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# Towards Effective Safety Cost Budgeting for Apartment Construction: A Case Study of Occupational Safety and Health Expenses in South Korea

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**Abstract:** The construction industry has experienced a lot of occupational accidents, and construction work is considered one of the most dangerous occupations. In order to reduce the number of occupational injuries from construction, the South Korean government legislated the occupational safety and health expense law, requiring companies to reserve a reasonable budget for safety management activities when budgeting for construction projects. However, safety budgets have not been spent based on the risk of accidents, and a large amount of the safety budget is spent either in the beginning or late stages of construction projects. Various accident risk factors, such as activity types, previous accident records, and the number of workers on a construction site, need to be considered when determining the safety budget. To solve such problems, this study investigated the expenditure trends of occupational safety and health expenses for 10 apartment construction projects in South Korea. This study also proposed an accident risk index that can be incorporated with the project costs, schedule, the number of workers, and historical accident records when budgeting for the safety costs. The results from the case study illustrate the limitations of the current planning strategy for safety expenditures and demonstrate the need for effective safety budgeting for accident prevention. The proposed safety cost expenditure guideline helps safety practitioners when budgeting for the occupational safety and health expenses while considering accident risk and the characteristics of safety cost expenditures in practice. The outcome of this research will contribute to the development of regulations for the budgeting of safety costs and help to prevent occupational injuries by providing a reasonable budget for safety management activities in an apartment construction project.

**Keywords:** occupational safety and health expenses; construction safety; safety cost expenditures; apartment construction

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## 1. Introduction

The construction industry in South Korea has rapidly grown over the last few decades [1], with infrastructure and residential facility constructions to accommodate the rapid expansion of the major cities. However, the construction industry has experienced a lot of occupational injuries, and construction work is considered one of the most dangerous occupations due to the dynamic and temporary nature of the workplace [2–4]. Specifically, most construction work takes place outdoors and work conditions (e.g., temperature, humidity, and light conditions) and the number of required workers frequently changes, which increases the difficulty of safety management. According to the Korea Occupational Safety and Health Agency (KOSHA), fatal injuries of construction workers have been increasing since the year 2000. In 2018, the construction industry experienced

the highest number of fatal accidents, accounting for 49.95% of total fatalities in South Korea [5]. The safety of construction workers is a global issue. In 2011, the construction industry employed almost 7% of the world's workforce, while the industry recorded 30–40% of the world's fatal injuries [6]. There are many different contributing factors associated with the occurrence of fatal accidents [7–9], but one of the major issues is the lack of appropriate countermeasures to reduce the risk of accidents in construction environments [10]. The South Korean government legislated the occupational safety and health expense law to ensure companies secured a minimum safety management budget, the size of which depends on the size and type of the construction project. The budget for safety costs for a general construction project must equal or exceed 1.86% of the total material and labor costs. Construction projects that have budgets less than 500 million Korean republic Won (KRW) are required to have a higher ratio (e.g., 2.93%) compared to that of projects with more than 500 million KRW of construction costs, to help protect workers in smaller construction projects.

The safety expense law aims to enhance the safety of construction workplaces and restricts the use of the safety budget to certain types of expenses. Specifically, the safety budget is only available for performing safety management activities such as purchasing personal protective equipment, safety education, safety consulting by experts, and so on. The safety expense law also includes a regulation that requires a construction firm to spend a certain amount of the safety budget according to the progress of the construction project. This regulation is adopted to effectively protect workers from an accident by requiring the firm to spend money on safety, but the requirement is insufficient for accident prevention. The regulation enforces construction firms to spend more than half of the budget before completion of 70% of the construction project. Under these conditions, safety budgets are spent either at the early or the late stages of the construction project. In addition, safety related studies argue that safety-cost planning in practice does not consider the risk of ongoing activities, which is not suitable to effectively prevent accidents at construction sites [11,12]. To reduce the accident risk and protect construction workers from accidents, safety costs should be allocated based on the risk of the on-going construction activity. In addition, the safety budget needs to be allocated while considering various safety-related risk factors such as the number of workers, historical accident records, and other site conditions. In short, there is a definite need to analyze how to effectively use the safety budget to decrease the risk of accidents and to advance the safety of construction sites.

To address current issues in safety-cost planning, this study first investigated the budgeting and execution of safety and health expenses by conducting a case study analysis of 10 apartment construction sites in South Korea. The results from this case study illustrated the current problems in safety-cost budgeting and executions in practice. In addition, data on factors related to accident risk (e.g., cost, schedule, number of workers on-duty) were also collected from case study sites to comprehensively assess the accident risk during construction projects. The accident risk index was lastly proposed to consider the abovementioned risk factors (i.e., construction schedule, construction costs, number of workers, and historical accident records) in the effective planning of budgets for safety costs. The recommendation for the expenditure of the safety budget is presented to facilitate the outcome of this study and help safety practitioners perform effective safety management activities. The remaining sections of the manuscript are organized as follows. The research background reviewed the previous research on accident prevention, safety management activities, and safety cost budgeting. The material and method section describe how to compute the accident risk index and analyze the trend of safety cost budgeting in apartment constructions. The remaining sections explain the results of the analysis and the conclusion of this research.

## 2. Literature Review

The safety of a construction worker is an important issue in many nations, since construction environments are complex and often unsafe due to their dynamic and labor-intensive characteristics (e.g., largely relying on a worker's labor and heavy equipment) [13]. In addition, construction works are often placed at elevations that could highly increase the risk of accident. The weather conditions are other factors that could adversely affect the safety of a worker on a construction site. As a result, the construction industry has recorded a poor safety performance and experienced a lot of fatal and non-fatal injuries [14]. According to Shafique and Rafiq (2019), the construction industry accounted for around 20% of the occupational fatalities that occurred in Japan, United Kingdom, the United States, and Hong Kong in 2017 [15]. The research from the Workplace Safety and Health institute (WSH) illustrated that construction sites in Asia experienced a greater number of fatal injuries compared to the sites in other continents. In South Korea, a large number of fatal injuries also occurred during construction [5]. Among the various types of accidents that can occur, falling from a great height is the leading cause of fatalities [16] and therefore the prevention of fall accidents is a critical issue for the safety of construction workers [17–20]. The Occupational Safety and Health Organization (OSHA) in the United States forced employers to provide a fall protection system that can prevent fall accidents when the work surface is located over 1.82 m (i.e., 6 feet) above the ground or a lower floor. The guardrail, safety net, and personal fall arrest system are the examples of the fall protection systems and the employees should not start their works before the installation of such fall protection systems in the workplace.

The occurrence of accidents are related to the various factors and previous research emphasized the significance of two accident-related factors, which are unsafe work environments and psychological/behavioral characteristics of an individual worker [21–23]. The above-mentioned fall protection systems are used for improving the safety of the workplace by modifying the work environments. However, an individual's unsafe behavior is a persisting issue, since a large portion of construction works are performed by a worker's hand or by manually using equipment. Behavior-based safety is the one solution that can prevent accidents originating from a worker's unsafe behaviors [24]. Several previous studies indicated that more than 80% of accidents could be attributed to a worker's unsafe behaviors [25–27]. Ascending/descending using stairs without holding a guardrail is an example of a worker employing unsafe behavior. Poor housekeeping in a construction site is a result of unsafe worker behavior that can involve neglecting activities such as storing equipment or cleaning the floor after completing a task. A worker's unsafe behaviors are often triggered by factors such as needing to meet excessive production targets, a competitive atmosphere, a tight construction schedule and a lack of available resource [28]. Also, inappropriate safety management activities conducted by the safety manager could strengthen a worker's attitude toward unsafe behavior during the construction process. In short, the prevention of accidents during construction is a complicated issue and it requires various efforts to be addressed including the improvement of the work environment, safety related education, safety observations, and proper safety interventions. Also, financial resources for safety management activities are vital for the success of accident prevention in construction.

Safety management is an important research topic to decide the proper amount of safety costs and to quantity the risk of accidents occurring for effective safety budget allocations. A study by Pinto et al. (2011) analyzed the financial costs of construction-related accidents. The occupational injuries assessed did not only badly affect the worker's well-being but also adversely affected the cost of the construction projects due to requiring high medical costs [29]. According to the analysis from Everett and Frank (1996), the occupational injuries from non-residential construction projects account for 7.9% to 15% of total construction costs [30]. This research illustrated that the prevention of occupational injuries is essential for both a worker's safety and the success of a construction project. The risk of accidents occurring is commonly defined as the significance of these risky

events in terms of the occurrence probability and the severity of a potential injury [31–33]. The previous risk assessment studies utilized the analytic hierarchy process (AHP) technique—which is a structured multi-attribute decision method for complex decision making—while maintaining consistency of experts' judgements [34]. The AHP technique has been utilized to rank various safety factors by assessing the severity and the probability of accidents [35] or injuries [36]. Such a risk assessment technique is beneficial for effectivity quantifying the risk level of accident-related factors, but the process largely relies on subjective decisions, which are prone to being biased. Also, assessment results from the previous studies are not suitable for safety cost budgeting at the project level, since they were conducted to rank different types of hazards. Further research on developing a safety risk index that includes the influences of the factors related to the risk of accidents is essential for effective safety cost budgeting at the project level.

Occupational safety and health expenses were legislated by the Korean government under the law to require securing appropriate budgets for safety management activities. The amount of safety costs required are determined based on the type and size of the relevant construction projects. Specifically, the safety budget is a proportion of the total labor and material costs. Table 1 presents the 15 categories for safety cost budgeting, which is classified by the type of works being conducted (i.e., 5 different construction types) and the total amount of construction costs (i.e., 3 different cost ranges). The usage of the safety cost is limited to the (1) labor costs of safety managers, (2) costs for protective equipment, (3) costs for personal protective equipment, (4) external safety inspection or consulting fees, (5) costs for safety education, (6) health care fees for workers, (7) safety technology fees, and (8) costs for the safety organization to be established in the construction headquarters. The safety costs play an important role in enhancing the safety level of the construction site; however, the allocations of the safety budget are still not optimal in terms of the prevention of accidents in the construction industry. For example, the risk levels for construction works are different depending on the stage of the construction project. As previously described, the risk level of falling accidents is not significant at the initial stage of the construction project, since the excavation and the foundation works are the main construction activities being completed at this stage. Also, the most of construction works at the late stage of the construction project are the finishing works, which are generally performed when the structural works of the building are completed. As a result, the risk of falling accidents at the late stage would not be significant compared to during the middle stage of the construction project. A safety cost expenditure guideline is beneficial to effectively allocate the safety budget for accident prevention and prevent occupational injuries. In this context, this study firstly investigated the expenditures of safety budgets using data from apartment construction projects and proposed an accident risk index and safety cost expenditure guideline to enhance the safety of construction workplaces and protect construction workers.

**Table 1.** Occupational safety and health expense rates by type and size of construction projects.

| Construction Types | Sizes of Construction Projects | | | Projects Required to Hire a Safety Manager ** |
|---|---|---|---|---|
| | Smaller Than 500 million KRW * | Between 500 million KRW * and 5000 million KRW * (Baseline Cost) | More Than 5000 million KRW * | |
| General Construction (A) | 2.93% | 1.86% (5.349 million KRW *) | 1.97% | 2.15% |
| General Construction (B) | 3.09% | 1.99% (5.499 million KRW *) | 2.10% | 2.29% |
| Heavy Construction | 3.43% | 2.35% (5.4 million KRW *) | 2.44% | 2.66% |
| Railway Construction | 2.45% | 1.57% (4.411 million KRW *) | 1.66% | 1.83% |
| Special Construction | 1.85% | 1.20% (3.25 million KRW *) | 1.27% | 1.31% |

* KRW: Korean Republic Won. ** defined by the Occupational Safety and Health Act in South Korea.

## 3. Materials and Methods

### *3.1. Occupational Safety and Health Expenses in Case Study*

This research study analyzed the expenditures on occupational health and safety expenses in apartment construction projects. The number of housing units, total construction periods, and total construction costs were considered during the selection of the construction sites. A total of 10 construction sites with a similar size, number of construction periods, and construction dates (between 2015 and 2017), were selected for the case study analysis (See Table 2 for details) to avoid possible distortionary issues hindering comparisons, such as inflation and temporal material shortages during the construction process.

**Table 2.** Information on the apartment construction sites for the case study.

| | Median | Min | Max |
|---|---|---|---|
| Number of Housing Units (EA) | 356 | 303 | 410 |
| Construction Periods (Months) | 28 | 24 | 32 |
| Construction Costs (million KRW) | 37,900 | 32,500 | 45,000 |
| Completion Date (YYYY-MM) | 2016-05 | 2015-02 | 2017-11 |

The 2.29% proportion of material and labor costs for construction projects were applied for the occupational health and safety expenses in construction sites for the case study. In the analysis, safety expenditures were categorized as (1) labor costs for safety professionals, (2) costs for protective devices and facilities for safety activities, (3) costs for personal protective equipment, and (4) costs for other safety related activities (e.g., safety consulting, safety education, and so on). The details of the safety budgeting and expenditures are summarized in Table 3.

**Table 3.** Budgeting and expenditure for occupational safety and health expenses from 10 case study sites.

| Case Study (10 Sites) | Safety Cost Budgeting (Million KRW) | | | Safety Cost Expenditure Ratio (%) | | | |
|---|---|---|---|---|---|---|---|
| | Labor Costs | Material Costs | Safety and Health Expenses | Labor Costs | Protective Device/Safety Facility | Personal Protective Equipment | Other Safety Activities |
| Site A | 12,478 | 13,212 | 588.3 | 48.7 | 32.6 | 11.2 | 7.5 |
| Site B | 11,700 | 11,700 | 535.9 | 46.3 | 35.7 | 11.9 | 6.1 |
| Site C | 12,639 | 12,639 | 622.7 | 44.9 | 35.4 | 13.2 | 6.5 |
| Site D | 15,750 | 15,750 | 721.4 | 50.3 | 31.8 | 12.7 | 5.2 |
| Site E | 12,032 | 12,032 | 611.3 | 46.2 | 34.5 | 14.5 | 4.8 |
| Site F | 15,365 | 15,365 | 723.8 | 47.4 | 32.3 | 12.5 | 6.8 |
| Site G | 11,154 | 11,154 | 557.3 | 51.8 | 30.6 | 11.4 | 6.2 |
| Site H | 14,580 | 14,580 | 677.1 | 46.1 | 33.2 | 14.6 | 6.1 |
| Site I | 12,578 | 12,578 | 560.9 | 46.5 | 32.0 | 13.9 | 7.6 |
| Site J | 14,972 | 14,972 | 658.6 | 50.4 | 33.6 | 11.1 | 4.7 |

Most of the safety budget was spent on the labor of safety professionals, protective devices, and personal protective equipment. On average, 47.9% of the safety budget was spent on the labor of safety professionals. The costs for protective devices and personal protective equipment were determined to be 33.2% and 12.7%, respectively. The other safety activities were 6.2% of the total safety budgets. As shown in Table 3, the labor costs and protective device/safety facilities were the two major components of the safety budget (81.1%) while other safety activities accounted for only a small portion of the budget (18.9%). Considering the fact that the labor costs would be spent evenly during the entire construction period, the expenditure trends (as shown in Figure 1) revealed that safety management related activities, including installation of the protective devices and purchasing the personal protective equipment, can be performed irregularly and this would increase the risk of accidents occurring on construction sites. The analysis results

demonstrate the need for better safety budget planning to enhance the safety level of the construction sites. This study introduced the accident risk index to be incorporated with construction site information (i.e., current progress, the number of workers, and construction costs) and historical accident records (i.e., the number of accidents associated with each activity) in safety cost budgeting. The accident risk index can be calculated in accordance with the construction progress (i.e., 0% to 100%) to determine the appropriate expenditure for occupational safety and health expenses at the project level.

### *3.2. Accident Risk Index*

The proposed index in this study considers: (1) the number of major accidents, (2) the number of workers on duty, (3) the required working time for the construction work, and (4) the amount of progress payments needed to measure the risk of accidents occurring. These factors are decided based on the fact that the risk level of an accident occurring during a certain stage of the project on a construction site is related to the number of workers on-duty, the progress of the project, the amount of payments that have been made linked to the progress of the project, and previous accident records. In fact, the factors related to the occurrence of accidents are numerous and the selection of these factors is highly related to the risk assessment level. Specifically, risk assessment could be performed with the various risk factors being assessed at different management levels (e.g., the task, activity, and project) and the level of risk management would affect the type of risk factors to consider. As examples, the task location, age of the workers, previous injury records, and the levels of experience could be included when managing the risk of accidents occurring at the task level. However, this study specifically aimed to assess risk management at the project level and the corresponding risk factors that are the information available at that level. The research from Gurcanli et al. (2015) utilized the total construction cost, number of required workers, required construction time, and the risk of completing various activities to decide a reasonable safety budget amounts and budget allocation for construction projects [37]. Similar to the previous study, four attributes were utilized in this study (i.e., the progress ratio, cost ratio, worker ratio, and risk ratio) and such attributes are measured by Equations (1)–(4). The progress ratio is the proportion of the required working time for an activity to the total construction time. The cost ratio is the proportion of construction costs for an activity to the total construction costs. The worker ratio is the proportion of the number of required workers for an activity to the total number of construction workers. The risk ratio is the proportion of the number of major accidents while completing an activity to the total number of major accidents in historical accident data. The accident risk index, representing the risk level of accidents at a certain period by combining the four aforementioned attributes, is calculated by Equation (5):

$$\text{Progress Ratio(i)} = \text{Construction Time(i)}/\text{Total Construction Time} \times 100 \quad (1)$$

$$\text{Cost Ratio(i)} = \text{Construction Cost(i)}/\text{Total Construction Cost} \times 100 \quad (2)$$

$$\text{Worker Ratio(i)} = \text{Construction Worker(i)}/\text{Total Construction Worker} \times 100 \quad (3)$$

$$\text{Risk Ratio(i)} = \text{Number of Major Accidents(i)}/\text{Total Number of Major Accidents} \times 100 \quad (4)$$

$$\text{Accident Risk(i)} = [\text{Progress Ratio(i)} + \text{Cost Ratio(i)} + \text{Worker Ratio(i)}] \times \text{Risk Ratio(i)} \quad (5)$$

where Construction Time(i), Construction Cost(i), Construction Worker(i), and Number of Major Accidents(i) are the construction time, construction costs, number of workers, and the number of major accidents for each activity or period(i), respectively.

The statistical data published by the KOSHA was utilized to calculate the risk ratio by measuring the number of major accidents that occurred during construction. The major accidents were defined by the KOSHA as accidents that resulted in a fatality or an illness requiring medical care after more than 3 months, or accidents where injuries affected more than 10 workers at once. This study utilized the historical accident data collected between 2014 and 2016 and a total of 118 major accidents were recorded. Laborers were recorded to have the largest number of major injuries (i.e., 27 accidents) while scaffolders and carpenters had the next highest numbers (i.e., 21 and 17 injuries, respectively). This study utilized the progress percentage, representing 10 different levels of construction progress (e.g., 10%, 20%, and 100%) from the beginning to the end of the construction project, to ease the implementation of the proposed accident risk index.

## 4. Case Study Data Analysis

### *4.1. Trends of Safety Expenditures and Computations for Progress, Cost, Worker, and Risk Ratios*

The expenditure on safety costs was reorganized corresponding to the construction project progress (e.g., every 10% progress) to investigate the problems for the expenditures in practice. The expenditures from 10 case study sites were then analyzed and detailed results are presented in Figure 1 and Table 4. As shown in Figure 1, more than 30% of safety budgets were spent before 20% of the projects' completion had occurred and relatively small amounts of safety budgets were used for 30% to 70% of the projects' progress. However, according to the historical accident data from the KOSHA, more than 50% of the major accidents occurred between 30% and 70% of the projects' completion (as shown in Figure 2). Such facts illustrated the problem of current safety cost expenditures and the need for better safety budget planning while considering the risk of accidents occurring to effectively prevent a major accident on a construction site.

**Table 4.** Details of safety cost expenditure corresponding to construction progress (Unit: thousand KRW).

| Case Study (10 Sites) | Construction Progress | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **10%** | **20%** | **30%** | **40%** | **50%** | **60%** | **70%** | **80%** | **90%** | **100%** |
| Site A | 105.89 | 94.13 | 41.18 | 35.30 | 41.18 | 41.18 | 47.06 | 46.06 | 76.48 | 58.83 |
| Site B | 75.02 | 85.74 | 48.23 | 37.51 | 26.79 | 32.15 | 37.51 | 69.66 | 80.38 | 42.87 |
| Site C | 87.18 | 93.41 | 49.82 | 49.82 | 43.59 | 56.04 | 56.04 | 68.50 | 80.95 | 37.36 |
| Site D | 79.35 | 115.42 | 64.92 | 50.49 | 43.28 | 64.92 | 72.14 | 72.14 | 93.78 | 64.92 |
| Site E | 73.36 | 91.70 | 61.13 | 48.91 | 30.57 | 48.91 | 67.25 | 73.36 | 73.36 | 42.79 |
| Site F | 123.05 | 101.34 | 65.14 | 43.43 | 50.67 | 57.91 | 57.91 | 72.38 | 86.86 | 65.14 |
| Site G | 94.74 | 78.02 | 44.58 | 39.01 | 33.44 | 44.58 | 39.01 | 61.30 | 78.02 | 44.58 |
| Site H | 108.33 | 108.33 | 60.93 | 54.16 | 33.85 | 54.16 | 67.70 | 67.70 | 74.47 | 47.39 |
| Site I | 78.53 | 95.36 | 61.70 | 44.87 | 28.05 | 33.65 | 44.87 | 72.92 | 67.31 | 33.65 |
| Site J | 98.80 | 105.38 | 65.86 | 46.11 | 39.52 | 46.11 | 39.52 | 79.04 | 85.62 | 52.69 |

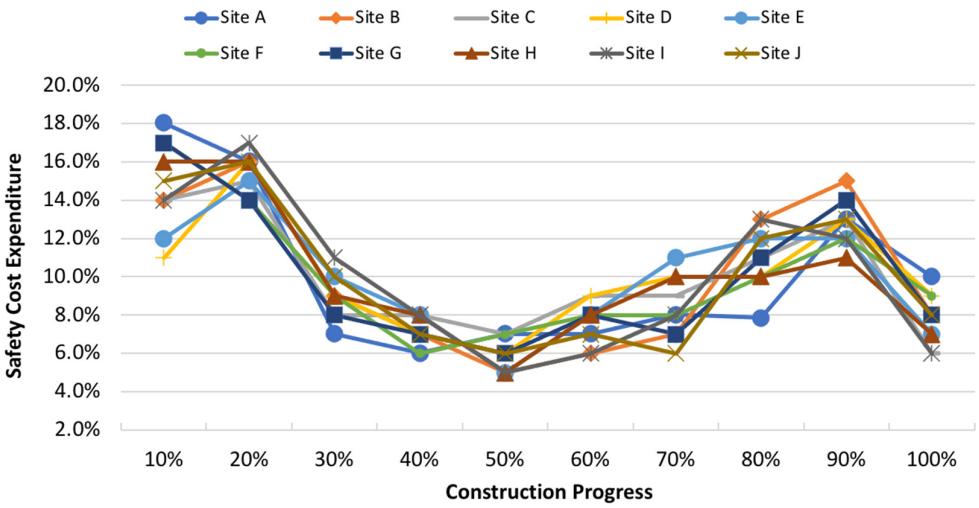


**Figure 1.** Expenditures on occupational safety and health expenses in apartment construction.

Data for attribute computations from the construction sites were also reorganized. The required time for the completion of an apartment construction was 730 days on average. The largest amount of project time (i.e., 146 days) was spent on the 0% to 10% progress stage, which includes the excavation and foundation works. The second largest time (i.e., 102 days) was required for the 80% to 90% progress stage, which is the period for the fishing works. The cost ratio was analyzed similarly, and the results showed that costs were evenly spent during the whole construction progress. The largest cost ratio is 12.5% at the end of the project (i.e., the 90% to 100% stage) and the lowest cost ratio is 6.0% between 20% and 30% progress.

The worker ratio, which is the ratio of the number of workers on-duty to the total number of workers, was further analyzed to investigate the change of the required workforce corresponding to the construction progress. On average, a total of 726 workers participated in an apartment construction project and the construction progress from 50% to 60% employed the largest number of workers, which was 18.2% of the total number of workers (See Table 5 for details). This construction period was the moment when both structural and finishing works were performed simultaneously. Similar to the historical accident records, construction works between 40% and 80% progress employed 74.1% of the total number of workers but corresponding safety expenditure was only 40.1% (See Figures 1 and 2 for details). This fact might be one of the reasons why the construction industry recorded a high rate of accidents, considering the comparably low safety cost expenditure for these periods.

**Table 5.** Number of workers on-duty corresponding to construction progress.

| Case Study (10 Sites) | Construction Progress | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 10% | 20% | 30% | 40% | 50% | 60% | 70% | 80% | 90% | 100% |
| Site A | 30 | 45 | 56 | 90 | 110 | 136 | 120 | 91 | 29 | 23 |
| Site B | 25 | 33 | 53 | 75 | 89 | 95 | 108 | 92 | 24 | 22 |
| Site C | 33 | 50 | 58 | 91 | 113 | 141 | 121 | 95 | 30 | 25 |
| Site D | 36 | 51 | 67 | 103 | 119 | 156 | 127 | 101 | 49 | 28 |
| Site E | 28 | 42 | 55 | 85 | 108 | 135 | 115 | 92 | 39 | 21 |
| Site F | 33 | 47 | 63 | 96 | 101 | 142 | 119 | 97 | 42 | 26 |
| Site G | 26 | 38 | 52 | 76 | 94 | 115 | 102 | 83 | 31 | 19 |
| Site H | 35 | 51 | 59 | 95 | 117 | 153 | 127 | 98 | 32 | 25 |
| Site I | 26 | 36 | 51 | 72 | 91 | 99 | 104 | 90 | 30 | 20 |
| Site J | 21 | 49 | 62 | 98 | 115 | 158 | 131 | 99 | 35 | 21 |

The risk ratio was lastly computed from the historical accident records collected between 2014 and 2016. The largest risk ratio is observed during the 40% and 50% construction progress stage that accounts for 20.34% of the major accidents (See Figure 2 for details). The construction period from 40% to 80% showed a higher accident risk (i.e., 55.08%) compared to other periods but safety cost expenditure during this period (i.e., 29.01%) was relatively small, as previously described. These facts demonstrate the existing safety cost expenditure problem and illustrate the necessity of an accident risk index for better safety budgeting for apartment construction projects.

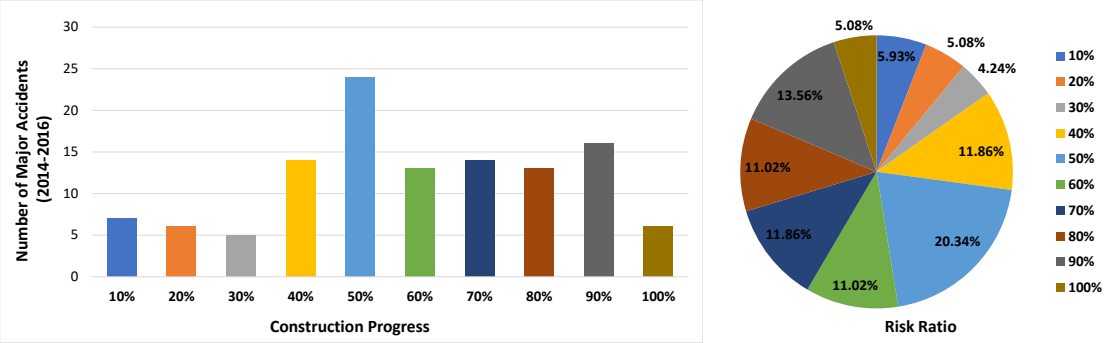


**Figure 2.** Number (left) and proportion (right) of major accidents that occurred between 2014 and 2016.

The computed ratios associated with the accident risk are summarized in Table 6. Also, the ratios and the trend of safety expenditures are visualized in Figure 3. The trend of the safety expenditure seems to be similar to the progress ratio, while the worker ratio shows a similar pattern to the risk ratio. These results would imply that the current expenditure of the safety cost is related to the required construction time, while the accident risk has a relationship with the number of workers on-duty. These results also indicate the need for an accident risk index to comprehensively assess various safety related factors and better safety budgeting for construction safety.

**Table 6.** Results of the progress ratio, cost ratio, worker ratio, and risk ratio computations.

| Attributes | | Construction Progress | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **10%** | **20%** | **30%** | **40%** | **50%** | **60%** | **70%** | **80%** | **90%** | **100%** |
| Progress | Avg. (days) | 146 | 37 | 28 | 42 | 62 | 79 | 86 | 95 | 102 | 53 |
| | Ratio (%) | 20.00 | 5.07 | 3.84 | 5.75 | 8.49 | 10.82 | 11.78 | 13.01 | 13.97 | 7.26 |
| Cost | Avg. (million KRW) | 3872 | 2112 | 3168 | 3520 | 4224 | 2816 | 2992 | 4083 | 3942 | 4370 |
| | Ratio (%) | 11.03 | 6.02 | 9.02 | 10.03 | 12.03 | 8.02 | 8.52 | 11.63 | 11.23 | 12.48 |
| Worker | Avg. (workers) | 29 | 44 | 58 | 88 | 106 | 133 | 117 | 94 | 34 | 23 |
| | Ratio (%) | 4.04 | 6.06 | 7.95 | 12.12 | 14.57 | 18.20 | 16.21 | 13.00 | 4.68 | 3.17 |
| Risk | Events | 7 | 6 | 5 | 14 | 24 | 13 | 14 | 13 | 16 | 6 |
| | Ratio (%) | 5.93 | 5.08 | 4.24 | 11.86 | 20.34 | 11.02 | 11.86 | 11.02 | 13.56 | 5.08 |

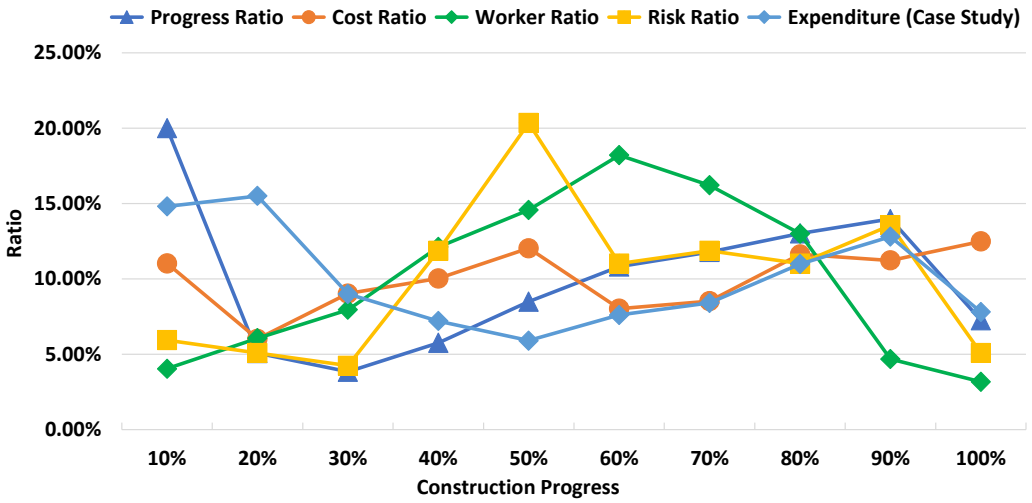


**Figure 3.** Visualization of the computed attributes and safety cost expenditure from case study sites.

### *4.2. Accident Risk Index for Safety Cost Budgeting*

The accident risk index was computed to determine the construction periods containing a high risk of accidents and to effectively budget safety costs. The computation results illustrated that the 40% to 50% progress stage has the highest accident risk (i.e., 717.73), which is equivalent to 22.27% of the total accident risk. The second largest accident risk was observed at the 60% to 70% progress stage and this period contained the second largest number of workers on-duty. The analysis results indicated that construction periods between the 40% to 90% progress stage accounted for 74.08% of the total accident risks. The results also demonstrated the importance of enhancing the safety management efforts during these periods (See Table 7 for details).

**Table 7.** Accident risk index and recommended schedule for the safety cost expenditure.

| | Construction Progress | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **10%** | **20%** | **30%** | **40%** | **50%** | **60%** | **70%** | **80%** | **90%** | **100%** |
| Accident Risk Index | 207.97 | 87.12 | 88.23 | 330.89 | 713.73 | 408.18 | 433.01 | 414.79 | 405.17 | 116.38 |
| Accident Risk Ratio | 6.49 | 2.72 | 2.75 | 10.32 | 22.27 | 12.73 | 13.51 | 12.94 | 12.64 | 3.63 |
| Rank | 7 | 10 | 9 | 6 | 1 | 4 | 2 | 3 | 5 | 8 |

The differences between the accident risk index and safety expenditures were investigated to suggest a guideline for better safety budgeting. The government's safety law forced companies to spend more than 50% and 70% of their construction safety budgets before 70% and 90% completion of their construction project, respectively. Considering the computed risk index figures during construction projects, more detailed recommendations are necessary to effectively utilize the safety budget and increase the effectiveness of the safety management activities to avoid major accidents. As shown in Figure 4, a huge gap between the computed accident risk ratio and the safety expenditures from analysis of the case studies was found in terms of safety cost executions. Considering that the accident risk index represents the risk level of construction environments during certain periods, the safety expenditure guideline rate is calculated by finding the average of the accident risk ratio and the expenditure ratio to consider the importance of completing various on-site safety management activities. For example, safety facilities should be built at the initial stage of the construction projects and purchasing protective equipment, including personal protective equipment, should be completed before the start of certain construction works. Therefore, this study proposed a safety cost expenditure guideline

(shown in Table 8) that consider both the characteristics of construction projects and the risk of accidents occurring for on-going construction projects. Considering that current legislation forces companies to spend more than 50% of their budgeted safety costs before 70% completion of their construction projects, the recommended guideline could help to budget safety costs for high risk periods by considering the accident related factors on construction sites.

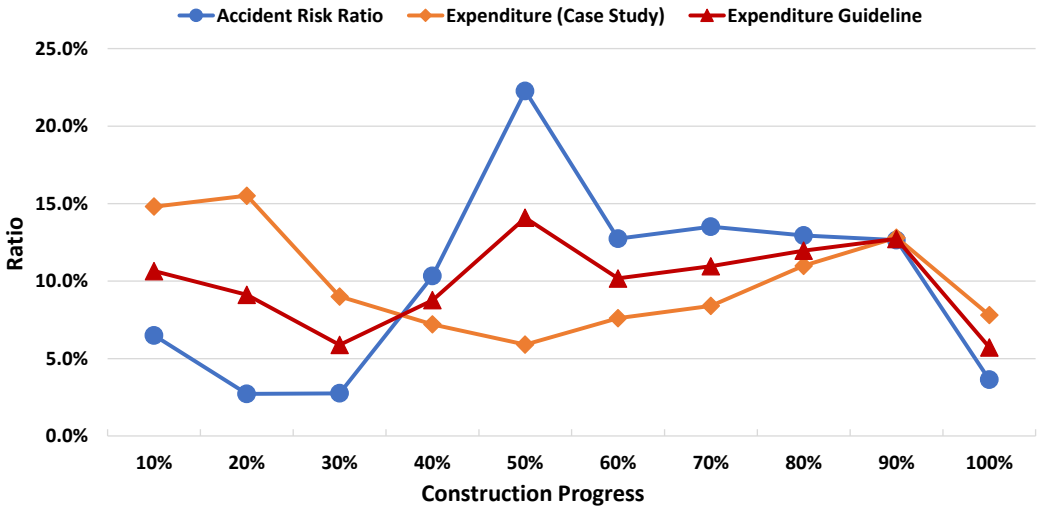


**Figure 4.** Visualization of the accident risk ratio, safety cost expenditure (Case Study), and safety cost expenditure guideline.

**Table 8.** Comparison of the accumulated accident risk ratio, accumulated expenditure ratio from the case study analysis, expenditure guideline rate provided by the occupational safety and health expense law, and expenditure guideline rate recommended by this study.

| | Construction Progress | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **10%** | **20%** | **30%** | **40%** | **50%** | **60%** | **70%** | **80%** | **90%** | **100%** |
| Accident Risk Ratio | 6.49 | 9.21 | 11.96 | 22.28 | 44.55 | 57.28 | 70.79 | 83.73 | 96.37 | 100 |
| Expenditure Ratio (Case Study) | 14.80 | 30.31 | 39.31 | 46.51 | 52.41 | 60.01 | 68.41 | 79.40 | 92.20 | 100 |
| Expenditure Guideline (Law) | | | | | 50 | 50 | 70 | 70 | 90 | |
| Expenditure Guideline (Recommended) | 10.65 | 19.76 | 25.63 | 34.39 | 48.48 | 58.65 | 69.60 | 81.56 | 94.28 | 100 |

## 5. Conclusions

The safety of construction workers is one of the important management factors for ensuring the success of the construction projects. This study investigated the expenditure for safety and health expenses by conducting a case study with 10 apartment construction projects in South Korea. The safety expenditures derived from the case study revealed that most of the mandated safety costs were spent during the initial and the last stages of the assessed construction projects and these expenditures did not correlate well with the risk level of accidents occurring during different stages of apartment construction. At the 50% progress stage, the highest accident rate and the lowest safety expenditure rate were observed, and this is a significant problem for the prevention of accidents on construction sites. In addition, the Occupational Health and Safety Expense Law does not have a detailed expenditure guideline covering the 0% to 40% construction progress stage, although almost 30% of the major accidents occur during this stage. To address these problems, this

study proposed an accident risk index that can incorporate the construction schedule, construction costs, the number of workers on-duty, and historical accident records in the safety cost budgeting. The safety cost expenditure guideline was also developed by combining the characteristics of the safety cost expenditure in practice and the risk level of accidents occurring corresponding to the construction schedule. The proposed accident risk index would offer information about the risk level of on-going construction activities. The recommended expenditure guideline helps to understand the required safety management efforts for the accident preventions corresponding to the construction schedule. Considering that the legal expenditure guideline would not provide any information about the risk of accidents occurring, the proposed guideline in this study will help safety practitioners to perform effective safety cost budgeting while considering the accident risks and enhancing the level of safety management for apartment constructions.

However, several limitations remained to be assessed by future research. There are many contributing factors (e.g., the construction methods, size of construction projects) to the occurrences of accidents on construction sites, but this study utilized only small sets of attributes for the computation of the accident risk index and the development of the safety cost expenditure guideline. Future research would be essential to investigate the relationships between the occurrence of accidents and various accident-related factors in apartment construction. In addition, this study performed safety cost budgeting corresponding to the construction schedule. Another important issue is how to utilize the safety costs for enhancing the safety of construction sites. The effectiveness of safety management activities needs to be further investigated to find the optimal use of safety budgets to increase construction safety.

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