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An Analysis on the Safety Networks and Risk Level of Crane-related Accidents using S.N.A.

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Abstract - *In this study, crane-related safety accidents that occurred on construction sites were analyzed using the data collected by the Korea Occupational Safety and Health Agency (KOSHA), and the networks of crane-related safety accidents were analyzed using the centrality and clustering techniques of SNA analysis. Based on the results of this analysis, the following conclusions were reached. In this study, wide range of machinery and equipment types used on construction sites, only mobile and tower cranes were analyzed in this study with regard to which safety accidents frequently occurred. It is necessary to analyze the networks of safety disasters related to various machinery and equipment types, and thus to establish data for the development of management measures by occupation type through follow-up research.*

I. Introduction

As construction technologies and methods have advanced, high-rise and large-scale buildings have been constructed and a variety of construction machinery and equipment are being utilized to efficiently perform construction tasks. These have contributed to improvements in productivity, and reductions in construction duration and costs. A crane, the most basic type of heavy equipment that is commonly used on construction sites, moves most of the resources (materials, machines, etc.) used on construction sites vertically and horizontally, improving the efficiency of construction tasks.

Aside from these advantages, cranes are also involved in various forms of serious safety accidents due to their high usability. From 1997 to 2013, there were 1,171 deaths caused by crane-related accidents across all industries in the United States; approximately half of this total (544) were in the construction industry [1]. Considering these facts, cranes are clearly very dangerous on construction sites, and the damage to property and life caused by crane accidents can be very serious. On most construction sites, however, heavy equipment is still selected and utilized based only on the experience of supervisors and operators.

Many studies have been conducted with the goal of reducing safety accidents related to construction equipment and cranes, including a study on the development of real-time support systems for the safe operation of mobile cranes [1], an analysis of forecasts of the movement of workers and equipment on construction sites [2], a study on the development of systems for the improvement of the safety of earthwork equipment [3], an in-depth analysis of fatal injuries caused by crane-related accidents [4], and a study on the safety status of tower crane operators [5]. These earlier studies were performed using different methodologies, but involved analyses of less than 100 safety accidents, and did not consider the origins and causes of actual crane-related safety accidents.

Against this backdrop, this study collected data on crane-related accidents that occurred over the past 3 years with the aim of overcoming the limitations of the earlier studies, and the networks and risk level of safety accidents related to each crane type were analyzed using SNA techniques to obtain key risk factors, with the aim of suggesting management measures that can be utilized on construction sites.

II. Analysis Methodology

Social network analysis (SNA) is a methodology used to structurally visualize various types of relations (organizations, humans, knowledge, etc.) using nodes and links, analyze their attributes and predict measures to optimize the structure of analysis targets. The methodology has been utilized in various fields including military science, business administration, pedagogy, engineering science, etc. In this study, of the various SNA methods, centrality and clustering analyses that can analyze a large amount of data and extract key influential factors were carried out to develop a network of crane-related safety accidents. Centrality analysis is used to identify which node is the most important, and to determine the degree of centrality that shows how many key nodes a network is concentrated on. Clustering analysis is used to find out which groups a network is comprised of, and to identify the characteristics of the network through relations between sub-groups. These analysis methods use the following equations.

① Degree Centrality (D.C.)

$$D.C = \frac{d(ni)}{(g-1)} \quad (1)$$

d(ni) = degree of node n, g = the total number of nodes

② Betweenness Centrality (B.C.)

$$B.C = \frac{\sum_{j>k} g\,jk(ni)/gjk}{[(g-1)(g-2)/2]} \quad (2)$$

gjk = the number of geodesics between nodes j and k
gjk(ni) = the number of geodesics between nodes j and k that contain node i

③ Clustering Index (SMI)

$$SMI = \frac{Outside\ Link\ Density\ -\ Inside\ Link\ Density}{Inside\ Link\ Density\ -\ Outside\ Link\ Density} \quad (3)$$

III. Analysis of Crane-Related Safety Accidents

Prior to the analysis of the networks of crane-related safety accidents, crane-related safety accidents were analyzed to examine the level of occurrence using the data of 444 safety accidents collected by the Korea Occupational Safety and Health Agency (KOSHA) from 2013 to 2015. The data used in this study were collected from 5 metropolitan cities (Seoul Special Metropolitan City, Daejeon Metropolitan City, Gwanju Metropolitan City, Daegu Metropolitan City and Busan Metropolitan City) where many construction projects have been carried out. The number of safety accident victims by crane type is as shown in Figure 1, and the top 20 occupations that showed the largest number of safety accidents are listed in Table 1. Figure 1 shows that mobile cranes had the highest number of accident victims, followed by tower cranes, overhead travelling cranes and jib cranes; this can be attributed to the fact that mobile cranes are widely used in both small-scale construction sites and large-scale construction sites thanks to their high usability. In addition, Table 1 shows that crane-related safety accidents occurred to general workers the most, followed by construction machinery operators, machinery and equipment workers, framing carpenters and steel benders.

IV. Analysis of The Networks Crane-Related Safety Accidents

To identify the key risk factors for crane-related safety accidents, Net-Miner, a software program for SNA analysis, was utilized. Data on safety accidents related to mobile cranes (315 cases) and tower cranes (106 cases) that occurred most frequently and thus require some kind of urgent remedial response were analyzed in this study only. Risk factors, disaster types, equipment operation conditions, working conditions and workers' occupations were entered as additional variables to analyze the data in detail. Betweenness centrality and clustering techniques were used to analyze the data.

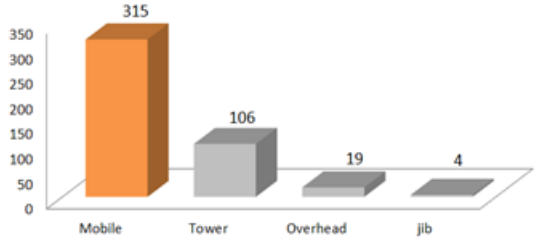

Figure 1. Number of safety accident by crane type (Unit: Person)

General worker	Construction machinery operator	Machinery & equipment worker	Framing carpenter	Steel bender
136	79	42	28	25
Steel worker	Welder	Cable workers	Scaffolder	Plumber
24	17	16	13	9
Indoor wiring electrician	Panel fitter	Construction carpenter	Painter	Foreman
8	8	6	5	4
Landscape worker	Mason	Transmission & distribution electrician	Sash worker	Steel plate worker
4	4	4	2	2

Table 1. No. of crane-related accident victims by occupation type (Unit: Person)

Figure 2 shows the results of a centrality analysis on safety accidents related to mobile cranes. A network of safety accidents was formed centering on nodes including "general worker (degree: 99)," "construction machinery operator (61)" and "steel worker (23)," and it was found that safety accidents frequently occurred while "lifting materials (131)," "installing steel frames (36)" and "leaving a crane (20)." Through clustering analysis, a total of 10 communities were obtained; among them, the modularity of the sixth community was 42.98, showing the strongest cohesion, and thus the sixth community was selected for further analysis. Figure 2 shows that 11 groups were generated within the data of mobile cranes. Groups other than G1 (0.810), G2 (0.859) and G4 (0.653) that showed the highest cohesion (SMI) were excluded from the final analysis. G1 indicates that many accidents (0.2) of being struck by steel frames (0.3) occur when steel workers use a mobile crane to install steel frames (in-out degree: 0.3), and G2 indicates that accidents of "falls (0.2)" frequently occur when machinery and equipment workers "stop (0.3)" and "leave a mobile crane (0.4)." In addition, G4 shows that general workers often experience accidents of being "caught in between (0.2)" when they use a mobile crane to "lift materials (0.3)."

Figure 3 shows the results of a centrality analysis on safety accidents related to tower cranes. A network of safety accidents was formed centering on nodes including "general works (degree: 32)," "machinery and equipment worker (22)," "framing carpenter (11)," and "steel bender (9)," and it was found that safety accidents frequently occurred while "lifting materials (61)," "dismantling (13)" and "installing (9)." Through clustering analysis, a total of 11 communities were obtained; among them, the modularity of the second community was 17.076, showing the strongest cohesion, and thus the second community was selected for further analysis. Figure 3 shows that 2 groups were generated within the data of tower cranes. Since the SMI of the two groups was higher than 0.8 (G1: 0.846, G2: 0.9), both of them were selected for the final analysis. G1 indicates that many accidents of being "caught in between (0.2)" "wire ropes (0.2)" or being "struck by an object (0.3)" occur when general workers use a tower crane to "lift materials (in-out degree: 0.4)," and that framing carpenters often experience accidents of being "hit against a mold (0.2)" when they use a tower crane to "lift materials (0.1)." It was also found that steel benders often experience accidents of being "hit (0.2)" against "a steel frame (0.5)" when they use a tower crane to "lift materials (0.1)." G2 shows that accidents of "collapses (0.4)" frequently occur when machinery and equipment workers "stop (0.5)" and "dismantle a tower crane (0.5)," and that accidents of "falls (0.2)" frequently occur when they "install a tower crane (0.3)."

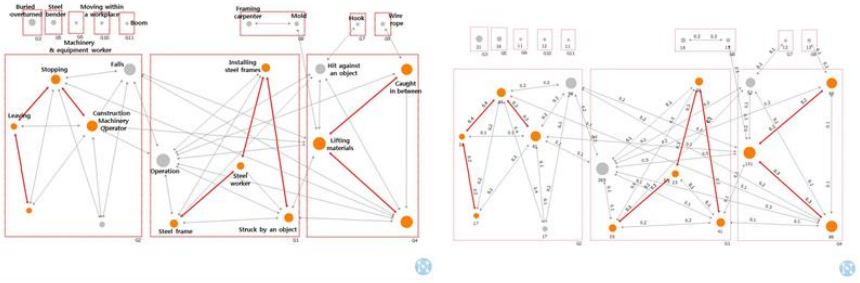

Figure 2. Centrality and Clustering of Mobile Crane

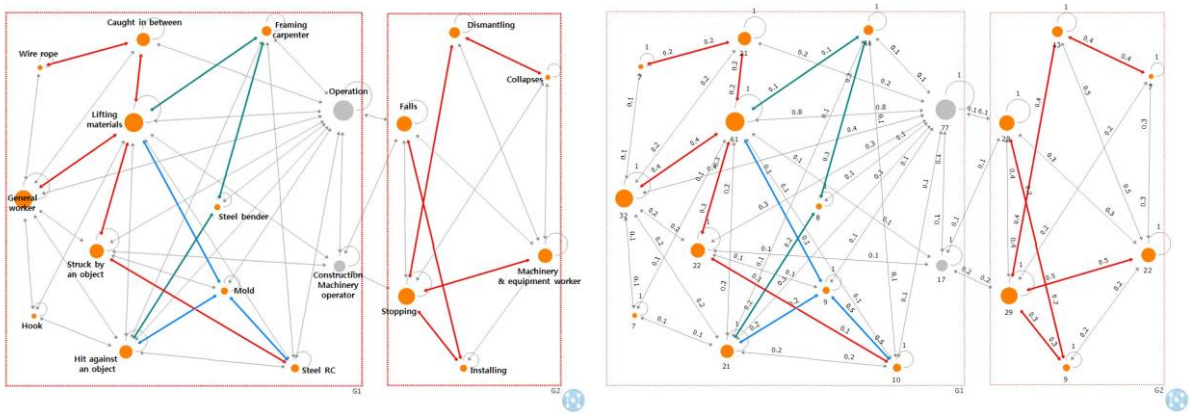

Figure 3. Centrality and Clustering of Tower Crane

V. Analysis of The Risk on Crane-Related Safety Accidents

It is important to examine to whom safety accidents on construction sites occur and due to what factors, but the risk level of the factors should also be analyzed. In this regard, the risk level of the crane-related safety accidents discussed in Chapter 4 above was also analyzed in this study. Risk analysis was performed based on a calculation method used by KOSHA. Table 2 shows that the risk level of mobile cranes and tower cranes with regard to which safety accidents frequently occur was 499.91 and 139.81, respectively. In detail, the risk level of items related to mobile cranes including "general worker," "caught in between" and "lifting materials" was high, and the risk level of items related to tower cranes including "general worker," "struck by an object" and "lifting materials" was high.

Table 2. Analysis of the risk level of crane-related safety accidents

Mobile crane					Tower crane				
Type		No. of victims	Disaster intensity	Risk level	Type		No. of victims	Disaster intensity	Risk level
Mobile crane		315	1.587	499.91	Tower crane		106	1.319	139.81
By occupation type	General worker	99	1.249	123.65	By occupation type	General worker	32	2.062	65.98
	Construction machinery operator	61	0.662	40.38		Machinery & equipment worker	22	0.784	17.25
	Steel worker	23	2.012	46.28		Framing carpenter	11	1.822	20.04
						Steel bender	9	0.508	4.57
By disaster type	Caught in between	69	0.828	57.13	By disaster type	Struck by an object	22	2.873	63.21
	Struck by an object	41	2.770	46.28		Hit against an object	21	0.563	11.82
						Caught in between	21	1.706	35.83
	Falls	17	0.239	4.06		Falls	28	0.674	18.87
						Collapses	7	1.159	8.11
By work type	Lifting materials	131	1.498	196.24	By work type	Lifting materials	62	1.395	86.49
	Installing steel frames	36	1.213	43.67		Dismantling	13	0.841	10.93
	Leaving a crane	20	0.402	8.04		Installing	9	0.896	8.06

VI. Conclusion

In this study, crane-related safety accidents that occurred on construction sites were analyzed using the data collected by the Korea Occupational Safety and Health Agency (KOSHA), and the networks of crane-related safety accidents were analyzed using the centrality and clustering techniques of SNA analysis. Based on the results of this analysis, the following conclusions were reached.

1. Crane-related safety accidents that occurred on construction sites were analyzed, and it was found that the number of accidents related to mobile cranes was the highest, followed by tower cranes, overhead travelling cranes and jib cranes. The crane-related safety accidents were also analyzed by occupation type, and it was found that many crane-related accidents occurred to general workers, construction machinery operators, machinery and equipment workers, framing carpenters, and steel benders.
2. An analysis of the networks of crane-related safety accidents was conducted, and it was found that mobile cranes formed networks centering on nodes including general worker, construction machinery operator and steel worker, and that safety accidents frequently occurred while “lifting materials,” “installing steel frames” and “leaving a crane.” Tower cranes formed networks centering on nodes including general worker, machinery and equipment worker, framing carpenter and steel bender, and safety accidents frequently occurred while “lifting materials,” “dismantling” and “installing.”
3. The risk level of crane-related safety accidents was analyzed, and it was found that the risk level of items related to mobile cranes including “general worker,” “caught in between” and “lifting materials” was high, and that the risk level of items related to tower cranes including “general worker,” “stuck by an object” and “lifting materials” was high.

If management measures are developed based on the key risk factors of crane-related safety accidents above, it is expected that these can contribute to a reduction in the crane-related safety accidents that occur on construction sites.

In this study, wide range of machinery and equipment types used on construction sites, only mobile and tower cranes were analyzed in this study with regard to which safety accidents frequently occurred. It is necessary to analyze the networks of safety disasters related to various machinery and equipment types, and thus to establish data for the development of management measures by occupation type through follow-up research.

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