area. Arquillos et al. [30] derived diverse variables such as age, size of company, and place of accident to analyze construction accidents in Spain. Lu et al. [31] examined the relationship between safety investment and safety performance in construction projects while considering construction project characteristics such as project type, size, and cost. Yim et al. [32] defined the gross floor area as the construction project size to calculate the construction cost of public buildings. Yi [33] defined the construction project size as the construction cost to analyze the compliance status of Funds for Occupational

Safety and Health Management for the construction industry and classified construction depending on the client types and construction project size.

The results of analyzing previous studies of risk estimation in the construction industry showed that previous studies have attempted to calculate quantitative risk levels in diverse manners. However, these studies have mostly targeted the entire construction industry or building construction. Considering previous studies of the calculation of the accident rate, it was possible to confirm a statistical approach toward accident probability for quantitative risk estimation. Several studies have employed classical methods of calculating the probability based on the ratio of the number of fatalities to the total number of workers to calculate the accident probability. Such studies have faced difficulties in calculating the total number of workers. Finally, as a result of analyzing previous studies on construction project size in risk management, it was noted that the construction project size influencing the accident probability was the employment size, construction area, and construction cost. Based on the analysis of previous studies on three topics, we attempt to calculate the quantitative risk levels of various infrastructure facilities in a statistical manner. Additionally, we try to estimate risks based on construction costs in order to solve problems in calculating risk levels using the total number of workers. Finally, we attempt to confirm the difference in risk levels according to construction project size in the same facility type by calculating risk levels considering the construction project size. Therefore, this study aims to calculate quantitative accident risk levels per infrastructure facility type according to construction project size. Here, infrastructure facilities have diverse forms depending on the types, and considering this, we used the construction cost classification as a criterion for construction project size.

3. Materials and Methods

As shown in Figure 1, the order of analysis was as follows: (1) data collection and classification; (2) calculation of fatality rate (FR) based on construction cost; (3) calculation of fatal construction probability by cost classification (FCPC) using Bayesian theorem; (4) reclassification of construction cost considering FCPC; and (5) calculation of risk level considering facility and cost (RLFC). Statistical analysis was conducted through SPSS 18 in this study.

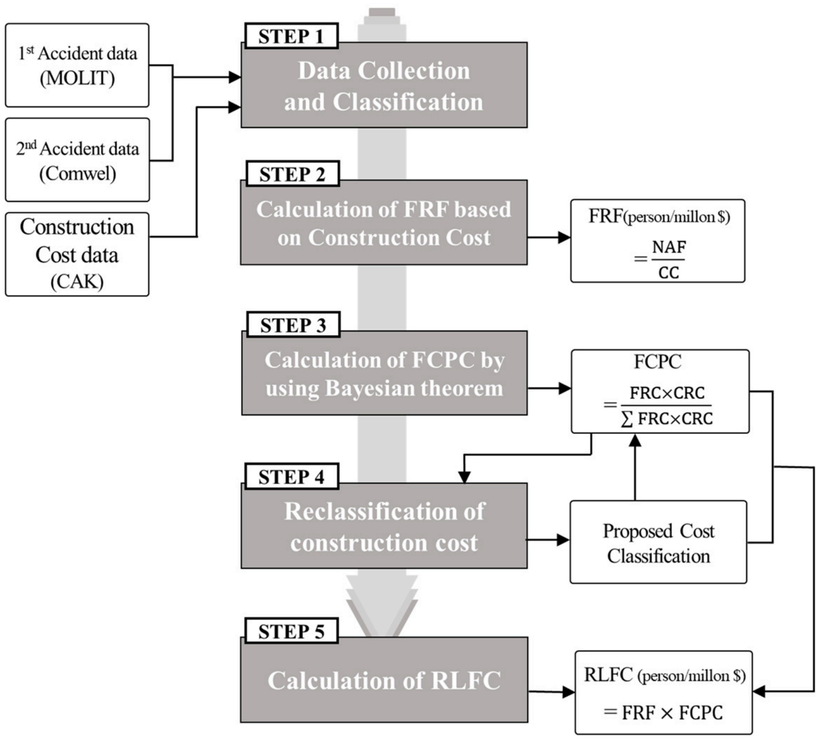

Figure 1. Study framework.

3.1. Data Collection and Classification

We collected two types of accident data and construction cost data to calculate fatality rates based on construction costs. First, for the first type of accident data, we collected the data of 15,503 accidents from 1 July 2019 to 7 October 2022 via the Construction Safety Management Integrated Information database system managed by the Ministry of Land, Infrastructure, and Transport (MOLIT) [34]. For the second type of accident data, we collected the data of 1731 accidents from 1 January 2016 to 9 November 2019 provided by the Compensation and Welfare Service (COMWEL). Finally, we collected construction cost data from the Research on General Construction Business from 2016 to 2021, provided by the Construction Association of Korea (CAK) [10].

In this study, we integrated and utilized two types of accident data collected for accident case analysis. The integrated data were collected for 2472 days, from 1 January 2016 to 7 October 2022. We collected 17,234 integrated data points, including fatalities and injuries, from the entire construction industry and attempted to derive fatality rates per type of infrastructure facility. Therefore, we utilized 512 fatality data points from infrastructure facilities. To this end, 29 infrastructure facilities among the total facility types in the collected data were classified into 10 facility types. Table 2. indicates the total number of fatalities, annual construction costs, and total facilities per type of infrastructure facility used in the study (refer to Tables S1 and S2 of the Supplementary Material for accident data and construction cost data).

Table 2. Number of fatalities and construction cost data by facility type.

Facility Type	Number of Fatalities	Construction Cost (USD Million/Year)
Bridge	53	1260.84
Dam	11	158.61
Road	122	5931.77
Water and sewage	119	1742.99
Retaining wall	23	2465.26
Railroad	33	2339.95
Tunnel	33	820.76
River	31	1595.71
Port and harbor	19	1310.19
Miscellaneous facilities	68	6539.29
Infrastructure facilities	512	24,165.37

Note: The exchange rate (KRW/USD) is KRW 1302 to USD 1 (as of 7 August 2023).

Moreover, the construction cost classification of the collected data differs for each organization, and all three types of data are classified according to the construction cost range. However, the classification range are different for each data set. Therefore, to calculate the fatal construction probability by cost classification, it is necessary to unify the construction cost classification of three types of data. In conclusion, 11 types of construction cost classification were integrated based on the classification of three types of data. In addition, code numbers per construction cost classification were assigned for use in this study. Table 3 indicates 11 construction cost classifications and the corresponding code numbers (refer to Table S3 of the Supplementary Material for construction cost classification by collected data).

Table 3. Code number by construction cost classification.

Code Number	Construction Cost Classification (USD Million)
C-1 *	Less than 0.03
C-2	Not less than 0.03 and less than 0.08
C-3	Not less than 0.08 and less than 0.15

Table 3. *Cont.*

Code Number	Construction Cost Classification (USD Million)
C-4	Not less than 0.15 and less than 0.38
C-5	Not less than 0.38 and less than 0.77
C-6	Not less than 0.77 and less than 3.84
C-7	Not less than 3.84 and less than 7.68
C-8	Not less than 7.68 and less than 15.36
C-9	Not less than 15.36 and less than 38.40
C-10	Not less than 38.40 and less than 76.80
C-11	Not less than 76.80

Note: The exchange rate (KRW/USD) is KRW 1302 to USD 1 (as of 7 August 2023). * C is cost classification.

3.2. Calculation of Fatality Rate Based on Construction Cost

In this study, the fatality rate is calculated using the number of fatalities and construction costs. As the collected construction cost data are annual, it is necessary to annualize the number of fatalities in order to calculate the fatality rate. The number of fatalities was annualized using the following Formula (1):

$$Number\ of\ Annualized\ Fatalities(NAF, person/year) = \frac{Number\ of\ fatalities}{Total\ data\ collection\ period} = Number\ of\ fatalities \times \frac{1}{\frac{Total\ data\ collection\ period}{365\ days}} = Number\ of\ fatalities \times \frac{365\ days}{2472\ days} \quad (1)$$

where the total data collection period is 2472 days, and 1 year is 365 days.

Furthermore, the fatality rate was calculated by considering the number of fatalities and construction cost per facility type through the following Formula (2):

$$Fatality\ Rate(FR, person/million\ dollars) = \frac{NAF}{CC} \quad (2)$$

where NAF is the number of annualized fatalities (person/year) and CC is the average of annual construction costs (USD million/year).

3.3. Calculation of Fatal Construction Probability by Construction Cost Classification

By applying the number of fatalities and construction cost according to the construction project size of the same facility to Formula (2), we can confirm the difference in the fatality rate per construction project size. However, as the annual construction cost is different for each facility type, it is difficult to determine the difference in the fatality rate for each of the same construction project sizes. According to the Bayesian theorem, it is possible to calculate the probability of an event when the probability of the evidence is known and the related evidence for the event is given. It is difficult to calculate the related evidence by reverse reasoning via related evidence, but it is possible to easily calculate it via the Bayesian theorem [35]. Therefore, it is possible to calculate the conditional probability according to the construction project size within the same facility by utilizing the collected number of fatalities, construction cost per facility type, and construction cost classification as related evidence in the Bayesian theorem.

The formal definition of the Bayesian theorem [36–38] is given as follows (Formula (3)):

$$P(X|Y) = \frac{P(Y|X) \times P(X)}{P(Y)} \quad (3)$$

where P(X | Y) is the posterior probability of X given Y, P(Y | X) is the likelihood of X given fixed Y, and P(X) and P(Y) are the probabilities of observing X and Y, respectively, without any given conditions.

The reorganized Formula (4) to use the Bayesian theorem is as follows:

$$P(t = L|q[1], \ldots, q[m]) = \frac{P(q[1], \ldots, q[m]|t = L) \times P(t = L)}{P(q[1], \ldots, q[m])} \quad (4)$$

Here, P(t = L | q [1],. . .,q[m]) is the posterior probability of the attribute t having the value L for case q, and P(q [1], . . ., q[m] | t = L) is the conditional probability of case q given that attribute t has the value L, P(t = L) is the prior probability that attribute t has a particular value L, and P(q [1], . . ., q[m]) is the joint probability that case q has a particular value.

The calculation of the probability using the reorganized Bayesian theorem requires the calculation of the following three probabilities: (1) the conditional probability of case q for the attribute t value; (2) the prior probability that the attribute t will have a specific value; and (3) the joint probability that case q will have a specific value. Probability (3) can be calculated by Formula (5) through Probabilities (1) and (2) according to the law of total probability.

$$P(q[1], \ldots, q[m]) = \sum_{k \in levels(t)} P(q[1], \ldots, q[m]|t = k) \times P(t = k) \quad (5)$$

Here, P(q [1], . . ., q[m]) is the joint probability of case q having a particular value, and P(q [1], . . ., q[m] | t = k) is the conditional probability of attribute t having the value k for the value of case q, and P(t = k) is the prior probability that attribute t has the value k.

In this study, we defined Probability (1) as the fatality rate by cost classification and Probability (2) as the construction rate by cost classification per facility type. These were calculated through the following Formulas (6) and (7):

$$Fatality\ Rate\ by\ Cost\ Classification(FRC, person/million\ dollars) = \frac{NAFC}{CCC} \quad (6)$$

$$Construction\ Rate\ by\ Cost\ Classification(CRC) = \frac{CCC}{Sum\ of\ CCC} \quad (7)$$

Here, *NAFC* is the number of annualized fatalities by cost classification (person/year), and *CCC* is the average of annual construction costs by cost classification (USD million/year).

The conditional probability to be calculated by the Bayesian theorem is the fatal construction probability by cost classification within the same facility. This was calculated as the following Formula (8) by applying Formulas (6) to (7) to Formulas (4) to (5).

$$Fatal\ Construction\ Probability\ by\ Cost\ Classification(FCPC) = \frac{FRC \times CRC}{\sum FRC \times CRC} \quad (8)$$

Here, FRC is the fatality rate by cost classification (person/USD million), and CRC is the construction rate by cost classification.

3.4. Reclassification of Construction Cost Considering Fatal Construction Probability

Several studies have indicated that small-size construction industries are more dangerous than large-size construction industries [16,39]. Additionally, this study was conducted by defining construction cost classification as the criterion for construction project size. However, the collected data were classified according to the range of administrative construction costs for each organization. Therefore, it is necessary to reclassify construction costs by considering risk levels.

K-means clustering enables the classification of multiple data sets by the number of clusters. The number of clusters can be set in advance to use k-means clustering. If there is no set number of clusters, it is possible to calculate the number of clusters via hierarchical cluster analysis or a method with the minimum distance deviation into clusters [40,41]. These methods involve methods such as the elbow method and dendrogram. In this study, we determined the number of clusters via the elbow method.

When performing k-means clustering, an initial centroid can be set equivalent to the determined number of clusters. Then, classification can be conducted according to the nearest criterion through several data points and the distance to the centroid. The same process is repeated with the centroid of a newly classified cluster. Finally, after repeating the cluster analysis until the specified criteria are met, the data are classified according to the final cluster determined.

In this study, we first integrated the construction cost classification of the three collected data sets into one. Then, the integrated construction cost classification was reclassified by considering risk levels per construction project size. To this end, we performed k-means clustering using the fatal construction probability, which was calculated by the construction cost classification before reclassification.

3.5. Calculation of Risk Level by Facility Type and Construction Cost Classification

This study aims to calculate the quantitative accident risk level per infrastructure facility type according to the construction project size. Previously, we calculated differences in risk levels per facility type through fatality rates. Furthermore, the differences in risk levels per construction project size were calculated through the FCPC. Formula (9) presents the risk levels considering the facility type and construction project size based on the two results.

$$Risk\ Level\ considering\ Facility\ and\ Cost(RLFC,\ person/million\ dollars) = FR \times FCPC \quad (9)$$

Here, *FR* is the fatality rate (person/USD million), and *FCPC* is the fatal construction probability by cost classification.

4. Results

4.1. Result of Fatality Rate Based on Construction Cost

Table 4 shows the fatality rates per type of infrastructure facility calculated by applying the number of fatalities and construction cost data in Table 2 to Formulas (1) and (2).

Table 4. FR * based on construction cost.

Facility Type	Number of Fatality	Number of Annualized Fatality (Person/Year)	Construction Cost (USD Million/Year)	FR
Bridge	53	7.83	1260.84	0.00621
Dam	11	1.62	158.61	0.01024
Road	122	18.01	5931.77	0.00304
Water and sewage	119	17.57	1742.99	0.01008
Retaining wall	23	3.40	2465.26	0.00138
Railroad	33	4.87	2339.95	0.00208
Tunnel	33	4.87	820.76	0.00594
River	31	4.58	1595.71	0.00287
Port and harbor	19	2.81	1310.19	0.00214
Miscellaneous facilities	68	10.04	6539.29	0.00154
Infrastructure facilities	512	75.60	24,165.37	0.00313

Note: The exchange rate (KRW/USD) is KRW 1302 to USD 1 (as of 7 August 2023). * FR is the fatality rate, and the unit is person/USD million. ▭: Shaded in the table up to the top three rankings.

Except for infrastructure facilities, which is the total sum of facility types, in the fatality data, the number of fatalities is high in the order of 'Road', 'Water and sewage', . . ., and 'Dam'. However, the fatality rate calculation results indicate that the fatality rate is highest in 'Dam', followed by 'Water and sewage', 'Bridge', 'Tunnel', . . ., and 'Retaining wall.' Figure 2 presents the comparison between NAF and FR per infrastructure type.

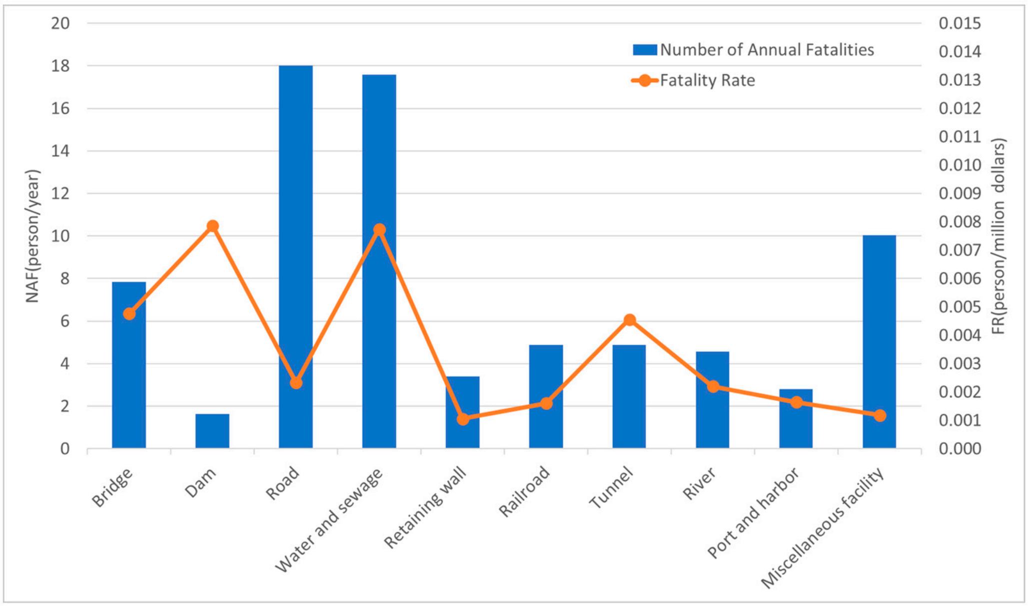

Figure 2. Number of annualized fatalities and fatality rate by facility type.

Figure 2 shows the NAF in a bar graph in units of one person per year. FR is displayed in a line graph in units of one person per USD million. Using the exchange rate as of 7 August 2023, the annual construction cost was converted to USD 1 per KRW 1302.

4.2. Result of Fatal Construction Probability by Construction Cost Classification

In this study, we calculated the fatal construction probability according to construction cost classification per type of infrastructure facility and considered the difference in line with the construction project size.

Table 5 indicates the NAFC and CCC according to facility type and construction cost classification to calculate the fatal construction probability. Except for infrastructure facilities, which is the total sum of facility types, the highest NAF was found at Road's C-6 (4.13 person/year), followed by Water and sewage's C-6 (3.84 person/year), and Water and sewage's C-7 (3.54 person/year). The highest CCC was found at Miscellaneous facilities' C-6 (USD 1919.99 million/year), followed by Road's C-6 (USD 1636.10 million/year) and Road's C-8 (USD 966.36 million/year).

Table 6 presents the FRC, CRC, and FCPC calculated by applying the data in Table 5 to Formulas (6)–(8). The FRC is the ratio of the number of annualized fatalities to the average annual construction cost per construction cost classification. The calculated FRC results show that Tunnel's C-1 is the highest at 3.29563 person/USD million, followed by Dam's C-1 (1.44184 person/USD million) and Bridge's C-1 (0.48567 person/USD million). Moreover, FRC was the lowest at Miscellaneous facilities' C-7 (0.00048 person/USD million) except for cases where no fatality occurred, followed by Retaining wall's C-9 (0.00052 person/USD million) and Railroad's C-7 (0.00054 person/USD million). As for the entire FRC, the maximum construction cost classification was found at C-3 in the top 10 FRCs, and the minimum construction cost classification was found at C-6 in the bottom 10 FRCs. The CRC is the ratio of the average annual construction cost per construction cost classification to the total average of the annual construction cost of each facility type. As for the calculated CRC results, the top three ranks were found at the construction cost classification C-6. The first rank is at Dam's C-6 (0.59511), the second rank is at River's C-6 (0.55641), and the third rank is Water and Sewage's C-6 (0.53216). Finally, FCPC is the conditional probability of fatal construction according to the construction project size within the same facility. The top three ranks are found to be Tunnel's C-11 (0.4), Retaining Wall's C-6 (0.39130), and Railroad's C-11 (0.35484).

Table 5. NAFC * and CCC ** by facility type.

Facility Type		Construction Cost Classification ***										
		C-1	**C-2**	**C-3**	**C-4**	**C-5**	**C-6**	**C-7**	**C-8**	**C-9**	**C-10**	**C-11**
Bridge	NAFC	0.59	0.15	0.89	0.89	0.74	1.18	0.89	0.30	0.59	0.30	1.33
	CCC	1.22	5.31	17.58	66.39	92.26	474.65	209.59	191.22	161.23	23.27	18.14
Dam	NAFC	0.15	0.15	0.15	0.00	0.15	0.15	0.15	0.30	0.15	0.15	0.15
	CCC	0.10	0.60	1.46	8.68	24.99	94.39	17.26	8.13	3.01	0.00	0.00
Road	NAFC	1.62	0.59	1.48	1.62	1.33	4.13	1.03	0.59	2.51	0.89	1.48
	CCC	9.59	48.89	137.52	338.61	407.78	1636.10	768.09	966.36	882.45	410.38	326.01
Water and sewage	NAFC	1.03	0.59	1.18	1.77	1.18	3.84	3.54	1.48	1.77	0.44	0.74
	CCC	2.56	6.82	21.52	98.13	207.12	927.55	244.94	129.07	58.96	21.75	24.56
Retaining wall	NAFC	0.30	0.44	0.15	0.00	0.15	1.33	0.30	0.00	0.30	0.15	0.30
	CCC	1.22	6.00	12.17	46.04	83.15	572.32	445.83	515.83	566.46	173.63	42.59
Railroad	NAFC	0.00	0.15	0.00	0.30	0.15	0.44	0.15	0.30	1.03	0.44	1.62
	CCC	0.13	0.49	1.61	12.21	29.66	390.45	275.65	415.40	705.88	145.21	363.26
Tunnel	NAFC	0.30	0.00	0.00	0.15	0.00	0.30	0.00	0.15	0.89	0.89	1.77
	CCC	0.09	0.44	1.20	7.76	19.98	188.24	114.32	151.59	207.16	87.63	42.36
River	NAFC	0.30	0.30	0.44	0.00	0.44	0.89	1.03	1.03	0.00	0.15	0.00
	CCC	5.08	11.60	40.07	169.12	341.53	887.88	91.14	43.54	5.76	0.00	0.00
Port and harbor	NAFC	0.00	0.30	0.00	0.30	0.15	0.30	0.30	0.30	0.30	0.44	0.44
	CCC	0.67	3.11	11.51	46.49	76.04	441.15	198.31	171.47	212.52	69.18	79.75
Miscellaneous facilities	NAFC	1.62	0.30	0.59	0.89	0.89	1.33	0.44	0.59	1.33	0.59	1.03
	CCC	49.76	119.18	237.58	573.54	614.14	1919.99	914.70	801.77	868.51	347.52	92.60
Infrastructure facilities	NAFC	5.91	2.95	4.87	5.91	5.17	13.88	7.83	5.02	8.86	4.43	8.86
	CCC	70.40	202.43	482.22	1366.97	1896.65	7532.73	3279.83	3394.37	3671.93	1278.57	989.27

Note: The exchange rate (KRW/USD) is KRW 1302 to USD 1 (as of 7 August 2023). * NAFC is the number of annualized fatalities by cost classification, and the unit is person/year. ** CCC is the average annual construction cost by cost classification, and the unit is USD million /year. *** Construction cost classification is confirmed in Table 3. □: Shaded in the table up to the top three rankings.

Table 6. FCPC * by facility type.

Facility Type		Construction Cost Classification **										
		C-1	**C-2**	**C-3**	**C-4**	**C-5**	**C-6**	**C-7**	**C-8**	**C-9**	**C-10**	**C-11**
Bridge	FRC ***	0.48567	0.02779	0.05041	0.01335	0.00800	0.00249	0.00423	0.00154	0.00366	0.01269	0.07326
	CRC ****	0.00096	0.00421	0.01394	0.05265	0.07317	0.37646	0.16623	0.15166	0.12787	0.01846	0.01439
	FCPC	0.07547	0.01887	0.11321	0.11321	0.09434	0.15094	0.11321	0.03774	0.07547	0.03774	0.16981
Dam	FRC	1.44184	0.24542	0.10118	0.00000	0.00591	0.00156	0.00856	0.03633	0.04908	0.00679	0.00814
	CRC	0.00065	0.00379	0.00920	0.05472	0.15753	0.59511	0.10879	0.05125	0.01897	0.00065	0.00065
	FCPC	0.11098	0.11098	0.11098	0.00000	0.11098	0.11098	0.11098	0.22197	0.11098	0.00052	0.00063
Road	FRC	0.16940	0.01208	0.01074	0.00480	0.00326	0.00253	0.00135	0.00061	0.00284	0.00216	0.00453
	CRC	0.00162	0.00824	0.02318	0.05708	0.06875	0.27582	0.12949	0.16291	0.14877	0.06918	0.05496
	FCPC	0.09402	0.03419	0.08547	0.09402	0.07692	0.23932	0.05983	0.03419	0.14530	0.05128	0.08547
Water and sewage	FRC	0.40371	0.08656	0.05489	0.01806	0.00570	0.00414	0.01447	0.01144	0.03005	0.02037	0.03005
	CRC	0.00147	0.00391	0.01235	0.05630	0.11883	0.53216	0.14053	0.07405	0.03383	0.01248	0.01409
	FCPC	0.05882	0.03361	0.06723	0.10084	0.06723	0.21849	0.20168	0.08403	0.10084	0.02521	0.04202
Retaining wall	FRC	0.24284	0.07378	0.01213	0.00000	0.00178	0.00232	0.00066	0.00000	0.00052	0.00085	0.00693
	CRC	0.00049	0.00244	0.00494	0.01868	0.03373	0.23216	0.18084	0.20924	0.22978	0.07043	0.01728
	FCPC	0.08696	0.13043	0.04348	0.00000	0.04348	0.39130	0.08696	0.00000	0.08696	0.04348	0.08696

Table 6. *Cont.*

Facility Type		Construction Cost Classification **										
		C-1	**C-2**	**C-3**	**C-4**	**C-5**	**C-6**	**C-7**	**C-8**	**C-9**	**C-10**	**C-11**
Railroad	FRC	0.00000	0.30354	0.00000	0.02418	0.00498	0.00113	0.00054	0.00071	0.00146	0.00305	0.00447
	CRC	0.00005	0.00021	0.00069	0.00522	0.01268	0.16686	0.11780	0.17752	0.30166	0.06206	0.15524
	FCPC	0.00000	0.03226	0.00000	0.06452	0.03226	0.09677	0.03226	0.06452	0.22581	0.09677	0.35484
Tunnel	FRC	3.29563	0.00000	0.00000	0.01903	0.00000	0.00157	0.00000	0.00097	0.00428	0.01011	0.04183
	CRC	0.00011	0.00053	0.00147	0.00945	0.02435	0.22934	0.13929	0.18469	0.25239	0.10677	0.05161
	FCPC	0.06667	0.00000	0.00000	0.03333	0.00000	0.06667	0.00000	0.03333	0.20000	0.20000	0.40000
River	FRC	0.05811	0.02546	0.01106	0.00000	0.00130	0.00100	0.01134	0.02374	0.00000	0.00679	0.00000
	CRC	0.00318	0.00727	0.02511	0.10599	0.21403	0.55641	0.05712	0.02728	0.00361	0.00318	0.00000
	FCPC	0.06615	0.06615	0.09923	0.00000	0.09923	0.19845	0.23153	0.23153	0.00000	0.00773	0.00000
Port and harbor	FRC	0.00000	0.09494	0.00000	0.00635	0.00194	0.00067	0.00149	0.00172	0.00139	0.00640	0.00555
	CRC	0.00051	0.00237	0.00878	0.03549	0.05804	0.33671	0.15136	0.13087	0.16220	0.05280	0.06087
	FCPC	0.00000	0.10526	0.00000	0.10526	0.05263	0.10526	0.10526	0.10526	0.10526	0.15789	0.15789
Miscellaneous facilities	FRC	0.03264	0.00248	0.00249	0.00154	0.00144	0.00069	0.00048	0.00074	0.00153	0.00170	0.01116
	CRC	0.00761	0.01822	0.03633	0.08771	0.09392	0.29361	0.13988	0.12261	0.13281	0.05314	0.01416
	FCPC	0.16923	0.03077	0.06154	0.09231	0.09231	0.13846	0.04615	0.06154	0.13846	0.06154	0.10769
Infrastructure facilities	FRC	0.08389	0.01459	0.01010	0.00432	0.00272	0.00184	0.00239	0.00148	0.00241	0.00346	0.00896
	CRC	0.00291	0.00838	0.01995	0.05657	0.07849	0.31172	0.13572	0.14046	0.15195	0.05291	0.04094
	FCPC	0.08016	0.04008	0.06613	0.08016	0.07014	0.18838	0.10621	0.06814	0.12024	0.06012	0.12024

Note: * FCPC is fatal construction probability by cost classification. ** Construction cost classification is confirmed in Table 3. *** FRC is the fatality rate by cost classification, and the unit is person/USD million. **** CRC is the construction rate by cost classification. : Shaded in the table up to the top three rankings.

However, FCPC presents probabilities within the same facility type, and therefore, it was possible to confirm FCPC ranks within the same facility. As a result, the first order of the construction cost classification per facility type was found to be Bridge's C-11, Dam's C-8, Road's C-6, Water and sewage's C-6, Retaining wall's C-6, Railroad's C-11, Tunnel's C-11, River's C-7 and C-9, Port and harbor's C-9 and C-10, Miscellaneous facilities' C-1, and Infrastructure facilities' C-6. In this manner, it was possible to confirm the top three construction cost classifications per facility type. Eight cases were the most frequent, corresponding to ranks from 1 to 3, and construction cost classifications C-6 and C-9 were the most common with eight cases, respectively.

4.3. Determining Clusters of Construction Costs Considering Fatal Construction Probability

In this study, we reclassified existing construction cost classifications through k-means clustering based on FCPC.

First, the number of clusters was decided to be five via the elbow method, and k-means clustering was performed. Figure 3 shows the results of the elbow method for FCPC of the entire infrastructure facility.

In Figure 3, the y-axis is inertia, which measures the mean square distance between centroids. The x-axis is the number of clusters to be used for k-means clustering. The elbow point was determined as 5, the number of clusters where the elbow method graph becomes smooth.

The construction cost was reclassified by performing k-means clustering through the determined number of clusters. The construction cost was reclassified into five categories from the existing eleven through cluster analysis. In the proposed cost classification, code numbers were provided as in the existing cost classification. Table 7 shows the existing cost classification and proposed cost classification along with corresponding code numbers.

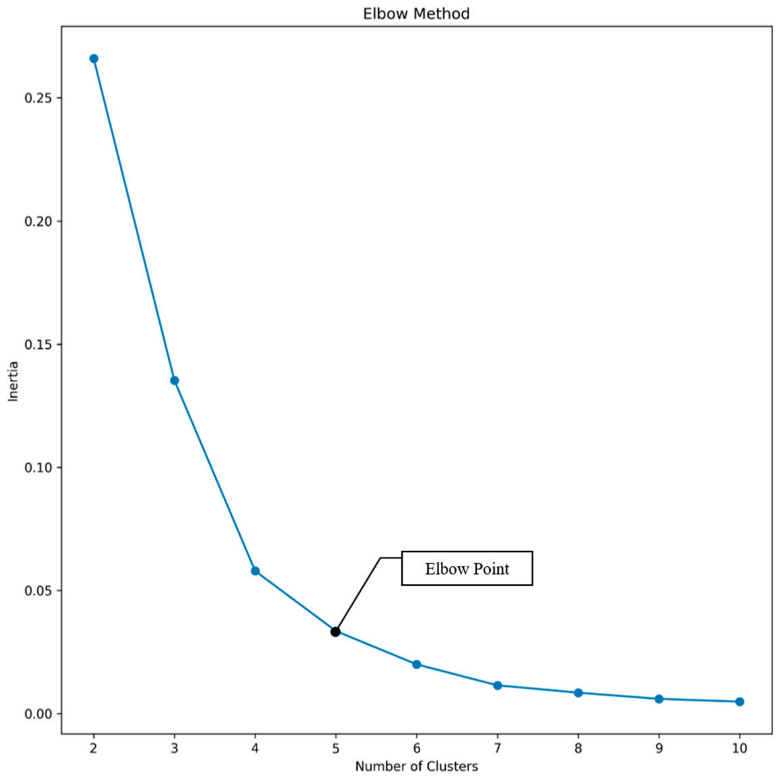

Figure 3. Elbow method of FCPC.

Table 7. Existing cost classifications of collected data and proposed cost classifications.

Code Number	Existing Cost Classification (USD Million)	Code Number	Proposed Cost Classification (USD Million)
C-1 *	Less than 0.03	PC-1 **	Less than 0.77
C-2	Not less than 0.03 and less than 0.08		
C-3	Not less than 0.08 and less than 0.15		
C-4	Not less than 0.15 and less than 0.38		
C-5	Not less than 0.38 and less than 0.77		
C-6	Not less than 0.77 and less than 3.84	PC-2	Not less than 0.77 and less than 3.84
C-7	Not less than 3.84 and less than 7.68	PC-3	Not less than 3.84 and less than 15.36
C-8	Not less than 7.68 and less than 15.36		
C-9	Not less than 15.36 and less than 38.40	PC-4	Not less than 15.36 and less than 76.80
C-10	Not less than 38.40 and less than 76.80		
C-11	Not less than 76.80	PC-5	Not less than 76.80

Note: The exchange rate (KRW/USD) is KRW 1302 to USD 1 (as of 7 August 2023). * C is the cost classification. ** PC is the proposed cost classification.

Table 7 indicates the integrated cost classification. As shown, we could know the existing cost classification was the most integrated into the small-scale classification through Table 7. The proposed construction cost classification, with the largest number of existing classifications integrated, was PC-1.

4.4. Risk Level Considering Facility Type and Construction Cost Classification

Since the construction cost was reclassified, the existing FCPC must be recalculated with the proposed cost classification. The recalculated results can be found in Table 8 (refer to Tables S4 and S5 of the Supplementary Material for Recalculated NAFC, CCC, FRC, and CRC).

Table 8. Recalculated FCPC * by proposed cost classification.

Facility Type	Proposed Cost Classification **				
	PC-1	**PC-2**	**PC-3**	**PC-4**	**PC-5**
Bridge	0.41509	0.15094	0.15094	0.11321	0.16981
Dam	0.39326	0.09831	0.29494	0.19663	0.01686
Road	0.38462	0.23932	0.09402	0.19658	0.08547
Water and sewage	0.32773	0.21849	0.28571	0.12605	0.04202
Retaining wall	0.30435	0.39130	0.08696	0.13043	0.08696
Railroad	0.12903	0.09677	0.09677	0.32258	0.35484
Tunnel	0.10000	0.06667	0.03333	0.40000	0.40000
River	0.32258	0.19355	0.45161	0.03226	0.00000
Port and harbor	0.26316	0.10526	0.21053	0.26316	0.15789
Miscellaneous facilities	0.44615	0.13846	0.10769	0.20000	0.10769
Infrastructure facilities	0.33667	0.18838	0.17435	0.18036	0.12024

Note: The exchange rate (KRW/USD) is KRW 1302 to USD 1 (as of 7 August 2023). * FCPC is the fatal construction probability by cost classification. ** The proposed cost classification is confirmed in Table 7.

As a result of confirming the recalculated FCPC ranking within the same facility, the first order of the proposed cost classification per facility type was found to be Bridge's PC-1, Dam's PC-1, Road's PC-1, Water and sewage's PC-1, Retaining wall's PC-2, Railroad's PC-5, Tunnel's PC-4 and PC-5, River's PC-3, Port and harbor's PC-1 and PC-4, Miscellaneous facilities' PC-1, and Infrastructure facilities' PC-1.

The recalculated FCPC result was applied to Formula (9) to calculate RLFC, and the ranking was calculated. For the ranking of RLFC, we calculated two types of rankings: a ranking according to the proposed cost classification within the same facility and another ranking according to the proposed cost classification of the entire facility type. The calculated RLFC and rankings can be found in Table 9.

As for the ranking according to the proposed cost classification within the same facility of the finally calculated RLFC, the RLFC of most facility types at PC-1 or PC-2 showed the first or second ranks. However, in Railroad and Tunnel, the first and second ranks of RLFC appeared at PC-4 and PC-5.

Table 9. Rank of RLFC *.

Facility Type	Proposed Cost Classification **	RLFC *	Rank by Facility Type	Rank between Overall RLFC
Bridge	PC-1	0.0025763586	1	5
	PC-2	0.0009368577	4	16
	PC-3	0.0009368577	3	15
	PC-4	0.0007026433	5	20
	PC-5	0.0010539649	2	13
Dam	PC-1	0.0040268713	1	1
	PC-2	0.0010067178	4	14
	PC-3	0.0030201535	2	3
	PC-4	0.0020134357	3	9
	PC-5	0.0001726568	5	44
Road	PC-1	0.0011680097	1	12
	PC-2	0.0007267616	2	19
	PC-3	0.0002855135	4	35
	PC-4	0.0005969827	3	23
	PC-5	0.0002595577	5	37

Table 9. *Cont.*

Facility Type	Proposed Cost Classification **	RLFC *	Rank by Facility Type	Rank between Overall RLFC
Water and sewage	PC-1	0.0033038119	1	2
	PC-2	0.0022025413	3	8
	PC-3	0.0028802463	2	4
	PC-4	0.0012706969	4	11
	PC-5	0.0004235656	5	30
Retaining wall	PC-1	0.0004192566	2	31
	PC-2	0.0005390443	1	28
	PC-3	0.0001197876	4	47
	PC-4	0.0001796814	3	43
	PC-5	0.0001197876	4	47
Railroad	PC-1	0.0002686889	3	36
	PC-2	0.0002015167	4	40
	PC-3	0.0002015167	4	40
	PC-4	0.0006717224	2	22
	PC-5	0.0007388946	1	18
Tunnel	PC-1	0.0005936639	3	24
	PC-2	0.0003957759	4	32
	PC-3	0.0001978880	5	42
	PC-4	0.0023746554	1	6
	PC-5	0.0023746554	1	6
River	PC-1	0.0009253158	2	17
	PC-2	0.0005551895	3	27
	PC-3	0.0012954421	1	10
	PC-4	0.0000925316	4	49
	PC-5	0.0000000000	5	50
Port and harbor	PC-1	0.0005634823	1	25
	PC-2	0.0002253929	5	38
	PC-3	0.0004507859	3	29
	PC-4	0.0005634823	1	25
	PC-5	0.0003380894	4	33
Miscellaneous facilities	PC-1	0.0006850269	1	21
	PC-2	0.0002125946	3	39
	PC-3	0.0001653513	4	45
	PC-4	0.0003070810	2	34
	PC-5	0.0001653513	4	45
Infrastructure facilities	PC-1	0.0010532454	1	-
	PC-2	0.0005893159	2	
	PC-3	0.0005454307	4	
	PC-4	0.0005642386	3	
	PC-5	0.0003761591	5	

Note: The exchange rate (KRW/USD) is KRW 1302 to USD 1 (as of 7 August 2023). * RLFC is the risk level considering facility and cost, and the unit is person/USD million. ** The proposed cost classification is confirmed in Table 7.

Next, for the ranking according to the proposed cost classification of the entire facility types of RLFC, the Dam's PC-1 (0.00402 person/USD million) ranked first, followed by Water and sewage's PC-1 (0.00330 person/USD million), and Dam's PC-3 (0.00302 person/USD million). In terms of 4th–10th ranking, Water and sewage's PC-3 (0.00288 person/USD million) ranked fourth, followed by Bridge's PC-1 (0.00258 person/USD million), Tunnel's PC-4 and PC-5 (0.00237 person/USD million), which were tied for sixth, Water and sewage's PC-2 (0.00220 person/USD million), Dam's PC-4 (0.00201 person/USD million), and River's PC-3 (0.00130 person/USD million).

5. Discussion

5.1. Change in Risk Level Due to Construction Cost Reclassifications

The proposed cost classification is a reclassification of the existing cost classification in consideration of the risk level. Consequently, it is necessary to analyze the differences between construction cost classifications. To this end, we divided the top FCPCs as per before and after construction cost reclassifications through cluster analysis and summarized them in Table 10.

Table 10. FCPC * before and after cluster analysis.

Rank	Before Cluster			After Cluster		
	Facility Type	**Cost Classification ****	**FCPC**	**Facility Type**	**Cost Classification ****	**FCPC ***
1	Tunnel	C-11	0.40000	River	PC-3	0.45161
2	Retaining wall	C-6	0.39130	Miscellaneous facilities	PC-1	0.44615
3	Railroad	C-11	0.35484	Bridge	PC-1	0.41509
4	Road	C-6	0.23932	Tunnel	PC-4	0.40000
5	River	C-7	0.23153	Tunnel	PC-5	0.40000
6	River	C-8	0.23153	Dam	PC-1	0.39326
7	Railroad	C-9	0.22581	Retaining wall	PC-2	0.39130
8	Dam	C-8	0.22197	Road	PC-1	0.38462
9	Water and sewage	C-6	0.21849	Railroad	PC-5	0.35484
10	Water and sewage	C-7	0.20168	Infrastructure facilities	PC-1	0.33667

Note: * FCPC is the fatal construction probability by cost classification. ** The cost classification is confirmed in Table 7.

First, FCPC before cluster analysis was the highest at Tunnel's C-11 (0.4). The top 10 FCPCs were found in the existing cost classification of C-6 or higher. Next, the FCPC after cluster analysis was the highest at River's PC-3 (0.45161). Most of the top 10 FCPCs were found in the proposed cost classification of PC-1, except for facility types such as Railroads and Tunnels.

Previous studies have shown that the smaller the construction site, the higher the risk level [16,29,39]. However, the FCPC results obtained through existing cost classification before cluster analysis are different. The top ten FCPCs were not found in the existing cost classification of C-1~C-5, which can be considered a small-size construction, but were mainly found after the top 40. However, the FCPC results obtained through the proposed cost classification after cluster analysis indicate that the PC-1 classification dominates the top ten. These results show that the result of reclassifying construction costs more appropriately explains the risk level according to the construction project size.

Next, the FCPC of Railroads and Tunnels among facility types appeared high in the largest construction cost classification, regardless of cluster analysis. The reason for this can be inferred from the average annual construction cost per existing construction cost classification for Railroads and Tunnels in Table 5. Table 5 shows that the sum of the average annual construction costs of the existing cost classification of C-1~C-5 for Railroads and Tunnels is minimal, at 1.88% and 3.59%, respectively. These are the lowest rates compared to other facility types. In other words, since Railroads and Tunnels have very few small-scale constructions, accidents are less likely to occur, which is reflected in the FCPC ranking.

5.2. Comparative Analysis with Previous Studies

Previous studies have mainly focused on the risk level of building construction, which makes it difficult to compare with the results of this study. However, Bang et al. [8] suggested that the risk level can be determined based on facility type and construction project size. They evaluated the risk level based on different construction project sizes and found that 'Assembly' facilities had the highest risk level compared to other facilities in several construction project sizes. However, 'Assembly' is not the riskiest of all construction project sizes.

We have ranked the risk level of facilities based on their construction project size in Table 11. As shown in the table, this study also confirms that there is a change in the ranking of facilities based on construction project size.

Table 11. Ranking of facilities by construction project size.

Rank	**Proposed Cost Classification ***				
	PC-1	**PC-2**	**PC-3**	**PC-4**	**PC-5**
1	Dam	Water and sewage	Dam	Tunnel	Tunnel
2	Water and sewage	Dam	Water and sewage	Dam	Bridge
3	Bridge	Bridge	River	Water and sewage	Railroad
4	Road	Road	Bridge	Bridge	Water and sewage
5	River	River	Port and Harbor	Railroad	Port and harbor
6	Miscellaneous facilities	Retaining wall	Road	Road	Road
7	Tunnel	Tunnel	Railroad	Port and harbor	Dam
8	Port and harbor	Port and harbor	Tunnel	Miscellaneous facilities	Miscellaneous facilities
9	Retaining wall	Miscellaneous facilities	Miscellaneous facilities	Retaining wall	Retaining wall
10	Railroad	Railroad	Retaining wall	River	River

Note: * The proposed cost classification is confirmed in Table 7.

It is a useful finding that the risk level can vary depending on the size of the construction project. This result can assist in the allocation of necessary resources for risk management at the design stage. For example, in the case of a highway construction project, most of the facilities included in this study may be related to road construction. Thus, by estimating the total cost of construction during the design phase, a standard for distributing risk management resources can be established based on the findings of this study. This can ensure that appropriate measures are taken to manage risks effectively.

6. Conclusions

Risk levels in the construction industry are affected by various factors. Therefore, this study suggested quantitative accident risk levels considering the type of infrastructure facilities and the size of the construction project.

This study was conducted in five steps. In Step 1, we collected data on 17,234 accidents through two types of accident data and selected 512 fatalities from infrastructure facilities. Then, we collected the construction cost data from 2016 to 2021. We classified the 29 types of infrastructure facilities collected from accident data into ten facility types. In addition, different construction cost classifications of the three collected data were integrated and classified into 11 types. In Step 2, we calculated FR via the number of fatalities and construction costs. To this end, the number of fatalities was also annualized according to the collected construction costs. In Step 3, FCPC was calculated for each facility type through the Bayesian theorem. First of all, to use the Bayesian theorem, we calculated FRC, the conditional probability, and CRC, the prior probability. Then, FCPC, the posterior probability, was calculated. In Step 4, construction cost classifications were reclassified in consideration of risk levels via k-means clustering conducted using FCPC for reclassifications in consideration of risk levels. K-means clustering was performed by first determining the number of clusters while using the elbow method. Finally, in Step 5, we calculated the quantitative risk level through FR and FCPC per facility type. To this end, we recalculated FCPC via the reclassified construction cost classification.

The findings of this study are as follows: First, as a result of calculating FR per type of infrastructure facility, 'Dam' was found to be the highest at 0.01024 person/USD million. Next, as a result of the k-means clustering of construction cost classification in consideration of risk levels, eleven types of cost classification were reclassified into five types. And, finally, the results of calculating the RLFC with the finally reclassified construction cost classification indicate that 'Dam' was found to be the highest at 0.00403 person/USD million in the construction of less than USD 0.77 million.

This study aimed to analyze the risk levels of various infrastructure facilities that were not covered in previous studies. This study estimated the risk levels for different types of infrastructure facilities and construction project sizes. Additionally, 11 construction cost classifications were reclassified into five categories, which confirmed consistency with the results of previous studies on construction risk levels. The importance of safety management from the design stage, such as DsF, is being highlighted. The risk levels presented in this study can be used as basic data for safety management in the design stage. Additionally, the reclassification of construction costs suggests that a separate classification of construction scale for safety management is necessary.

The limitations of this study are as follows: First, the accident data included fatalities and injuries, but these were not integrated and considered when calculating risk levels. Second, while the risk level was calculated for each facility type, the risk level for each work type was not calculated. As the same work type exists in infrastructure facilities, even if the facility type is different, it is necessary to calculate the risk level for each work type. Therefore, after this study, the risk level by facility type and work type must be calculated by integrating fatalities and injury data.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/buildings14051283/s1. Table S1: Accident data by facility type. Table S2: Annual construction cost by facility type. Table S3: Construction cost classification by collected data. Table S4: Recalculated NAFC and CCC by proposed cost classification. Table S5: Recalculated FRC and CRC by proposed cost classification.

Author Contributions: Conceptualization, J.L. and J.J.; methodology, J.L. and J.J.; resources, J.J.; writing—original draft preparation, J.L.; writing—review and editing, J.J.; supervision, J.J.; funding acquisition, J.J. All authors have read and agreed to the published version of the manuscript.

Funding: This study was supported by the research program funded by the Seoul National University of Science and Technology (SeoulTech).

Data Availability Statement: The data generated and analyzed during this research are available from the corresponding author upon reasonable request.

Conflicts of Interest: The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

1. Park, I.; Kim, J.; Han, S.; Hyun, C. Analysis of fatal accidents and their causes in the Korean construction industry. *Sustainability* **2020**, *12*, 3120. [CrossRef]
2. Guo, Q.; Amin, S.; Hao, Q.; Haas, O. Resilience assessment of safety system at subway construction sites applying analytic network process and extension cloud models. *Reliab. Eng. Syst. Saf.* **2020**, *201*, 106956. [CrossRef]
3. Ju, W.; Wu, J.; Kang, Q.; Jiang, J.; Xing, Z. A method based on the theories of game and extension cloud for risk assessment of construction safety: A case study considering disaster-inducing factors in the construction process. *J. Build. Eng.* **2022**, *62*, 105317. [CrossRef]
4. Ministry of Employment and Labor (MOEL). Industrial Accident Status Analysis in 2021. Available online: https://www.moel.go.kr/policy/policydata/view.do?bbs_seq=20221201394 (accessed on 3 June 2023).

5. Guo, B.H.; Zou, Y.; Fang, Y.; Goh, Y.M.; Zou, P.X. Computer vision technologies for safety science and management in construction: A critical review and future research directions. *Saf. Sci.* **2021**, *135*, 105130. [CrossRef]
6. Ministry of Employment and Labor (MOEL). Occupational Safety and Health Act 2022. Available online: https://www.law.go.kr/LSW/eng/engLsSc.do?menuId=2&section=lawNm&query=Occupational+Safety+and+Health+Act&x=0&y=0 (accessed on 3 June 2023).
7. Jeong, J.; Jeong, J. Quantitative risk evaluation of fatal incidents in construction based on frequency and probability analysis. *J. Manag. Eng.* **2022**, *38*, 04021089. [CrossRef]
8. Bang, S.; Jeong, J.; Lee, J.; Jeong, J.; Soh, J. Evaluation of Accident Risk Level Based on Construction Cost, Size and Facility Type. *Sustainability* **2023**, *15*, 1565. [CrossRef]
9. Soh, J.; Jeong, J.; Jeong, J.; Lee, J. Quantitative Risk Evaluation by Building Type Based on Probability and Cost of Accidents. *Buildings* **2023**, *13*, 327. [CrossRef]
10. Construction Association of Korea (CAK). Research of General Construction Business, 2016~2021. Available online: http://www.cak.or.kr/stat/statisticsMain.do?menuId=7 (accessed on 22 March 2023).
11. Hatipkarasulu, Y. Project level analysis of special trade contractor fatalities using accident investigation reports. *J. Safety Res.* **2010**, *41*, 451–457. [CrossRef] [PubMed]
12. Kheni, N.A.; Gibb, A.G.; Dainty, A.R. Health and safety management within small-and medium-sized enterprises (SMEs) in developing countries: Study of contextual influences. *J. Constr. Eng. Manag.* **2010**, *136*, 1104–1115. [CrossRef]
13. Dumrak, J.; Mostafa, S.; Kamardeen, I.; Rameezdeen, R. Factors associated with the severity of construction accidents: The case of South Australia. *Constr. Econ. Build.* **2013**, *13*, 32–49. [CrossRef]
14. Zhou, Z.; Goh, Y.M.; Li, Q. Overview and analysis of safety management studies in the construction industry. *Saf. Sci.* **2015**, *72*, 337–350. [CrossRef]
15. Kim, H.; Kim, K.; Kim, H. Vision-based object-centric safety assessment using fuzzy inference: Monitoring struck-by accidents with moving objects. *J. Comput. Civil. Eng.* **2016**, *30*, 04015075. [CrossRef]
16. Choi, S.D.; Guo, L.; Kim, J.; Xiong, S. Comparison of fatal occupational injuries in construction industry in the United States, South Korea, and China. *Int. J. Ind. Ergon.* **2019**, *71*, 64–74. [CrossRef]
17. Baradan, S.; Usmen, M.A. Comparative injury and fatality risk analysis of building trades. *J. Constr. Eng. Manag.* **2006**, *132*, 533–539. [CrossRef]
18. Leu, S.S.; Chang, C.M. Bayesian-network-based safety risk assessment for steel construction projects. *Accid. Anal. Prev.* **2013**, *54*, 122–133. [CrossRef] [PubMed]
19. Chen, H.; Luo, X.; Zheng, Z.; Ke, J. A proactive workers' safety risk evaluation framework based on position and posture data fusion. *Autom. Constr.* **2019**, *98*, 275–288. [CrossRef]
20. Luo, Q.; Huang, L.; Xue, X.; Chen, Z.; Zhou, F.; Wei, L.; Hua, J. Occupational health risk assessment based on dust exposure during earthwork construction. *J. Build. Eng.* **2021**, *44*, 103186. [CrossRef]
21. He, K.; Zhu, J.; Wang, H.; Huang, Y.; Li, H.; Dai, Z.; Zhang, J. Safety risk evaluation of metro shield construction when undercrossing a bridge. *Buildings* **2023**, *13*, 2540. [CrossRef]
22. Chi, S.; Caldas, C.H. Image-based safety assessment: Automated spatial safety risk identification of earthmoving and surface mining activities. *J. Constr. Eng. Manag.* **2012**, *138*, 341–351. [CrossRef]
23. Jo, B.W.; Lee, Y.S.; Kim, J.H.; Asad Khan, R.M. Trend analysis of construction industrial accidents in Korea from 2011 to 2015. *Sustainability* **2017**, *9*, 1297. [CrossRef]
24. Dong, X.S.; Wang, X.; Largay, J.A.; Platner, J.W.; Stafford, E.; Cain, C.T.; Choi, S.D. Fatal falls in the US residential construction industry. *Am. J. Ind. Med.* **2014**, *57*, 992–1000. [CrossRef] [PubMed]
25. Chua, D.K.; Goh, Y.M. Poisson model of construction incident occurrence. *J. Constr. Eng. Manag.* **2005**, *131*, 715–722. [CrossRef]
26. Tymvios, N.; Gambatese, J.A. Perceptions about design for construction worker safety: Viewpoints from contractors, designers, and university facility owners. *J. Constr. Eng. Manag.* **2016**, *142*, 04015078. [CrossRef]
27. Nowobilski, T.; Hoła, B. Estimating the probability of accidents on building scaffoldings. *Saf. Sci.* **2022**, *152*, 105777. [CrossRef]
28. Choi, J.; Gu, B.; Chin, S.; Lee, J.S. Machine learning predictive model based on national data for fatal accidents of construction workers. *Autom. Constr.* **2020**, *110*, 102974. [CrossRef]
29. Gurcanli, G.E.; Bilir, S.; Sevim, M. Activity based risk assessment and safety cost estimation for residential building construction projects. *Saf. Sci.* **2015**, *80*, 1–12. [CrossRef]
30. Arquillos, A.L.; Romero, J.C.R.; Gibb, A. Analysis of construction accidents in Spain, 2003–2008. *J. Safety Res.* **2012**, *43*, 381–388. [CrossRef] [PubMed]
31. Lu, M.; Cheung, C.M.; Li, H.; Hsu, S.C. Understanding the relationship between safety investment and safety performance of construction projects through agent-based modeling. *Accid. Anal. Prev.* **2016**, *94*, 8–17. [CrossRef] [PubMed]
32. Yim, J.H.; Park, J.M.; Kim, O.K. Cost Estimating Method of Public Building Construction through Construction Scale. *J. Korea Inst. Build. Constr.* **2015**, *15*, 307–316. [CrossRef]
33. Yi, K.J. Compliance Status of OSH Expense Regulation by Client Types and Project Amount. *J. Korea Inst. Build. Constr.* **2015**, *15*, 73–79. [CrossRef]
34. Ministry of Land. Infrastructure and Transport (MOLIT). Construction Safety Management Integrated Information System. Available online: https://www.csi.go.kr/index.do.csi (accessed on 6 February 2023).

35. Kelleher, J.D.; Mac Namee, B.; D'arcy, A. *Fundamentals of Machine Learning for Predictive Data Analytics: Algorithms, Worked Examples, and Case Studies*; MIT Press: Cambridge, MA, USA, 2020.
36. Adams, F.K. Risk perception and Bayesian analysis of international construction contract risks: The case of payment delays in a developing economy. *Int. J. Proj. Manag.* **2008**, *26*, 138–148. [CrossRef]
37. Alizadeh, S.S.; Mortazavi, S.B.; Mehdi Sepehri, M. Assessment of accident severity in the construction industry using the Bayesian theorem. *Int. J. Occup. Saf. Ergon.* **2015**, *21*, 551–557. [CrossRef] [PubMed]
38. Wang, J.; Guo, F.; Song, Y.; Liu, Y.; Hu, X.; Yuan, C. Safety risk assessment of prefabricated buildings hoisting construction: Based on IHFACS-ISAM-BN. *Buildings* **2022**, *12*, 811. [CrossRef]
39. Cheng, C.W.; Leu, S.S.; Lin, C.C.; Fan, C. Characteristic analysis of occupational accidents at small construction enterprises. *Saf. Sci.* **2010**, *48*, 698–707. [CrossRef]
40. Chemweno, P.; Morag, I.; Sheikhalishahi, M.; Pintelon, L.; Muchiri, P.; Wakiru, J. Development of a novel methodology for root cause analysis and selection of maintenance strategy for a thermal power plant: A data exploration approach. *Eng. Fail. Anal.* **2016**, *66*, 19–34. [CrossRef]
41. Sepasgozar, S.M.; Davis, S.R.; Loosemore, M. Dissemination practices of construction sites' technology vendors in technology exhibitions. *J. Mana. Eng.* **2018**, *34*, 04018038. [CrossRef]