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Construction Equipment Accidents by Time

Hyunho Jung[1], Youngcheol Kang[2]*, Sanghyeok Kang[3]

[1] *Graduate Research Assistant, Department of Architecture and Architectural Engineering, Yonsei University,* E-mail address: jhh1234@yonsei.ac.kr
[2] *Assistant Professor, Department of Architecture and Architectural Engineering, Yonsei University,* E-mail address: yckang@yonsei.ac.kr
[3] *Associate Professor, Department of Civil and Environmental Engineering, Incheon National University,* E-mail address: lifesine@inu.ac.kr

Abstract: This paper investigates the construction equipment accidents by time. Construction sites are unique with many different hazardous conditions which cause accidents. According to the Occupational Safety and Health Administration (OSHA), accidents related to construction equipment are one of the most leading causes of fatal injuries in the construction industry. While there have been many studies investigating the equipment-related accidents, few research studies provided in-depth analyses about the time that accidents frequently occurred. By using the OSHA accidents data collected between 1997 and 2012, this paper analyzed the accidents data by time, equipment type including excavator, backhoe, dozer, and crane, accident cause, and injury class. The analyses revealed that the time window with most accidents was between 13:00 and 13:59. In terms of the injury class, the time windows with the highest numbers of equipment accidents were between 13:00 and 13:59 and between 11:00 and 11:59 for fatality and hospitalization, respectively. For the accident causes, equipment operator's error was the highest number of accident causes. It is expected that findings from the analyses can be used to more strategically develop management plans and guidelines to prevent accidents related to construction equipment to practitioners.

Key words: construction equipment accident, safety, equipment, accident time, accident frequency

1. INTRODUCTION

The construction industry has been regarded as one of the most hazardous industries [1]. Maccollum [2] pointed out that the US construction industry accounts for approximately 7% of the total workforce, but construction worker deaths account for about 20% of all industrial fatalities. For over two decades, numerous studies have been conducted to reduce accidents in the construction industry [3-6]. Unfortunately, considering the fact that 1,008 out of 4,779 fatalities occurred in the construction industry in 2018 [7], the statistics remain very similar nowadays.

Among the various causes of work-related injuries and fatalities in the construction industry, those related to construction equipment have been one leading cause in the U.S. [8]. One-quarter of the fatal accidents in construction industry are the result of collisions, rollovers, stuck-by accidents, and other equipment-related accidents [1]. In 2014, the Bureau of Labor Statistics reported that the construction industry experienced 902 fatalities of which 15.2% (137 fatalities) resulted from workers coming into contact with objects or construction equipment [9]. Among the 92 construction equipment fatalities, 27 cases were related to excavating machinery such as backhoe, bulldozer, and excavator and 14 cases were related to cranes [10].

Regarding the accidents related to construction equipment, while there have been many studies investigating the technologies preventing accidents [11-14] and causes of accidents [15-18], few studies have investigated when, how frequently, and how severely accidents related to construction equipment have occurred.

This study investigates the accidents related to construction equipment by time. From 20,997 accidents recorded between 1997 and 2012 in the Occupational Safety and Health Administration (OSHA) Integrated Management Information System (IMIS) database, this study extracted data containing equipment type and time that the accident occurred. From those data, this study identified the time that accidents occurred for four types of equipment including backhoe, crane, dozer, and excavator. In addition, this study presents the accidents by time and major injury class and by time and accident causes categorized by the authors from the description of each accident in the dataset. The findings of this study contribute to helping practitioners establish more sophisticated plans to prevent construction equipment accidents, which can eventually contribute to reducing such accidents.

2. Literature Review

The section consists of two sub-sections. The first sub-section presents the studies about equipment accidents. The second sub-section summarizes the studies about accidents by time.

2.1. Studies about equipment accidents

Table 1 summarizes the studies investigating safety in construction equipment. As shown in the table, we classified the studies into two categories: preventing technology and accident cause analysis.

There have been many studies proposing technologies to prevent accidents related to construction equipment. For example, Teizer et al. [11] used radio frequency remote sensing and actuating technology to prevent accidents by providing warnings to equipment operators in real time. Golovina et al. [12] presented a method for recording, identifying, and analyzing interactive hazardous near miss situations between workers-on-foot and heavy construction equipment by using spatiotemporal global position system (GPS) data. Zhu et al. [13] proposed filters for predicting workers' movements and mobile equipment to prevent collisions between them.

Another topic being studied about equipment accidents was related to causes of accidents. Beavers et al. [15] studied proximal causes of crane-related fatalities by using the OSHA accident data recorded between 1997 and 2003. Hinze et al. [16] investigated the causes of "stuck-by" accidents and identified the frequencies of each cause categorized in terms of age, material involved, human errors, and environmental factors. Kazan and Usmen [18] used OSHA's earthmoving equipment accident data and investigated the frequencies of accidents in terms of fatal and nonfatal by environmental factors and human factors.

2.2. Studies about accidents by time

There are several research studies including information about the time that certain types of accidents occurred [19-23]. Kines [19] studied the construction workers' falls through roofs. In the study, he found that the time window between 13:00 and 15:59 has the highest number of fatal accidents and that between 10:00 and 12:59 has most serious accidents in the construction industry in Denmark. Huang and Hinze [4] conducted a research study about fall accidents and found that the time window with the least accidents was between noon and 13:00 and that with the most accidents was between 10:00 and 11:00 in the morning and between 13:00 and 14:00 in the afternoon. When investigating the causes of 40 fatal accidents occurred in Singapore construction sites, Ling et al. [20] found that many fatal accidents occurred around tea breaks which are around 10 am, 3 pm, and 12:30 pm. For the safety management of highway construction projects, Kim et al. [21] found that accident occurrence time varies depending on the types of works such as drainage, tunnel, and structure. Because of this time difference, they recommended that safety precautions and management should vary by work type and time. Wong et al. [22] investigated major causes of fatal accidents using falls from height (FFH) data in Hong Kong. The authors found that fatal accidents occurred more frequently between 10:00 and 11:00, 13:00 and 15:00, and 17:00 and 18:00. As the first two time periods are when workers start their works in the morning and afternoon, respectively and the last time period is when workers wrap up their works, the authors asserted that careful inspection should be done when workers start and finish their works. Chiang et al. [23] studied fatal construction accidents in Hong Kong. They found that most fatal accidents occurred in late morning and early afternoon.

We conducted a literature review about equipment accidents and accident time. While there have been many studies for these topics, there has been no study investigating the equipment accidents by time. The current body of knowledge lacks when accidents related to construction equipment occurred, how frequently they occurred, and how severe they are. With the information, practitioners will be able to establish more effective plans to reduce the accidents related to construction equipment.

Table 1. Research studies about equipment accidents

Topic Category	Paper	Contents
Technologies preventing accidents	Teizer et al. [11]	This research presented real-time pro-active RF warning sensing and actuating technology that is able to enhance construction equipment safety.
	Golovina et al. [12]	The study showed method of identifying dangerous near miss situations between workers-on-foot and heavy construction equipment.
	Zhu et al. [13]	This study introduced Kalman filters for predicting the movements of the workers and mobile equipment on construction sites.
	Pradhananga and Teizer [14]	This research presents technology and algorithms that is able to identify equipment activity using GPS data.
Accident Causes	Beavaers et al. [15]	Using crane-related fatal events, this study investigated proximal and distal causes of fatalities which are organized as "stuck by load", "electrocution", "crushed during assembly/disassembly", "failure of boom/cable", "crane tip over", "stuck by counter weight", and "falls"
	Hinze et al. [16]	This paper presented the accident analyses focusing on stuck-by accident through comprehensively analyzing the accidents involved factors and frequency of cases.
	Hinze and Teizer [1]	This paper studied visibility-related fatalities by analyzing OSHA data and examined the root causes of visibility-related fatal accidents.
	Hinze et al. [17]	This study identified the major causes of earthmoving equipment fatalities and studied the relationship between the nature of an accident and moving direction of equipment as well as the role of the victim and direction of moving of equipment.
	Kazan and Usmen [18]	This paper presented variables and their effects on the injury severity for earthmoving equipment. The causal factors in this study were categorized as human factors and environmental factors.

3. Methodology

To investigate when accidents related to construction equipment occur, this study used the OSHA IMIS database. After obtaining the raw data from OSHA, it was necessary to sort out the accident data related to construction equipment. This was done by using some keywords such as backhoe, excavator, crane, trackhoe, and bulldozer. Considering the degree of frequent use in construction sites and the degree of involvement in accidents, this study focuses on four types of equipment: backhoe, crane, dozer, and excavator. Backhoe and dozer are the equipment highly used and frequently involved in accidents [24]. Dozers are included because accidents involved in the equipment showed high level of fatality [8]. Cranes are included as the number of crane accidents is always high [24].

For the accident data related to construction equipment, this study extracted four parameters including accident occurrence time, equipment type, injury class, and accident cause. For each accident, the raw dataset already contained the injury class information such as fatality, hospitalization, and non-hospitalization. The accident occurrence time and accident cause were extracted from the case summary. Figure 1 shows an example. The OSHA IMIS data provide a brief case summary for each accident. From the summary, we captured the time information. For the accidents that relate to the aforementioned four types of equipment, 415 accidents data contain time information.

Case Summaries	Cause	Time	Original Class
At 9:00 a.m. on January 12, 1999, Employee #1 was the operator of an excavator or digger which made an excavation approximately 5 foot deep and 20 foot long. The excavator made contact with an electrical line of 7,000 volts. While trying to get off the machine, Employee #1 stepped onto the ground which resulted in his being electrocuted.	1	9	FATALITY

Figure 1. Data Coding: An Example

In addition to the time information, the cause of accidents was extracted by reviewing the case summaries. We developed seven categories shown in Table 2. Different research team members coded the accident causes individually. Then, each coded cause was cross-checked by the members collectively. If the cause of one accident was coded differently by the research team members, the team reviewed it together and made the final decision.

Table 2. Accident causes coded from the case summaries in the dataset

Number	Accident Cause
1	Equipment operator’s error
2	Accident caused by co-workers
3	Accident caused by site condition such as ground collapse and weather
4	Lack of communication
5	Mechanical defect
6	Lack of prior investigation
7	Inadequate rules and systems

For the data, this study presents the descriptive statistics. In order to discuss the results, several variables used in this study were organized by cross-tabulation. Accidents by time and equipment, by time and injury class, and by time and accident causes are presented in the following section.

4. Results

This section consists of three sub-sections. The first sub-section presents the accident by time and equipment. The second sub-section deals with the accident by time and injury class. The third sub-section discusses the accident by time and accident cause.

4.1. Accidents by time and equipment

Table 3 shows the number of accident by time and equipment type. The table also presents the percentage values calculated as the ratio of the number of accidents occurred in a specific time window and the total number of accidents for each type of equipment. Each time window was set at one hour interval. Considering the time that labors usually work, two time windows from 0:00 to 6:59 and from 19:00 to 23:59 include longer time periods than other windows. There can be some interesting findings from the table. First, the time window with the most accidents was between 13:00 and 13:59, followed by 11:00 and 11:59. More than 25% of equipment-related accidents occurred at these time windows. This finding is consistent with a previous study discussing that accidents occur frequently before and after lunch break in construction sites [23]. Second, for the type of equipment, the crane has the highest number of accidents. It should not be concluded that the crane is the most dangerous equipment. This is because this study did not take the work hours into account. The crane is one of the most widely used equipment on construction sites [25]. Cranes are very expensive yet commonly operated machinery on sites. Thus, it is reasonable to assume that the overall work hour of cranes is higher than the work hours of other types of equipment. If comparing the number of accidents per one workhour, it is possible that other types of equipment have higher values than cranes. When comparing the number of accidents for each time window and types of equipment together, the crane, dozer, and excavator have the highest numbers of accidents between 11:00 and 11:59. The excavator has the same number of accidents between 10:00 and 10:59 as well. For the backhoe, time window between 11:00 and 11:59 shows the highest number of accidents.

Table 3. Accidents by Time and Equipment Type

Time	Equipment				Total
	Backhoe	Crane	Dozer	Excavator	
0:00 ~ 6:59	3 (3.1%)	3 (1.5%)	1 (2.4%)	0 (0.0%)	7 (1.7%)
7:00 ~ 7:59	6 (6.3%)	10 (5.1%)	2 (4.9%)	4 (4.9%)	22 (5.3%)
8:00 ~ 8:59	6 (6.3%)	16 (8.1%)	3 (7.3%)	7 (8.6%)	32 (7.7%)
9:00 ~ 9:59	4 (4.2%)	21 (10.7%)	6 (14.6%)	11 (13.6%)	42 (10.1%)
10:00 ~ 10:59	12 (12.5%)	20 (10.2%)	2 (4.9%)	13 (16.1%)	47 (11.3%)
11:00 ~ 11:59	13 (13.5%)	25 (12.7%)	6 (14.6%)	5 (6.2%)	49 (11.8%)
12:00 ~ 12:59	8 (8.3%)	14 (7.1%)	3 (7.3%)	7 (8.6%)	32 (7.7%)
13:00 ~ 13:59	11 (11.5%)	30 (15.2%)	8 (19.5%)	13 (16.1%)	62 (14.9%)
14:00 ~ 14:59	9 (9.4%)	21 (10.7%)	3 (7.3%)	7 (8.6%)	40 (9.6%)
15:00 ~ 15:59	11 (11.5%)	10 (5.1%)	1 (2.4%)	6 (7.4%)	28 (6.8%)
16:00 ~ 16:59	5 (5.2%)	9 (4.6%)	2 (4.9%)	2 (2.5%)	18 (4.3%)
17:00 ~ 17:59	3 (3.1%)	4 (2.0%)	1 (2.4%)	3 (3.7%)	11 (2.7%)
18:00 ~ 18:59	2 (2.1%)	4 (2.0%)	2 (4.9%)	2 (2.5%)	10 (2.4%)
19:00 ~ 23:59	3 (3.1%)	10 (5.1%)	1 (2.4%)	1 (1.2%)	15 (3.6%)
Total	96 (100%)	197 (100%)	41 (100%)	81 (100%)	415 (100%)

4.2. Accidents by Time and Injury Class

Table 4 summarizes the numbers of accidents by time and injury class. First of all, when comparing the total numbers of accidents by injury class, 230 cases out of 415 were fatalities and only 28 cases ere non-hospitalization. This indicates that accidents involved in construction equipment are substantially severe. The time windows with the highest number of accidents were different by injury class. Those time windows are 13:00 to 13:59, 11:00 to 11:59, and 9:00 to 9:59 for fatality, hospitalization, and non-hospitalization, respectively.

As the time windows with the highest number of accidents vary by injury class, it was thought that the trend of the number of accidents over time may differ by injury class. Figure 2 illustrates the numbers of accidents over time by injury class. As shown in the figure, both the numbers of fatality and hospitalization tend to increase until noon. After the time window between noon and 12:59 which is usually lunch time so the work hours should be reduced, the numbers of accidents increase dramatically between 13:00 and 13:59. Non-hospitalization, on the other hand, has the highest number of accidents between 9:00 and 9:59 and the numbers tend to decrease. One presumable reason why the trends of the numbers of accidents are different by injury class is that the causes of accidents are different.

Table 4. Accidents by Time and Injury Class

Time	Injury Class			Total
	Fatality	Hospitalization	Non-Hospitalization	
0:00 ~ 6:59	3 (1.3%)	3 (1.9%)	1 (3.6%)	7 (1.7%)
7:00 ~ 7:59	10 (4.4%)	8 (5.1%)	4 (14.3%)	22 (5.3%)
8:00 ~ 8:59	17 (7.4%)	13 (8.3%)	2 (7.1%)	32 (7.7%)
9:00 ~ 9:59	22 (9.6%)	13 (8.3%)	7 (25.0%)	42 (10.1%)
10:00 ~ 10:59	26 (11.3%)	18 (11.5%)	3 (10.7%)	47 (11.3%)
11:00 ~ 11:59	23 (10.0%)	25 (15.9%)	1 (3.6%)	49 (11.8%)
12:00 ~ 12:59	20 (8.7%)	10 (6.4%)	2 (7.1%)	32 (7.7%)
13:00 ~ 13:59	38 (16.5%)	22 (14.0%)	2 (7.1%)	62 (14.9%)
14:00 ~ 14:59	23 (10.0%)	17 (10.8%)	0 (0.00%)	40 (9.6%)
15:00 ~ 15:59	13 (5.7%)	12 (7.6%)	3 (10.7%)	28 (6.7%)
16:00 ~ 16:59	12 (5.2%)	5 (3.2%)	1 (3.6%)	18 (4.3%)
17:00 ~ 17:59	9 (3.9%)	2 (1.3%)	0 (0.0%)	11 (2.7%)
18:00 ~ 18:59	7 (3.0%)	3 (1.9%)	0 (0.0%)	10 (2.4%)
19:00 ~ 23:59	7 (3.0%)	6 (3.8%)	2 (7.1%)	15 (3.6%)
Total	230 (100%)	157 (100%)	28 (100%)	415 (100%)

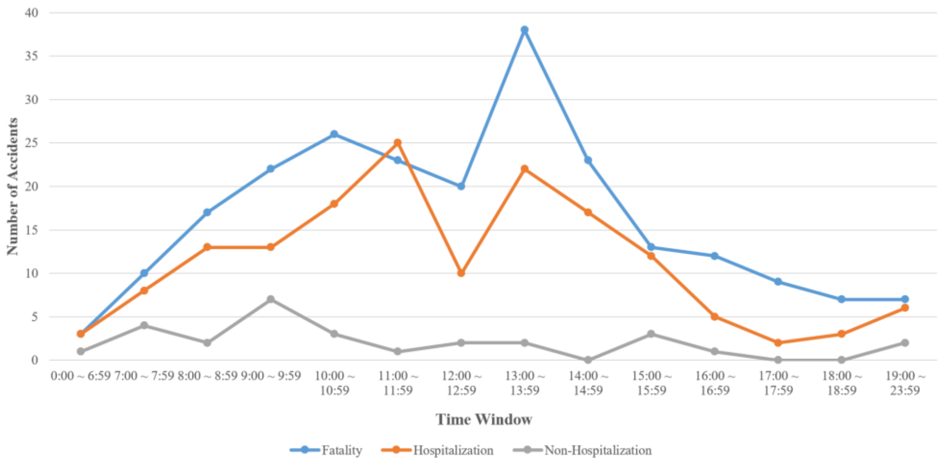

Figure 2. Accidents by Time and Injury Class

4.3. Accidents by Time and Accident Cause

Table 5 presents the accidents by time and accident cause. As not all data contain information about the accident causes, the total number of data in Table 5 is 220. As shown in the table, 90 accidents were involved in the equipment operator's error. It represents 41% of the total number of accidents. The accident cause with the second most accidents is the accidents caused by co-workers. As 44 accidents are categorized as this cause, 134 accidents or 61% of accidents were related to human errors. The number of accidents related to mechanical defect is 38. The number of accidents caused by site condition such as ground collapse and weather is 29. From these values, it can be concluded that construction equipment accidents are more caused by errors of the workers such as operators and co-workers.

Table 5. Accidents by Time and Accident Cause

Time	**Accident Cause**						
	1	**2**	**3**	**4**	**5**	**6**	**7**
0:00 ~ 6:59	1 (1.1%)	1 (2.3%)	0 (0.0%)	0 (0.0%)	1 (2.6%)	0 (0.0%)	0 (0.0%)
7:00 ~ 7:59	7 (7.8%)	4 (9.1%)	1 (3.4%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)
8:00 ~ 8:59	9 (10.0%)	4 (9.1%)	2 (6.9%)	1 (20.0%)	0 (0.0%)	0 (0.0%)	1 (12.5%)
9:00 ~ 9:59	11 (12.2%)	8 (18.2%)	3 (10.3%)	0 (0.0%)	5 (13.2%)	1 (16.7%)	1 (12.5%)
10:00 ~ 10:59	11 (12.2%)	5 (11.4%)	3 (10.3%)	0 (0.0%)	4 (10.5%)	1 (16.7%)	1 (12.5%)
11:00 ~ 11:59	12 (13.3%)	6 (13.6%)	2 (6.9%)	1 (20.0%)	6 (15.8%)	1 (16.7%)	1 (12.5%)
12:00 ~ 12:59	7 (7.8%)	2 (4.5%)	4 (13.8%)	1 (20.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)
13:00 ~ 13:59	11 (12.2%)	1 (2.3%)	8 (27.6%)	1 (20.0%)	9 (23.7%)	2 (33.3%)	1 (12.5%)
14:00 ~ 14:59	6 (6.7%)	4 (9.1%)	2 (6.9%)	0 (0.0%)	7 (18.4%)	0 (0.0%)	1 (12.5%)
15:00 ~ 15:59	6 (6.7%)	1 (2.3%)	2 (6.9%)	0 (0.0%)	1 (2.6%)	0 (0.0%)	2 (25.0%)
16:00 ~ 16:59	4 (4.4%)	3 (9.1%)	1 (3.4%)	0 (0.0%)	1 (2.6%)	0 (0.0%)	0 (0.0%)
17:00 ~ 17:59	1 (1.1%)	1 (2.3%)	0 (0.0%)	1 (20.0%)	3 (7.9%)	0 (0.0%)	0 (0.0%)
18:00 ~ 18:59	2 (2.2%)	3 (6.8%)	1 (3.4%)	0 (0.0%)	1 (2.6%)	0 (0.0%)	0 (0.0%)
19:00 ~ 23:59	2 (2.2%)	1 (2.3%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	1 (16.7%)	0 (0.0%)
Total	90 (100%)	44 (100%)	29 (100%)	5 (100%)	38 (100%)	6 (100%)	8 (100%)

When interpreting the trend shown in Figure 2, it was thought that one possible reason why the time windows with most accidents were different by injury class is different accident causes. Figure 3 illustrates the accidents by time and accident cause. Note that we removed the causes with less than 10 accidents in the figure. There can be two interesting findings from the figure. First, trend over time for the non-hospitalization accidents in Figure 2 is similar to that for the accidents caused by co-workers in Figure 3. The number of accidents for both is the highest between 9:00 and 9:59 and tends to decrease with time. This study cannot validate the causal relationship between the two. But, it may be interesting to further investigate the relationship in future studies. Second, the time windows with the most accidents are between 11:00 and 11:59 and between 13:00 and 13:59. One can conjecture that reduced concentration due to continued work and drowsiness after lunch can be the reasons why those time windows have high numbers of accidents. As those reasons are related to human errors, the number of accident causes related to human errors such as operators' error and accidents caused by co-workers should be high at those time windows. As shown in Figure 3, equipment operator' error shows high number of accidents at those time windows. However, there is only one accident caused by co-workers between 13:00 and 13:59. Surprisingly, accidents related to site condition and mechanical defect show high numbers of accidents between 13:00 and 13:59. As those causes are not human errors, there is no reason for those causes to have high numbers of accidents at the time window. Future studies further investigating the causes of accidents involved in construction equipment are recommended.

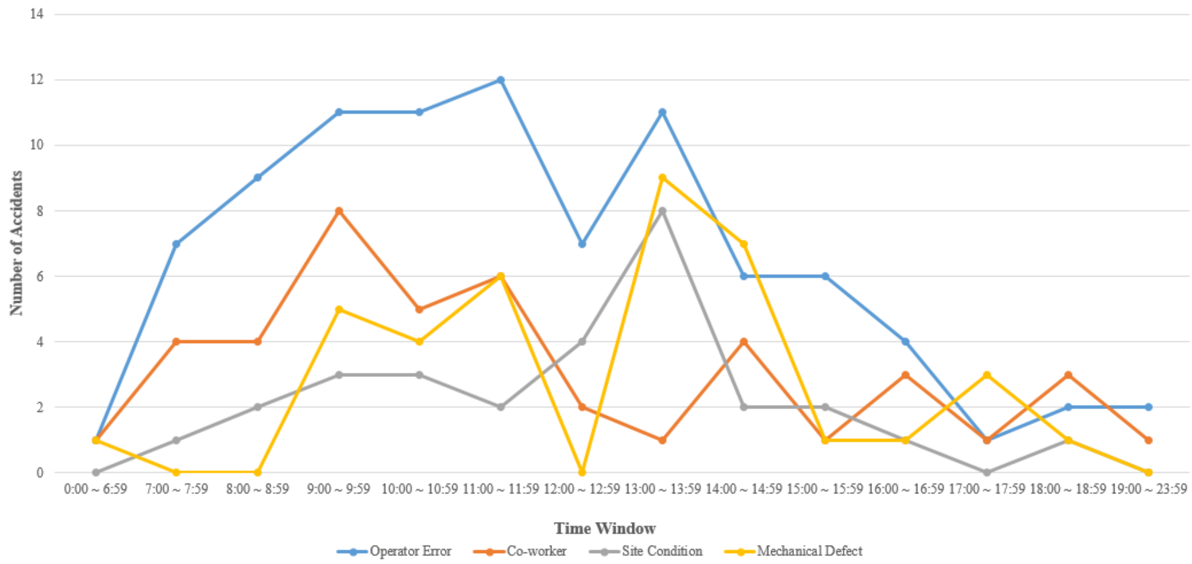

Figure 3. Accidents by Time and Accident Cause

5. Discussion and Conclusion

This study investigated the construction equipment accidents by time. By using the OSHA IMIS accident data, this study analyzed the accidents by time, by time and injury class, and by time and accident cause. From the analyses, this study found that construction equipment accidents were most frequent before and after lunch break, between 11:00 and 11:59 and 13:00 and 13:59. Reduced concentration due to continued work or urge to finish works before lunch break can be presumable reasons for the high number of accidents before lunch break. Drowsiness after lunch can be one possible reason for the high number of accidents after lunch break. As more than 50% of construction equipment accidents are fatality as shown in Table 4, it is very important to reduce these accidents. For this, future research studies about the accidents occurred in these time windows are recommended. This study also found that the time windows with highest number of accidents were different by injury class. The time window with the most fatality accidents is between 13:00 and 13:59. For the accident causes, this study found that more than 60% of construction equipment accidents were caused by human errors such as operator's error and accidents related to co-workers. Thus, research on how to reduce human errors of equipment operators is required for future studies.

The major contribution of this study is to provide information about construction equipment accidents. Understanding when construction equipment accidents occurs, how severe they are, and why they occur should help practitioners establish safety management plans and safety training programs. This leads to reduce the construction equipment accidents that more than 50% of victims die. Specifically, practitioners should focus on reducing human errors after lunch break as those are the cause and time window with most fatalities. One major limitation of this study is the lack of work hours for each time window. With the information, one can study the number of accidents per work hour and this measure should more precisely represent more dangerous time windows. Another limitation is that this study simply presents the numbers of accidents by various dimensions. Future studies conducting statistical analyses with the dataset are recommended.

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