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CAUSES OF SAFETY RISK DURING TOWER CRANE OPERATIONS ON CONSTRUCTION SITES IN VIETNAM

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Abstract

The construction industry holds significant importance for any nation; however, it remains a high-risk sector characterized by a significant number of fatalities and grave injuries. Among these risks, tower crane operations stand out as a leading contributor to the heightened risk rate. This research paper endeavors to assess the safety risks inherent in tower crane operations at construction sites in Vietnam. This assessment is conducted from the perspective of various stakeholders involved in tower crane activities, namely managers, operators, and workers. To achieve this, a meticulously structured questionnaire utilizing a five-point Likert scale was formulated and distributed to gather insights from 78 proficient individuals engaged in tower crane-related tasks. The outcomes from all participants collectively underscore 21 distinct causes that give rise to safety risks during tower crane operations in Vietnam. Nonetheless, noticeable differences in opinions appear when looking at answers from managers, operators, and workers. The operators and workers showed that "Winds (wind intensity seriously affects the lifted load and tower crane itself)" are the most common safety risk. On the other hand, the managers highlighted the issue of whether the "Tower crane operator is an in-house staff member or outsourced" as their main concern. The managers, operators and workers showed that "Experience and skills of the operator during operating tower crane", "Maintenance management degree of the tower crane and lifting aids", and "Overhead power lines in the tower crane's work region" are the most severe cause of safety risk, respectively. Operators and workers pointed out that the "Degree of maintenance management for tower cranes and lifting aids"has the highest safety risk level. However, managers highlighted that "Winds (wind intensity seriously affects the lifted load and tower crane itself)" pose the highest safety risk level.

Keywords: tower crane operations; safety risk; construction sites; construction safety; construction industry.

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1. Introduction

The construction industry holds the unenviable record of having the highest number of accidents, resulting in tragic fatalities, enduring injuries, and other grave consequences [1–10]. In advanced countries, the accident rate is three to four times higher than that of other industries, and this number rises to three to six times higher in less developed countries [11]. For instance, in the United Kingdom (UK) alone, the construction sector accounted for approximately 59,000 non-fatal work-related injuries from 2019 to 2022, along with 66 fatal injuries to workers from 2017 to 2022 [12]. Similarly, Turkey witnessed 393,160 occupational accidents within the construction industry between 2012 and 2020 [10], and in Korea, there were 137,323 injuries and 2,846 deaths recorded from 2011 to 2016 [13]. In Vietnam, the construction industry also experiences a significant number of accidents and fatalities, constituting 12.23% of the total accidents and 12.26% of the total deaths in the year 2022 [14].

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The utilization of tower cranes in construction projects, particularly for commercial centers, high-rise buildings, skyscrapers, and factories, is widespread. Their numbers are expected to increase over time due to their indispensable role in lifting and relocating various types of loads, especially bulky construction materials [15–17]. Nonetheless, the employment of tower cranes comes with substantial costs; they account for approximately 36% of the total procurement expenses in construction projects [18]. Paradoxically, tower cranes are also associated with a disproportionately high rate of severe accidents, leading to numerous serious injuries and tragic fatalities [9, 19–22]. These accidents not only jeopardize the safety of workers but also pose immediate threats to construction structures, machinery, and equipment, as well as pedestrians and nearby facilities [3, 23]. For instance, in Australia, tower cranes were linked to 47 fatalities in accidents spanning from 2003 to 2015 [24], with an annual average of 240 crane-related serious injuries [25]. Similarly, tower cranes were involved in 38 accidents in Korea between 2001 and 2011, constituting around 7.2% of all lifting equipment accidents [17]. The Occupational Safety and Health Administration (OSHA) [26] reported 137 crane-related deaths during the years 1992 to 2001 in the United States, representing about 17% of all construction-related fatalities in England [27]. Notably, Vietnam has also witnessed several tower crane-related accidents, such as a notable incident in May 2020 when three severe injuries and three deaths occurred due to a tower crane-related incident.

The operation of tower cranes on construction sites is responsible for a substantial number of accidents, many of which result in severe injuries and fatalities. This is often attributed to the challenging circumstances under which tower cranes function, operating in congested settings and facing pressures of labor and time constraints [16]. In Korea, tower crane operations accounted for 18.4% of all fatal accidents on construction sites between 2001 and 2011 [17]. In the US, the use of tower cranes contributed to approximately 5% of the total fatalities in crane-related incidents [28]. Notably, Tam & Fung [3] documented 12 tower crane-related accidents in Hong Kong from 1998 to 2005. In the UK, there were five accidents involving tower cranes on construction sites between 2000 and 2009 [29]. Vietnam has also experienced tower crane-related accidents, such as there were two tower crane-related accidents with one death in 2016 in Hanoi and Nghean. The incident in May 2020 resulted in three fatalities and three serious injuries, and another incident in March 2021 with two fatalities and one serious injury during crane operations.

Numerous papers have examined the safety risks associated with cranes on construction sites [30–38], with only a limited focus on tower cranes. Li, Chan, & Skitmore [39] presented a safety training model for the dismantling of tower cranes on construction sites. Their study demonstrated the superiority of the proposed model over traditional approaches. Shin [17] assessed safety risk factors during the installation and dismantling of tower cranes on construction sites in Korea. Analyzing 38 tower crane-related accidents between 2001 and 2011, the study identified five major factors, with human error emerging as the most significant cause of accidents during these operations. Salihu, Aliyu, & Abubakar [40] outlined safety risk factors associated with the installation and dismantling of tower cranes on construction sites in Nigeria. Their research not only examined the likelihood of occurrence and the degree of influence of these factors but also identified the most critical risk factor among the 21 identified. Neitzel, Seixas, & Ren [9] reviewed available information on tower crane injuries and provided recommendations for enhanced injury prevention strategies. Ngo [15] identified 21 factors contributing to accidents during the installation and dismantling of tower cranes on construction sites in Vietnam.

There exist several studies that delve into safety considerations during the operation of tower cranes on construction sites. Shapira & Lyachin [16] conducted an examination and analysis of 21

factors influencing tower crane safety on construction sites in Israel, categorizing them into safety management, project conditions, human factors, and the environment. The factor "Operator proficiency" exhibited the highest mean degree of influence, while the "Weather" factor demonstrated the lowest mean degree of influence. Employing the analytic hierarchy process (AHP) model, Shapira & Simcha [36] evaluated the weights of safety risk factors in tower crane operations on Israeli construction sites. The study encompassed 21 safety risk factors and revealed that the "Site-level safety management" factor held the highest weight at 14.18%, while "Length of work shift (operator)" possessed the lowest weight at 3.96%. In the context of Hong Kong, Tam & Fung [3] identified significant safety risk factors during the use of tower cranes on construction sites. They recognized four major risk factors: (i) time constraints imposed by investors, principal contractors, or employers; (ii) tower crane operations managed by subcontractors; (iii) inadequate training; and (iv) lapses in attention or misjudgment of tower crane operation-related parameters. The study also put forth recommendations for enhancing tower crane safety on construction sites. Shapira, Simcha, & Goldenberg [21] developed an integrated model comprising four modules to quantify safety risk factors during tower crane operations on construction sites. Additionally, Zhou et al. [41] identified safety risk factors in tower crane operation on construction sites in China using the qualitative (AcciMap) technique.

Globally, scant studies address safety risk causes associated with tower cranes, with many of these studies focusing on specific aspects of tower crane operations. Consequently, it is essential to assess and compare safety risk causes related to tower crane operations on construction sites in Vietnam from the perspective of other construction project stakeholders, including managers, erection and dismantling workers, and tower crane-related workers. This paper's primary objectives encompass several aspects. Initially, it identifies the causes of safety risks during tower crane operations on construction sites in Vietnam. Subsequently, it highlights the most prevalent safety risks caused during these operations within the Vietnamese context. Furthermore, the paper pinpoints the most severe safety risk in the realm of tower crane operations. Ultimately, the study gauges the significance of safety risk caused by calculating a relative significance index score.

2. Methodology

The research methodology encompassed the following aspects: Twenty-one (21) safety risk causes, previously defined in a study [16] and presented in Table 1, were considered. These causes were categorized into four (4) groups: Causes associated with project conditions, the environment, human factors, and safety management. Within these groups, the project conditions category comprised ten (10) causes, the environment group comprised three (3) causes, the human group comprised five (5) causes, and the safety management group included three (3) causes. To evaluate the prevalence, degree of influence (severity), and significance of the identified safety risk causes from the perspective of various participants, a well-structured questionnaire was devised. This questionnaire employed a five-point Likert scale to gauge the frequency of occurrence and importance of the causes. Frequency of appearance was ranked as follows: 1 - improbable, 2 - unlikely, 3 - possible, 4 - probable, and 5 - almost certain. The degree of influence was ranked as follows: 1 - negligible, 2 - minor injury, 3 - major injury, 4 - fatality, and 5 - multiple fatalities. The collected data underwent analysis to determine the frequency of appearance, severity, and importance indices. Moreover, agreement on the ranking of the importance of safety risk causes related to tower crane operation between two groups of parties was subjected to testing.

The assessment of the safety risk level of these causes was accomplished by computing their relative significant index score (RSIS), which constitutes a function of both the degree of influence and the likelihood of occurrence of the safety risk factors. The RSIS represents the cumulative signif-

icance score of all risks divided by the number of respondents, effectively quantifying the relative importance of these factors. The comparative significance among factors was established through their respective RSIS values. These values were subsequently compared against a table of standard risk values developed by the Construction Plant Hire Association (CPA) [42]. It shows that RSIS of 1-6 is low; RSIS of 7-8 is moderate; RSIS of 15-16 is high and RSIS of 20-25 is very high. The analytical treatment of data was conducted using MS Excel.

Table 1. A list of safety risk causes is categorized into four groups [16]

No	Safety risk causes
	Project conditions
1	Tower cranes are obstructed by unfavorable work regions and crowded sites.
2	Overhead power lines in the tower crane's work region.
3	The operator's view is limited (blind lifts).
4	There are two or more tower cranes in the work region (overlapping tower cranes).
5	The operator's sight angle and distance are impaired by the height of the cabin.
6	Inconvenience of the cabin affects the operator.
7	Work shift is often lengthened for operator and tower crane-related workers or working into the night.
8	Tower crane-related workers and operators use different languages on the construction site.
9	Added aids help operators to increase safety (in excess of standard aids demanded by safety regulations).
10	The type of load and rigging affect safety.
	Environment
11	Winds (wind intensity seriously affects the lifted load and tower crane itself).
12	Weather includes bad temperatures and other weather phenomena that affect visibility and the human body.
13	Bad visibility pertains to lighting or weather (mostly of operators but also tower crane-related workers).
	Human causes
14	Experience and skills of the operator during operating tower cranes.
15	The behavioral types and mental ability of the tower crane operator.
16	Tower crane operators are inside (staff in the construction company) or are outsourced.
17	The behavioral types and mental abilities of the manager.
18	Experience as a signal person and rigging worker.
	Safety management
19	Safety management level at the construction site.
20	Company safety policy and safety management level at the construction company.
21	Maintenance management degree of the tower crane and lifting aids.

Spearman's rank correlation, a non-parametric test, holds a distinct place in statistical analysis. Non-parametric tests are commonly known as distribution-free tests due to their independence from specific distribution assumptions. In the context of this research, Spearman's rank correlation coefficient serves to quantify the extent of concordance among different parties. This coefficient assumes values between -1 and $+1$, where -1 signifies an absolute negative relationship (indicating disagree-

ment), while +1 signifies an absolute positive relationship (indicating agreement). As elucidated by Assaf and Al-Hejji [43], Spearman's rank correlation is succinctly outlined below:

$$r = 1 - \left[\left(6\sum d^2\right) / \left(n^3 - n\right)\right] \quad (1)$$

where r is the Spearman rank correlation coefficient between two parties, d is the difference between ranks assigned to variables for each cause, and n is the number of pairs of rank.

3. Results and Discussion

3.1. Respondents profile

A comprehensive total of 110 questionnaires were dispatched to individuals encompassing managers, operators, and tower crane-related workers. Among these, a total of seventy-eight valid responses were collected, resulting in an impressive 70.9% response rate. The particulars of the respondents, including their educational background, job characteristics, and years of experience, are presented in Table 2. Notably, operators constitute the largest proportion, accounting for 52.6%, while managers, including safety managers, equipment managers, and project managers, comprise the smallest segment at 21.8%. It is noteworthy that all respondents possess a minimum of a post-secondary education. Secondary graduation holds the highest representation, standing at 60.3%, whereas MSc degree holders are the least represented at 10.2%. In terms of work experience, the majority of respondents, 56.3%, have between 11 to 15 years of experience (32.0%), and 16 to 20 years (24.3%), respectively, working with tower cranes on construction sites. Additionally, respondents have tower crane-related working experience distributed as follows: 0 to 5 years (10.3%), over 20 years (12.8%), and 6 to 10 years (20.6%).

Table 2. Respondents profile

No	Item	Number	Percentage
	Job description		
1	Managers (Safety managers; Equipment managers and project managers)	17	21.8
2	Operators	41	52.6
3	Tower crane-related workers	20	25.6
	Total	**78**	**100**
	Educational qualifications		
1	High school	14	18.0
2	Secondary graduation	47	60.3
3	Bachelors	9	11.5
4	MSc	8	10.2
	Total	**78**	**100**
	Years of experience		
1	0-5	8	10.3
2	6-10	16	20.6
3	11-15	25	32.0
4	16-20	19	24.3
5	Over 20	10	12.8
	Total	**78**	**100**

3.2. Ranking safety risk causes by parties

Ranking safety risk causes based on their frequency of occurrence, degree of severity, and safety risk level as perceived by managers, operators, and tower crane-related workers are depicted in Tables 3–5, respectively. Notably, Tables 3 and 5 illustrate that operators and tower crane-related workers concurred in identifying "Winds (wind intensity seriously affects the lifted load and tower crane itself)" as the most prevalent cause of safety risk, while the factor "Maintenance management degree of the tower crane and lifting aids" emerged as having the highest safety risk level. Moreover, Table 6 highlights the prominence of safety management-related causes, while other causes hold comparatively lesser significance.

Table 3 presents the viewpoints of managers. They pointed out that the most common safety risk is "Tower crane operator is inside (staff in the construction company) or is outsourced" with a mean value of 3.47. On the other end of the spectrum, the least likely cause is "Tower crane-related workers and operators using different languages on the construction site" with a mean value of 2.12. The factor "Experience and skills of operator during operating tower crane" attained the highest degree of impact, registering a mean value of 2.77. In contrast, the cause "Inconvenience of cabin affecting the operator" garnered the lowest degree of influence, with a mean value of 1.35. Table 3 further reveals that "Winds (wind intensity seriously affects the lifted load and tower crane itself)" attained the highest RSIS score of 8.63. Conversely, "Tower crane-related workers and operators using different languages on the construction site" obtained the lowest RSIS score of 3.36. Notably, three safety risk causes obtained high RSIS values exceeding 8.0. These causes signify a moderate level of risk and necessitate appropriate control measures during tower crane operations to curtail risks and enhance construction site safety. Causes ranged from 4th to 21st obtained RSIS values ranging from 7.66 to 3.36, respectively. These causes represent lower levels of risk and are considered acceptable without the need for specific control methods. Within the four groups of causes, environment-related factors garnered the highest RSIS value of 7.47.

Table 3. Ranking of sources (group) of safety risk by managers

No	Causes	Likelihood of occurrence			Degree of severity		Safety risk level		
		Mean	Std.Dev	Rank	Mean	Rank	RSIS	Rank	Risk level
	Project conditions	**2.61**	**1.04**		**2.12**		**5.6**		**L**
1	The Tower crane is obstructed by unfavorable work regions and a crowded site	3.12	1.50	6^{th}	2.35	9^{th}	7.34	8^{th}	L
2	Overhead power lines in the tower crane's work region	2.18	0.88	20^{th}	2.53	5^{th}	5.51	15^{th}	L
3	The operator's view is limited (blind lifts)	2.77	0.83	14^{th}	2.71	2^{nd}	7.48	7^{th}	L
4	There are two or more tower cranes in the work region (overlapping tower cranes)	2.25	0.66	18^{th}	2.12	12^{th}	4.74	17^{th}	L
5	The operator's sight angle and distance are impaired by the height of the cabin	3.18	1.43	4^{th}	2.41	8^{th}	7.66	4^{th}	L
6	Inconvenience of the cabin affects the operator	2.59	1.28	17^{th}	1.35	21^{th}	3.50	20^{th}	L
7	Work shift is often lengthened for operator and tower crane-related workers or working into the night	2.82	0.73	11^{th}	1.88	16^{th}	5.32	16^{th}	L
8	Tower crane-related workers and operators use different languages on construction site	2.12	0.78	21^{th}	1.59	20^{th}	3.36	21^{th}	L

No	Causes	Likelihood of occurrence			Degree of severity		Safety risk level		
		Mean	Std.Dev	Rank	Mean	Rank	RSIS	Rank	Risk level
9	Added aids help operators to increase safety (in excess of standard aids demanded by safety regulations)	2.88	1.23	9^{th}	2.11	13^{th}	6.10	13^{th}	L
10	Type of load and rigging way affect safety	2.24	1.03	19^{th}	2.10	14^{th}	4.73	18^{th}	L
	Environment	**3.24**	**0.99**		**2.30**		**7.47**		**L**
11	Winds (wind intensity seriously affects the lifted load and tower crane itself)	3.41	1.06	2^{nd}	2.52	6^{th}	8.63	1^{st}	M
12	Weather includes bad temperatures and other weather phenomena that affect visibility and the human body	3.29	1.11	3^{rd}	1.87	17^{th}	6.20	12^{th}	L
13	Bad visibility pertains to lighting or weather (mostly of operator but also tower crane-related workers)	3.01	0.79	7^{th}	2.51	7^{th}	7.59	6^{th}	L
	Human causes	**2.98**	**1.08**		**2.25**		**6.69**		**L**
14	Experience and skills of operator during operating tower crane	3.00	0.94	8^{th}	2.77	1^{st}	8.29	3^{rd}	M
15	The behavioral types and mental abilities of the tower crane operator	2.81	0.88	12^{th}	2.24	11^{th}	6.31	10^{th}	L
16	The Tower crane operator is inside (staff in the construction company) or is outsourced	3.47	1.37	1^{st}	1.86	18^{th}	6.53	9^{th}	L
17	The behavioral types and mental abilities of the manager	2.75	1.09	15^{th}	1.71	19^{th}	4.71	19^{th}	L
18	Experience as signal person and rigging worker	2.87	1.11	10^{th}	2.65	3^{rd}	7.63	5^{th}	L
	Safety management	**2.88**	**1.04**		**2.33**		**6.76**		**L**
19	Safety management level at the construction site	3.17	1.23	5^{th}	2.64	4^{th}	8.41	2^{nd}	M
20	Company safety policy and safety management level at the construction company	2.80	1.18	13^{th}	2.00	15^{th}	5.65	14^{th}	L
21	Maintenance management degree of the tower crane and lifting aids	2.65	0.70	16^{th}	2.34	10^{th}	6.23	11^{th}	L

M: Moderate; L: Low

Operators' viewpoints are presented in Table 4. The findings reveal that "Winds (wind intensity seriously affects the lifted load and tower crane itself)" emerge as the most prevalent safety risk cause, garnering a mean value of 3.73. Conversely, the least likely cause is "Overhead power lines in the tower crane's work region" registering a mean value of 2.63. The factor "Maintenance management degree of the tower crane and lifting aids" exhibits the most pronounced degree of impact, with a mean value of 3.71. In contrast, the cause "Added aids help the operator to increase safety (in excess of standard aids demanded by safety regulations)" attains the lowest degree of influence, with a mean value of 2.17. Notably, Table 4 highlights that "Maintenance management degree of the tower crane and lifting aids" obtains the highest RSIS score of 12.57. In contrast, "Added aids help the operator to increase safety (in excess of standard aids demanded by safety regulations)" secures the lowest RSIS score of 6.46. Sixteen causes exhibit high RSIS values exceeding 8.0. Among these, causes ranked from 17th to 21st obtain RSIS values ranging from 7.93 to 6.46, respectively. Among the four groups

of causes, safety management-related factors exhibit the highest RSIS value of 11.30.

Table 4. Ranking of sources (group) of safety risk by operators

No	Causes	Likelihood of occurrence			Degree of severity		Safety risk level		
		Mean	Std.Dev	Rank	Mean	Rank	RSIS	Rank	Risk level
	Project conditions	**2.93**	**1.25**		**2.83**		**8.27**		**M**
1	The Tower crane is obstructed by unfavorable work regions and a crowded site	3.02	1.15	14^{th}	3.22	4^{th}	9.74	6^{th}	M
2	Overhead power lines in the tower crane's work region	2.63	1.22	21^{th}	3.39	2^{nd}	8.93	13^{th}	M
3	The operator's view is limited (blind lifts)	2.73	1.29	19^{th}	3.15	6^{th}	8.60	14^{th}	M
4	There are two or more tower cranes in the work region (overlapping tower cranes)	2.68	1.27	20^{th}	2.88	10^{th}	7.72	19^{th}	L
5	The operator's sight angle and distance are impaired by the height of cabin	2.76	1.26	18^{th}	2.87	11^{th}	7.93	17^{th}	L
6	Inconvenience of cabin affects the operator	2.93	1.08	16^{th}	2.78	12^{th}	8.14	16^{th}	M
7	Work shift is often lengthened for operator and tower crane-related workers or working into the night	3.34	1.11	7^{th}	2.73	15^{th}	9.13	9^{th}	M
8	Tower crane-related workers and operator use different languages on construction site	2.92	1.59	17^{th}	2.37	20^{th}	6.93	20^{th}	L
9	Added aids help operator to increase safety (in excess of standard aids demanded by safety regulations)	2.98	1.24	15^{th}	2.17	21^{th}	6.46	21^{th}	L
10	Type of load and rigging way affect safety	3.33	1.28	8^{th}	2.72	16^{th}	9.12	10^{th}	M
	Environment	**3.48**	**0.99**		**2.86**		**10.02**		**M**
11	Winds (wind intensity seriously effects on the lifted load and tower crane itself)	3.73	0.87	1^{st}	3.12	7^{th}	11.65	2^{nd}	M
12	Weather includes bad temperatures and other weather phenomena that affect visibility and human body	3.42	1.07	4^{th}	2.71	17^{th}	9.33	8^{th}	M
13	Bad visibility pertains to lighting or weather (mostly of operator but also of tower crane-related workers)	3.29	1.03	10^{th}	2.76	13^{th}	9.08	12^{th}	M
	Human causes	**3.31**	**1.14**		**2.78**		**9.23**		**M**
14	Experience and skills of operator during operating tower crane	3.39	1.28	5^{th}	3.24	3^{rd}	11.00	4^{th}	M
15	The behavioral types and mental ability of the tower crane operator	3.10	1.34	13^{th}	2.75	14^{th}	8.54	15^{th}	M
16	Tower crane operator is inside (staff in the construction company) or is outsourced	3.59	1.03	2^{nd}	2.54	18^{th}	9.09	11^{th}	M
17	The behavioral types and mental abilities of the manager	3.17	1.00	12^{th}	2.49	19^{th}	7.89	18^{th}	L
18	Experience of signalperson and rigging worker	3.32	1.04	9^{th}	2.90	9^{th}	9.63	7^{th}	M

No	Causes	Likelihood of occurrence			Degree of severity		Safety risk level		
		Mean	Std.Dev	Rank	Mean	Rank	RSIS	Rank	Risk level
	Safety management	**3.38**	**1.15**		**3.33**		**11.30**		**M**
19	Safety management level at the construction site	3.48	0.95	3^{rd}	3.17	5^{th}	11.06	3^{rd}	M
20	Company safety policy and safety management level at the construction company	3.28	1.29	11^{th}	3.11	8^{th}	10.28	5^{th}	M
21	Maintenance management degree of the tower crane and lifting aids	3.38	1.20	6^{th}	3.71	1^{st}	12.57	1^{st}	M

M: Moderate; L: Low

Table 5 provides an insight into the perspectives of tower crane-related workers. . They showed that "Winds (wind intensity seriously affects the lifted load and tower crane itself)" is the most common cause of safety risk with a mean value of 3.65 and the least likely cause is "Overhead power lines in the tower crane's work region" with a mean value of 2.30. The cause of "Overhead power lines in the tower crane's work region" had the highest degree of impact with a mean value of 3.40. The cause of "Added aids help operators to increase safety (in excess of standard aids demanded by safety regulations)" had the lowest degree of influence with a mean value of 1.35. Table 5 also shows that the "Maintenance management degree of the tower crane and lifting aids" had the highest RSIS of 9.15. In contrast, "The behavioral types and mental abilities of the manager" had the lowest RSIS of 3.63. There were only 2 causes with a high RSIS > 8.0. The causes ranged from 3rd to 21st and had an RSIS of 7.82 – 3.63, respectively. In four groups of causes, the safety management causes had the highest RSIS of 9.15.

Table 5. Ranking of sources (group) of safety risk by workers

No	Causes	Likelihood of occurrence			Degree of severity		Safety risk level		
		Mean	Std.Dev	Rank	Mean	Rank	RSIS	Rank	Risk level
	Project conditions	**2.77**	**1.17**		**2.36**		**6.41**		**L**
1	Tower crane is obstructed by unfavorable work region and crowded site	2.95	0.76	9^{th}	2.80	4^{th}	8.26	2^{nd}	M
2	Overhead power lines in the tower crane's work region	2.30	0.98	21^{th}	3.40	1^{st}	7.82	3^{rd}	L
3	Operator's view is limited (blind lifts)	2.50	0.89	18^{th}	3.00	2^{nd}	7.50	5^{th}	L
4	There are two or more tower cranes in the work region (overlapping tower cranes)	2.55	1.10	17^{th}	2.65	5^{th}	6.76	10^{th}	L
5	Operator's sight angle and distance are impaired by height of cabin	2.85	0.93	13^{th}	2.64	6^{th}	7.55	4^{th}	L
6	Inconvenience of cabin affects the operator	2.40	0.94	20^{th}	2.45	8^{th}	5.88	16^{th}	L
7	Work shift is often lengthened for operator and tower crane-related workers or working into the night	3.15	1.35	4^{th}	2.20	10^{th}	6.93	8^{th}	L
8	Tower crane-related workers and operator use different languages on construction site	3.10	1.57	6^{th}	1.60	18^{th}	4.96	18^{th}	L
9	Added aids help operator to increase safety (in excess of standard aids demanded by safety regulations)	2.84	1.53	14^{th}	1.35	21^{th}	3.85	20^{th}	L

No	Causes	Likelihood of occurrence			Degree of severity		Safety risk level		
		Mean	Std.Dev	Rank	Mean	Rank	RSIS	Rank	Risk level
10	Type of load and rigging way affect safety	3.05	1.67	7^{th}	1.50	19^{th}	4.58	19^{th}	L
	Environment	**3.36**	**1.32**		**2.00**		**6.73**		**L**
11	Winds (wind intensity seriously effects on the lifted load and tower crane itself)	3.65	1.23	1^{st}	2.05	15^{th}	7.48	6^{th}	L
12	Weather includes bad temperatures and other weather phenomena that affect visibility and human body	3.30	1.49	2^{nd}	1.80	16^{th}	5.94	14^{th}	L
13	Bad visibility pertains to lighting or weather (mostly of operator but also of tower crane-related workers)	3.14	1.23	5^{th}	2.15	12^{th}	6.77	9^{th}	L
	Human causes	**2.84**	**1.39**		**2.02**		**5.75**		**L**
14	Experience and skills of operator during operating tower crane	2.75	1.59	15^{th}	2.55	7^{th}	7.01	7^{th}	L
15	The behavioral types and mental ability of the tower crane operator	2.74	1.51	16^{th}	2.14	13^{th}	5.91	15^{th}	L
16	Tower crane operator is inside (staff in the construction company) or is outsourced	3.25	1.41	3^{rd}	1.75	17^{th}	5.69	17^{th}	L
17	The behavioral types and mental abilities of the manager	2.49	1.10	19^{th}	1.45	20^{th}	3.63	21^{th}	L
18	Experience of signalperson and rigging worker	2.94	1.32	10^{th}	2.19	11^{th}	6.49	12^{th}	L
	Safety management	**2.96**	**1.38**		**2.45**		**7.29**		**L**
19	Safety management level at the construction site	2.90	1.12	12^{th}	2.10	14^{th}	6.09	13^{th}	L
20	Company safety policy and safety management level at the construction company	2.93	1.53	11^{th}	2.25	9^{th}	6.64	11^{th}	L
21	Maintenance management degree of the tower crane and lifting aids	3.04	1.50	8^{th}	2.99	3^{rd}	9.15	1^{st}	M

M: Moderate; L: Low

Table 6. Ranking of sources (groups) of safety risk by all parties (combined)

No	Causes	Frequency of occurrence		Degree of severity		Safety risk level		
		Mean	Rank	Mean	Rank	RSIS	Rank	Risk level
1	Project condition-related causes	2.77	4^{th}	2.44	2^{nd}	6,91	4^{th}	L
2	Environment-related causes	3.36	1^{st}	2.37	3^{rd}	7.89	2^{nd}	L
3	Human factors-related causes	3.04	3^{rd}	2.35	4^{th}	7.22	3^{rd}	L
4	Safety management-related causes	3.07	2^{nd}	2.70	1^{st}	8.45	1^{st}	M

M: Moderate; L: Low

3.3. The importance of rank correlation

The application of Spearman's rank correlation coefficient facilitates the assessment of the level of concordance or discordance in conjunction with the importance ranking attributed by two of the parties, while excluding the ranking assigned by the third party. As presented in Table 7, the outcomes derived from Eq. (1) reveal the extent of alignment. Notably, there exists a commendable level

of consensus in the ranking of safety risk causes between the two distinct groups of parties. The highest degree of concurrence, approximately 65.2%, materializes between managers and operators. In contrast, the lowest level of agreement, about 54.5%, is observed between operators and tower crane-related workers. Given the relative alignment in the ranking of causes among each group of parties, the findings of this research can be deemed reliable.

Table 7. Spearman rank correlation coefficient

No	Parties	Spearman rank correlation coefficient	Significance level
1	Managers and operators	0.652	0.95
2	Managers and tower crane-related workers	0.583	0.95
3	Operators and tower crane-related workers	0.545	0.95

4. Conclusions

The study aimed to assess safety risk causes encountered during the operation of tower cranes on construction sites in Vietnam, based on the perspectives of various construction project participants: managers, operators, and tower crane-related workers. The survey revealed unanimous identification of 21 distinct safety risk causes during tower crane operations in Vietnam. Nevertheless, disparities in viewpoints emerged among managers, operators, and workers. Operators and workers highlighted "Winds (wind intensity seriously affects the lifted load and tower crane itself)" as the most prevalent safety risk, while managers focused on "Tower crane-related workers and operators using different languages on the construction site". Delving deeper, the consensus among all groups indicated that the most severe causes of safety risk include "Experience and skills of the operator during operating tower crane", "Maintenance management degree of the tower crane and lifting aids", and "Overhead power lines in the tower crane's work region". Interestingly, operators and workers underscored "Maintenance management degree of the tower crane and lifting aids" as possessing the highest safety risk level, while managers deemed "Winds (wind intensity seriously effects on the lifted load and tower crane itself)" as the top safety risk level.

Among the causative factors, safety management-related causes emerged as the most pivotal, while operator and worker-related causes assumed a relatively lesser significance. The assessment of safety risk causes through ranking demonstrated a noteworthy degree of agreement between distinct groups of parties. This alignment in ranking enhances the credibility of the research findings. Notably, the safety risks emanating from cranes on construction sites in Vietnam could be a potential avenue for future research exploration.

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