Journal of Science and Technology in Civil Engineering, HUCE, 2024, 18 (4): 83–97

CAUSES OF CRANE SAFETY RISK IN THE VIETNAMESE CONSTRUCTION INDUSTRY

Ngo Thanh Long[a,*], Nguyen Hoang Giang[a]

[a]*Faculty of Mechanical Engineering, Hanoi University of Civil Engineering, 55 Giai Phong road, Hai Ba Trung district, Hanoi, Vietnam*

Article history:
Received 20/8/2024, Revised 15/10/2024, Accepted 18/12/2024

Abstract

Crane is one of the most important machineries in the construction field. They are used to move large or heavy loads on most construction sites. However, crane operations in construction are very dangerous activities and contribute to a big ratio of serious accidents around the world and in Vietnam. The paper aimed to identify and evaluate crane safety risk causes as well as groups of causes in the Vietnamese construction industry. The paper evaluated from the perspective of various related people involved in crane activities, namely drivers, managers, and workers. A well-structured questionnaire using a five-point Likert scale was produced and sent to collect data from 60 valid crane-related practitioners. The paper finds 59 specific causes that give rise to crane safety risks in the Vietnamese construction industry. However, there are noteworthy differences in answers from managers, drivers, and workers. The managers, drivers, and workers showed the most common safety risks "Stress of crane workers due to time pressure", "Insufficient safety awareness and behavior of crane workers", and "Subcontractor does not establish safety funds for the construction safety", respectively. They pointed out that "Crane manufacturers with bad manufacturing quality" are the most severe cause of safety risk. The managers, drivers, and workers also showed the highest safety risk level of cause "Stress of crane workers due to time pressure", "Insufficient supervise of main contractor for the crane foundation and installation task", and "Government lacks a good implementation of certificate management and graduation for crane operators", respectively. Crane management of construction site-related causes is the most common safety risk and the highest safety risk level. Regulatory bodies and stakeholders-related causes have the highest degree of severity.

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

https://doi.org/10.31814/stce.huce2024-18(4)-07

1. Introduction

The construction field has a high risk and causes a lot of deaths at construction sites [1–9]. It also represents 21.5% of fatal accidents and 12.7% of non-fatal accidents [10]. For example, Construction in the United States is one of two sectors that have the highest fatality rate with 1056 deaths in 2022 [11]. The developed countries contribute about 20-40% of deadly accidents in the construction sector [12]. Brazil had 31.904 construction-related accidents and 263 deaths in 2018 [13]. The construction industry in Vietnam contributes to many serious accidents. It accounts for about 18.27% of accidents in the total number of accidents and 20.03% of deaths in the total number of deaths in accidents in 2023 [14]. The construction site is a complex environment and uses many cranes for moving and lifting material and heavy objects. Therefore, cranes are one of the primary causes of fatalities and the most serious items of equipment on construction sites [15, 16]. The cranes cause about 17% of all construction equipment-related accidents [17]. The United States contributed 377 crane-related accidents and 39.3% of fatal accidents between 2011 and 2020 [18]. China had 27.9% of fatal accidents from 2012 to 2016 [19]. Hong Kong accounted for 18,6% of crane-related fatalities in

*Corresponding author. *E-mail address:* longnt@huce.edu.vn (Long, N. T.)

all construction-related deaths [20]. Japan contributed to 41 crane-related fatalities in 2006 [21]. In Korea, there were 46 crane-related fatalities and 9.1% of all machinery-related fatalities in 2016 [22]. In Australia 47 crane-related fatalities from 2003 to 2015 and 240 serious injuries in crane-related accidents every year were reported [23]. Spain had 1314 crane-related accidents including 8 deaths from 2012 to 2021 [24]. Vietnam has had some serious crane-related accidents in Vungtau, Dongthap, Binhduong, Bacgiang, and so on. For example, Vungtau province had a crane-related accident with a death in February 2024. Dongthap province had a crane-related accident with two deaths in August 2015. Binhduong province had three dangerous injured workers and three fatalities in a crane-related accident in February 2020. There was a crane-related accident with three dangerous injured people in Bacgiang province in July 2023.

Crane safety in construction sites is a very concerning topic and has attracted many researchers around the world. Nevertheless, most researchers concentrate on mobile crane safety and tower crane safety. Tower crane safety was done by many researchers [25–34]. Mobile crane safety has attracted many researchers [16, 35–38]. The combination of the safety of different types of cranes (such as tower cranes, mobile cranes, and so on) was done by a few researchers. Shepherd et al. [39] considered over 500 crane related-deaths between 1985 and 1995 in the United States construction industry including mobile cranes, aerial lifts and tower cranes. The study showed that mobile cranes contributed most to fatalities and there were 4 crane accident-related causes. The gravitation energy cause (51.05%) includes falls of objects, falls of people, and falls of crane overturns. The electrical energy electrocution cause (41.33%) includes overhead power lines and portable equipment. The machine energy cause (6.48%) includes a person caught between and a person run over. The other cause was (1.14%). Beavers et al. [15] analyzed 125 case files involving 126 cranes from 127 crane-related deaths in the United States during the years 1997-2003. The study also detected that mobile cranes contributed to over 88% of crane-related fatalities. "Mobilization" had the highest frequency of fatalities. In a study, Aneziris et al. [40] represented a logical model for quantifying the appearance likelihood and effect levels of the various crane-related accident types including overturning or collapsing cranes, falling objects or falling loads from cranes. The paper used crane-related accidents that were reported by the Geintegreerd Informatie Systeem Arbeids Inspectie (GISAI). Milazzo et al. [41] evaluated crane safety in the US. The paper showed causes of crane-related fatalities that were reported by the Bureau of Labor Statistics-Census of Fatal Occupational Injuries (CFOI) in the period 1992-2006. The study showed that crane-related accidents have not undergone a great change. Sadeghi et al. [42] reviewed 106 papers from construction management and engineering journals in the period 2000-2019 to find 59 factors that affect crane safety. The research showed that most of the selected papers care about crane safety risk relating to crane equipment. However, factors relating to crane stakeholders, regulatory bodies, and the environment have not gotten the attention of researchers. Virginia et al. [24] showed the primary factors in crane-related accidents in the construction field in Span. The paper reviewed 1314 crane-related accidents in the period 2012-2021 to analyze. The result of the paper showed that workers having no more than one year of experience contribute 63.33% of crane accidents.

Generally, previous studies consider crane-related safety risk causes. They focus on specific aspects of the crane. Consequently, this paper assessed and compared crane-related safety risk causes on construction sites in Vietnam from the perspective of other construction project stakeholders, including managers, drivers, and workers. This paper aims to achieve several key objectives. Firstly, it identifies the safety risk caused by cranes on construction sites in Vietnam. Lastly, the paper evaluates these risk causes and groups of causes based on their likelihood of occurrence, severity, and overall

risk levels.

2. Methodology

The research methodology contained the following phases: Fifty-nine (59) crane-related safety risk causes, previously defined in a study [42] were presented in Table 1. These causes were categorized into four (4) groups: Causes associated with regulatory bodies and stakeholders, the crane management of construction sites, workers and staff on construction sites, and environment and equipment. Within these groups, the cause group relating the regulatory bodies and stakeholders contained nine (9) causes, the cause group relating the crane management of the construction site contained fifteen (15) causes, the cause group relating workers and staff on construction site the contained seventeen (17) causes, and the cause group relating environment and equipment included eighteen (18) causes. To evaluate the regularity, severity, and significance of the identified safety risk causes from the perspective of various participators, a well-structured questionnaire was established. The questionnaire uses a 5-point Likert scale. The likelihood of occurrence of safety risk was ranked as follows: 1 - improbable, 2 - remote, 3 - possible, 4 - probable, and 5 - almost certain. The severity was ranked as follows: 1 - negligible, 2 - minor injury, 3 - major injury, 4 - death, and 5 - multiple deaths. There are four sections in the questionnaire: (1) general information including job description, educational qualification, and years of experience; (2) 5 point Likert scale of probability of appearance and 5 point Likert scale of intensity of impact with interpretation; (3) crane-related safety risk causes; and (4) other opinions. The collected data were analyzed to determine the likelihood of occurrence, severity, and importance indices. Moreover, agreement on the degree of crane-related safety risk caused in construction sites among two groups of surveyed people was subjected to ranking and testing.

The research uses MS Excel to treat data and find the likelihood of occurrence, severity, and safety risk level of factors. The safety risk level of causes was shown by a relatively significant index score (RSIS). The RSIS is equal to the combined risk score divided by the population. The combined risk score is equal to the probability risk score multiplied by the intensity of the impact risk score. The RSIS can be calculated by the following equation:

$$RSIS = \alpha_{\text{mean}} \cdot \beta_{\text{mean}} = \frac{\sum \alpha}{N} \cdot \frac{\sum \beta}{N} \tag{1}$$

where α_{mean} is the likelihood mean value, $\sum \alpha$ is the sum of the likelihood risk score, β_{mean} is the degree of influence mean value, $\sum \beta$ is the sum of the degree of influence risk score, and N is the number of respondents per case. This formula allows us to determine the relative significance of each risk caused by considering both how likely it is to occur and how influential it is.

These RSIS valuations were nextly compared against the standard risk values developed by the Construction Plant Hire Association (CPA) [43]. It suggests that RSIS of 1-6 is low and acceptable, and does not require any control actions. RSIS of 7-8 is moderate and is acceptable but it needs a sufficient level of control with operations. RSIS of 15-16 is high and palatable only if no other solution is applicable and with high-level controls in the workplace. RSIS of 20-25 is very high and is an unacceptable risk, plan out or add further controls.

Spearman's rank correlation coefficient was shown. In the context of this research, the coefficient serves to compute the extent of concordance among different surveyed groups. As proposed by Assaf and Al-Hejji [44], Spearman's rank correlation coefficient can be calculated by the following equation:

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

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

Table 1. A list of safety risk causes categorized into four groups [42]

No	Code	Factors
		Regulatory bodies and stakeholders
1	R1	Insufficient construction safety management regulations, procedures, and rules for cranes from the government
2	R2	Insufficient inspection and supervision of safety management by the government on the construction site
3	R3	Bad implementation of certificate management and graduation for crane operators
4	R4	Insufficient crane management by the government (including check and record the manufacture and operation of crane)
5	R5	Main contractor lacks a rational crane safety management system
6	R6	Main contractor with an incomplete attitude for crane safety
7	R7	Main contractor lacks safety funds for the construction safety
8	R8	Subcontractor lacks safety funds for the construction safety
9	R9	Crane with bad manufacturing quality
		Crane management of construction site
10	C1	Main contractor lacks safety supervision and safety management for subcontractor
11	C2	Main contractor do not show safety instruction at construction site for the subcontractor, chief manager, safety officers, and supervisors
12	C3	Main contractor lacks safety plans with crane at construction site
13	C4	Main contractor without the bonus and penalty strategy for safety management at construction sites
14	C5	Main contractor lacks safety education for technical staff and supervisors
15	C6	Main contractor does not fully supervise the crane foundation and installation task
16	C7	Subcontractor does not fully train safety for crane workers
17	C8	Subcontractor lacks safety instructions to crane workers on critical threats and risks
18	C9	Subcontractor does not fully inspect equipment of crane and workers in the installation, operation, and dismantling
19	C10	Subcontractor has different levels during inspections and maintenance
20	C11	Subcontractor maintains the crane in bad condition
21	C12	Subcontractor lacks safety plans for crane installation, operation, and dismantling
22	C13	Subcontractor is pressured by main contractor
23	C14	Crane with unfavourable working space and ground conditions
24	C15	No establishing working area and setting warning sign for crane installation, operation, and dismantling
		Workers and staff on construction site
25	W1	Crane workers with insufficient safety awareness and behaviour
26	W2	Crane workers with stress due to time pressure
27	W3	Crane workers (signaller, slinger, crane operator and, erection/dismantling worker) with insufficient experience, knowledge, skills and, qualifications)
28	W4	Supervisor with unsuitable characteristics (skills, knowledge, responsibility consciousness, professional ethics, so on)
29	W5	Supervisor does not follow the accepted inspection plan (patrol, monthly inspection and quarterly inspection, so on)

No	Code	Factors
30	W6	Supervisor does not fully implement crane safety management in work environment including risk assessment, hazard checking, and routine safety inspections, etc.
31	W7	Supervisor lacks safety guidance for crane – related workers
32	W8	Signaller does not provide lift signal in clear and exact manner to operator
33	W9	Rigger can not hook and remove the load in the safe and exact manner
34	W10	Erection/dismantling workers do not follow the safety instructions and procedures when working
35	W11	Erection/dismantling workers without safety protection equipment
36	W12	Erection/dismantling workers' uncomfortable behaviour and psychological characteristics
37	W13	Crane operator without routine checking with components of crane before and after working
38	W14	Crane operator with unsuitable decision and behaviour affecting the safety operation
39	W15	Crane operators with uncomfortable behaviour and psychological characteristics
40	W16	Crane operators with bad physical condition while operating
41	W17	Difficult communication between crane operator, signaller, and rigger
		Environment and equipment
42	E1	Working area of crane has overlap (many cranes work together)
43	E2	Other actions in the working area of crane
44	E3	Auxiliary equipment is added due to increase safety
45	E4	Operator with the blind view (blind lifts) during crane operation
46	E5	Crane-related workers with the bad visibility at the construction site
47	E6	Crane safety devices with unsuitable quality and reliability
48	E7	Subsidiary equipment (such as installation tools, wire rope, etc.) with unsuitable quality and reliability
49	E8	The low reliability of crane attachment devices (such as bolts, embedded parts, adhering bars, welds, etc.) between the building and the crane
50	E9	The low reliability of crane foundation components such as tension piles, supporting structure, concrete base, etc.
51	E10	The bad quality and reliability of crane structural parts and accessories
52	E11	The inconvenience level of the crane operator cab
53	E12	The unsuitable work height of the crane or height of the cab
54	E13	Obstacle in the crane's work region and other disadvantages
55	E14	Unfavourable weather including bad temperatures and other weather phenomena
56	E15	Wind with inconvenience effect at construction site
57	E16	The bad ground conditions for mobile cranes
58	E17	Crane frequently works in surrounding of live power lines
59	E18	Crane or lifting load hits against the other objects at the construction site

3. Results and Discussion

3.1. Respondents profile

A total of 80 questionnaires were sent to practitioners who are handling crane-related works, including managers (government safety regulators; safety managers; equipment managers and project managers), crane drivers, and crane-related workers (signaller, rigger, iron workers). Sixty valid

answers were received, resulting in an impressive 75% response rate, including managers (40%), crane drivers (31.7%), and crane-related workers (28.3%) as in Table 2. Louanglath [45] shows that the minimum sample size for an unknown population for 95% confidence interval with 5% error level is approximately 34. Table 2 presents the general information of the respondents such as their job description, educational qualification, and years of experience. About 11.7%, 18.3%, 41.7%, 15.0% and 13.3% of the respondents have between 0 and 5 years of experience, between 6 and 10 years of experience, between 11 and 15 years of experience, between 16 and 20 years of experience, and more than 20 years of experience, respectively. In terms of educational qualification, high school holders are the least represented at 11.7%, secondary graduation holds the highest representation, standing at 48.3%.

Table 2. Respondents profile

No	Item	Number	Percentage
	Job description		
1	Managers (Government safety regulators; safety managers; equipment managers and project managers)	24	40.0
2	Crane drivers	19	31.7
3	Crane-related workers	17	28.3
	Total	60	100
	Educational Qualification		
1	High school	7	11.7
2	Secondary graduation	29	48.3
3	Bachelors	13	21.7
4	MSc	11	18.3
	Total	60	100
	Years of experience		
1	0-5	7	11.7
2	6-10	11	18.3
3	11-15	25	41.7
4	16-20	9	15.0
5	Over 20	8	13.3
	Total	60	100

3.2. Ranking safety risk causes by parties

Ranking frequentness, severity, and degree of safety risk of safety risk causes based on the perspective of managers, drivers, and crane-related workers are described in Tables 3 - 5, respectively. Remarkably, Tables 3 and 5 represent that all managers, drivers, and crane-related workers concurred in identifying "Crane with bad manufacturing quality-R9" as the highest degree of severity. Managers suppose that "Crane workers with stress due to time pressure" cause is the most common safety risk and the highest safety risk level. Crane-related workers suppose that "Bad implementation of certificate management and graduation for crane operators" is the highest safety risk level with RSIS score of 12.82.

Table 3 declares the opinions of managers. They show that the most frequent safety risk cause is "Crane workers with stress due to time pressure-W2" with a mean value of 3.33. Otherwise, the least

probable cause is "Insufficient construction safety management regulations, procedures, and rules for crane from government-R1" with a mean value of 2.50. The cause "Crane with bad manufacturing quality-R9" attained the highest degree of severity, registering a mean value of 3.88. On the other hand, the cause "Subcontractor lacks safety funds for the construction safety-R8" garnered the lowest degree of severity with a mean value of 2.25. Table 3 also shows that "Crane workers with stress due to time pressure-W2" cause had the highest RSIS score of 11.25. In contrast, the "Subcontractor lacks safety funds for the construction safety-R8" cause had the lowest RSIS score of 6.47. Notably, Table 6 presents that safety risk causes relating to the group of crane management of construction site was the most common safety risk and the highest RSIS. The group of regulatory bodies and stakeholders had the highest degree of severity.

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

No	Code	Likelihood of occurrence			Degree of severity			Safety risk level		
		Mean	Std. Dev	Rank	Mean	Std. Dev	Rank	RSIS	Rank	Risk level
	Regulatory bodies and stakeholders	2.81	1.14		3.12	1.12		8.77		M
1	R1	2.50	1.18	59th	3.54	1.25	3rd	8.85	30th	M
2	R2	3.00	1.14	13th	3.46	1.02	4th	10.38	9th	M
3	R3	2.88	1.19	26th	3.38	1.21	9th	9.70	15th	M
4	R4	2.58	1.32	57th	2.67	1.17	56th	6.89	56th	L
5	R5	3.04	1.04	10th	3.33	1.13	12th	10.14	12th	M
6	R6	2.83	0.96	36th	3.25	0.99	20th	9.21	23th	M
7	R7	2.83	1.09	36th	2.29	1.00	58th	6.49	58th	L
8	R8	2.88	1.08	26th	2.25	1.07	59th	6.47	59th	L
9	R9	2.79	1.25	44th	3.88	1.23	1st	10.82	4th	M
	Crane management of the construction site	2.85	1.01		3.11	1.12		8.87		M
10	C1	2.96	1.04	16th	3.21	1.14	24th	9.49	20th	M
11	C2	2.88	0.99	26th	3.29	1.12	17th	9.46	21st	M
12	C3	2.79	0.98	44th	3.21	1.06	24th	8.96	28th	M
13	C4	2.79	0.97	44th	2.33	1.01	57th	6.51	57th	L
14	C5	2.75	1.03	49th	3.04	1.00	34th	8.37	43th	M
15	C6	2.63	1.01	55th	3.25	1.19	20th	8.53	37th	M
16	C7	2.75	0.94	49th	3.13	1.04	30th	8.59	36th	M
17	C8	2.79	1.02	44th	3.04	1.00	34th	8.49	39th	M
18	C9	3.00	1.02	13th	3.42	1.10	5th	10.25	11th	M
19	C10	2.92	1.06	22nd	3.04	1.20	34th	8.87	29th	M
20	C11	3.13	1.11	6th	3.29	1.27	17th	10.29	10th	M
21	C12	2.71	0.91	53th	3.21	1.10	24th	8.69	33rd	M
22	C13	3.04	1.00	10th	2.88	1.42	43th	8.75	31st	M
23	C14	2.75	1.07	49th	3.33	1.17	12th	9.17	24th	M
24	C15	2.89	1.03	26th	3.00	1.02	39th	8.63	34th	M
	Workers and staff on the construction site	2.91	1.06		3.14	1.21		9.14		M
25	W1	3.21	1.06	3rd	3.42	1.14	5th	10.96	3rd	M
26	W2	3.33	0.92	1st	3.38	1.10	9th	11.25	1st	M
27	W3	3.25	1.07	2nd	3.42	1.06	5th	11.10	2nd	M
28	W4	2.75	1.26	49th	2.92	1.32	40th	8.02	49th	M
29	W5	2.96	1.16	16th	2.88	1.30	43th	8.51	38th	M

No	Code	Likelihood of occurrence			Degree of severity			Safety risk level		
		Mean	Std. Dev	Rank	Mean	Std. Dev	Rank	RSIS	Rank	Risk level
30	W6	2.92	1.14	22nd	3.08	1.28	33th	8.99	25th	M
31	W7	2.83	1.05	36th	3.17	1.17	28th	8.97	27th	M
32	W8	2.88	0.90	26th	3.13	1.30	30th	8.98	26th	M
33	W9	3.00	0.98	13th	3.38	1.21	9th	10.13	13th	M
34	W10	2.83	1.13	36th	3.71	1.20	2nd	10.51	6th	M
35	W11	2.88	1.03	26th	3.33	1.24	12th	9.58	19th	M
36	W12	2.58	1.02	57th	2.79	1.18	50th	7.21	55th	L
37	W13	2.88	1.12	26th	2.88	1.23	43th	8.27	44th	M
38	W14	2.63	0.97	55th	3.04	1.27	34th	7.98	51st	L
39	W15	2.71	1.08	53th	3.13	1.26	30th	8.46	41st	M
40	W16	2.83	1.05	36th	2.83	1.13	46th	8.03	48th	M
41	W17	2.96	1.12	16th	2.83	1.13	46th	8.38	42th	M
	Environment and equipment	2.97	1.02		3.03	1.19		8.99		M
42	E1	3.08	1.02	9th	2.83	1.27	46th	8.74	32nd	M
43	E2	2.96	1.34	16th	2.71	1.08	54th	8.01	50th	M
44	E3	2.88	1.08	26th	2.71	1.16	54th	7.79	54th	L
45	E4	3.17	1.01	5th	3.33	1.13	12th	10.56	5th	M
46	E5	3.21	1.06	3rd	3.25	1.11	20th	10.43	7th	M
47	E6	2.83	0.96	36th	3.42	1.14	5th	9.68	16th	M
48	E7	2.96	1.08	16th	3.25	1.33	20th	9.62	17th	M
49	E8	2.92	0.97	22nd	3.29	1.23	17th	9.60	18th	M
50	E9	2.96	1.04	16th	3.17	1.43	28th	9.37	22nd	M
51	E10	2.79	1.10	44th	3.04	1.08	34th	8.49	40th	M
52	E11	2.88	0.99	26th	2.75	1.03	52th	7.91	52th	L
53	E12	2.83	0.92	36th	2.92	1.14	40th	8.26	45th	M
54	E13	3.04	0.91	10th	2.83	1.05	46th	8.62	35th	M
55	E14	2.88	0.99	26th	2.75	1.07	52th	7.91	53rd	L
56	E15	3.13	0.95	6th	3.21	1.22	24th	10.03	14th	M
57	E16	2.92	0.97	22th	2.79	1.38	50th	8.14	47th	M
58	E17	3.13	0.95	6th	3.33	1.17	12th	10.42	8th	M
59	E18	2.83	0.96	36th	2.92	1.35	40th	8.26	45th	M

M: Moderate; L: Low.

Drivers' viewpoints are presented in Table 4. The findings show that the most common safety risk cause is "Crane workers with insufficient safety awareness and behaviour –W1" with a mean value of 3.21. Otherwise, the least probable causes are "Insufficient construction safety management regulations, procedures, and rules for crane from government-R1" and "Crane frequently works in surrounding of live power lines–E17" with a mean value of 2.50. The cause "Crane with bad manufacturing quality–R9" attained the highest degree of severity, registering a mean value of 3.88. On the other hand, the cause "The inconvenience level of the crane operator cab–E11" garnered the lowest degree of severity with a mean value of 2.53. Table 4 also shows that the "Main contractor does not fully supervise the crane foundation and installation task–C6" cause had the highest RSIS score of 9.48. In contrast, "The unsuitable work height of the crane or height of the cab–E12" cause had the lowest RSIS score of 7.18. Notably, safety risk causes relating to the group of crane management of the construction site and group of workers and staff on construction site were the most common safety risk with a mean value of 2.97. The group of crane management of construction site had the highest degree of severity with a mean value of 2.98 and the highest RSIS score of 8.85.

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

No	Code	Likelihood of occurrence			Degree of severity			Safety risk level		
		Mean	Std. Dev	Rank	Mean	Std. Dev	Rank	RSIS	Rank	Risk level
	Regulatory bodies and stakeholders	2.88	0.98		2.92	1.05		8.41		M
1	R1	2.68	1.06	56th	2.79	0.92	33th	7.49	49th	L
2	R2	2.84	1.07	40th	3.11	1.20	4th	8.83	13th	M
3	R3	2.68	1.11	56th	2.95	1.08	12th	7.91	40th	L
4	R4	2.95	0.97	20th	2.63	0.96	50th	7.76	44th	L
5	R5	2.95	0.97	20th	3.00	1.25	9th	8.84	10th	M
6	R6	3.00	0.94	9th	2.95	0.97	12th	8.84	10th	M
7	R7	3.00	0.88	9th	2.90	0.99	20th	8.68	18th	M
8	R8	2.95	0.85	20th	2.84	0.96	28th	8.38	31st	M
9	R9	2.84	0.96	40th	3.17	1.12	1st	8.98	9th	M
	Crane management of the construction site	2.97	0.89		2.98	0.95		8.85		M
10	C1	3.05	0.85	3rd	2.84	0.96	28th	8.68	22nd	M
11	C2	2.95	0.97	20th	3.16	0.96	2nd	9.31	3rd	M
12	C3	2.95	0.97	20th	3.16	1.02	2nd	9.31	3rd	M
13	C4	3.00	0.94	9th	2.90	0.88	20th	8.68	18th	M
14	C5	2.90	0.94	37th	2.90	0.94	20th	8.38	30th	M
15	C6	3.05	0.85	3th	3.11	1.00	4th	9.48	1st	M
16	C7	3.00	0.82	9th	3.05	1.03	6th	9.16	5th	M
17	C8	2.84	0.83	40th	2.95	0.85	12th	8.38	31st	M
18	C9)	3.05	0.85	3rd	3.05	1.03	6th	9.32	2nd	M
19	C10	2.95	0.85	20th	2.84	0.96	28th	8.38	31st	M
20	C11	2.90	0.88	37th	3.00	1.00	9th	8.68	18th	M
21	C12	2.95	1.03	20th	3.05	0.85	6th	9.00	8th	M
22	C13	2.95	0.91	20th	2.90	0.88	20th	8.53	24th	M
23	C14	3.05	0.85	3rd	2.84	0.96	28th	8.68	22nd	M
24	C15	3.00	0.82	9th	2.95	0.97	12th	8.84	10th	M
	Workers and staff on the construction site	2.97	0.97		2.83	0.99		8.39		M
25	W1	3.21	0.98	1st	2.84	1.07	28th	9.13	6th	M
26	W2	3.05	0.97	3rd	2.79	1.13	33rd	8.52	27th	M
27	W3	3.00	0.88	9th	3.00	1.00	9th	9.00	7th	M
28	W4	2.95	1.03	20th	2.79	0.98	33rd	8.22	36th	M
29	W5	2.95	0.91	20th	2.95	0.91	12th	8.69	14th	M
30	W6	2.95	0.85	20th	2.95	0.91	12th	8.69	14th	M
31	W7	2.95	0.91	20th	2.95	0.97	12th	8.69	14th	M
32	W8	2.79	0.98	50th	2.90	0.99	20th	8.08	37th	M
33	W9	2.95	0.91	20th	2.90	0.99	20th	8.53	25th	M
34	W10	2.95	0.91	20th	2.95	0.97	12th	8.69	14th	M
35	W11	2.95	0.91	20th	2.90	0.94	20th	8.53	25th	M
36	W12	3.00	1.11	9th	2.79	1.08	33rd	8.37	34th	M
37	W13	2.95	1.08	20th	2.63	1.01	50th	7.76	45th	L
38	W14	2.84	0.96	40th	2.58	0.90	54th	7.33	55th	L
39	W15	3.00	1.11	9th	2.68	1.06	45th	8.05	38th	M
40	W16	3.00	1.00	9th	2.79	0.98	33rd	8.37	34th	M
41	W17	3.00	1.00	9th	2.68	1.00	45th	8.05	38th	M
42	E1	2.74	0.93	54th	2.68	1.00	45th	7.35	53rd	L

No	Code	Likelihood of occurrence			Degree of severity			Safety risk level		
		Mean	Std. Dev	Rank	Mean	Std. Dev	Rank	RSIS	Rank	Risk level
	Environment and equipment	2.85	0.93		2.69	0.93		7.66		L
43	E2	2.84	1.07	40th	2.63	1.01	50th	7.48	51st	L
44	E3	2.84	1.07	40th	2.68	1.00	45th	7.63	46th	L
45	E4	2.79	0.92	50th	2.79	0.92	33rd	7.78	41st	L
46	E5	2.79	0.86	50th	2.79	0.86	33rd	7.78	41st	L
47	E6	2.84	1.07	40th	2.58	1.02	54th	7.33	55th	L
48	E7	3.05	0.97	3rd	2.79	0.98	33rd	8.52	27th	M
49	E8	3.00	0.94	9th	2.90	0.99	20th	8.68	18th	M
50	E9	3.11	0.94	2nd	2.74	1.05	42nd	8.50	29th	M
51	E10	2.95	0.91	20th	2.58	0.90	54th	7.60	47th	L
52	E11	2.84	0.90	40th	2.53	0.91	59th	7.18	59th	L
53	E12	2.79	0.79	50th	2.58	0.90	54th	7.19	58th	L
54	E13	2.68	0.82	56th	2.74	0.81	42nd	7.35	53rd	L
55	E14	2.84	0.90	40th	2.63	0.83	50th	7.48	51st	L
56	E15	2.90	0.99	37th	2.68	0.89	45th	7.77	43rd	L
57	E16	2.84	0.96	40th	2.58	0.90	54th	7.33	55th	L
58	E17	2.68	0.82	56th	2.79	0.86	33rd	7.49	49th	L
59	E18	2.74	0.81	54th	2.74	0.87	42nd	7.49	48th	L

M: Moderate; L: Low.

Crane-related workers' viewpoints are presented in Table 5. The findings show that the most common safety risk cause is "Subcontractor lacks safety funds for the construction safety–R8" with a mean value of 3.47. Otherwise, the least probable cause is "Insufficient inspection and supervision of safety management by the government on the construction site–R2" with a mean value of 2.59. The cause "Crane with bad manufacturing quality-R9" attained the highest degree of severity, registering a mean value of 4.00. On the other hand, the cause "Auxiliary equipment is added due to increased safety–E3" garnered the lowest degree of severity with a mean value of 2.41. Table 5 also presents that "Bad implementation of certificate management and graduation for crane operators–R3" cause had the highest RSIS score of 12.82. In contrast, "Auxiliary equipment is added due to increased safety–E3" cause had the lowest RSIS score of 6.81. Notably, safety risk causes relating to groups of workers and staff on the construction site were the most common safety risk with a mean value of 3.01. The group of regulatory bodies and stakeholders had the highest degree of severity with a mean value of 3.40 and The group of crane management of construction sites had the highest RSIS score of 10.63.

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

No	Code	Likelihood of occurrence			Degree of severity			Safety risk level		
		Mean	Std. Dev	Rank	Mean	Std. Dev	Rank	RSIS	Rank	Risk level
	Regulatory bodies and stakeholders	3.06	1.39		3.40	1.32		10.37		M
1	R1	3.00	1.50	31st	3.65	1.27	3rd	10.94	12th	M
2	R2	2.59	1.37	59th	3.53	1.28	8th	9.14	45th	M
3	R3	3.35	1.37	2nd	3.82	1.13	2nd	12.82	1st	M
4	R4	2.82	1.29	50th	3.00	1.41	46th	8.47	53rd	M
5	R5	3.18	1.19	15th	3.59	1.12	7th	11.40	5th	M
6	R6	3.00	1.41	31st	3.47	1.42	12th	10.41	21st	M
7	R7	3.18	1.47	15th	2.71	1.57	57th	8.60	52nd	M

No	Code	Likelihood of occurrence			Degree of severity			Safety risk level		
		Mean	Std. Dev	Rank	Mean	Std. Dev	Rank	RSIS	Rank	Risk level
8	R8	3.47	1.38	1st	2.82	1.43	53th	9.80	31st	M
9	R9	2.94	1.56	38th	4.00	1.23	1st	11.76	2nd	M
	Crane management of construction site	3.20	1.18		3.33	1.24		10.63		M
10	C1	3.29	0.99	5th	3.53	1.18	8th	11.63	3rd	M
11	C2	3.24	1.03	8th	3.53	1.18	8th	11.42	4th	M
12	C3	3.18	1.19	15th	3.47	1.28	12th	11.02	10th	M
13	C4	3.29	1.11	5th	2.77	1.20	54th	9.11	47th	M
14	C5	3.12	1.27	18th	3.12	1.22	40th	9.72	32nd	M
15	C6	3.00	1.32	31st	3.65	1.37	3rd	10.94	12th	M
16	C7	3.24	1.15	8th	3.47	1.38	12th	11.23	8th	M
17	C8	3.35	1.17	2nd	3.35	1.22	22nd	11.24	6th	M
18	C9)	3.29	1.31	5th	3.41	1.33	16th	11.24	7th	M
19	C10	3.24	1.09	8th	3.24	1.09	28th	10.47	18th	M
20	C11	3.12	1.05	18th	3.53	1.18	8th	11.00	11th	M
21	C12	3.24	1.15	8th	3.24	1.03	28th	10.47	18th	M
22	C13	3.24	1.39	8th	3.00	1.28	46th	9.71	34th	M
23	C14	3.00	1.17	31st	3.65	1.50	3th	10.94	12th	M
24	C15	3.12	1.27	18th	3.00	1.17	46th	9.35	40th	M
	Workers and staff on construction site	3.01	1.21		3.23	1.27		9.67		M
25	W1	3.06	1.20	27th	3.18	1.24	35th	9.72	33rd	M
26	W2	3.35	1.46	2nd	3.18	1.33	35th	10.65	17th	M
27	W3	3.06	1.25	27th	3.35	1.46	22nd	10.26	23rd	M
28	W4	2.94	1.20	38th	3.06	1.14	41st	8.99	49th	M
29	W5	3.00	1.32	31st	3.00	1.32	46th	9.00	48th	M
30	W6	2.94	1.14	38th	3.18	1.33	35th	9.34	41st	M
31	W7	3.06	1.09	27th	3.35	1.12	22nd	10.26	23rd	M
32	W8	3.12	1.05	18th	3.47	1.13	12th	10.82	15th	M
33	W9	3.12	1.36	18th	3.24	1.30	28th	10.09	25th	M
34	W10	2.94	1.20	38th	3.41	1.37	16th	10.03	27th	M
35	W11	3.06	1.20	27th	3.06	1.20	41st	9.36	39th	M
36	W12	3.00	1.06	31st	3.29	1.21	25th	9.88	28th	M
37	W13	3.12	1.27	18th	3.24	1.30	28th	10.09	25th	M
38	W14	2.65	1.11	57th	3.18	1.24	35th	8.41	54th	M
39	W15	2.88	1.27	46th	3.29	1.31	25th	9.50	38th	M
40	W16	2.94	1.14	38th	3.18	1.29	35th	9.34	41st	M
41	W17	2.88	1.22	46th	3.00	1.32	46th	8.65	51st	M
	Environment and equipment	2.93	1.21		3.11	1.27		9.15		M
42	E1	2.94	1.14	38th	3.00	1.23	46th	8.82	50th	M
43	E2	3.12	1.17	18th	3.29	1.26	25th	10.27	22nd	M
44	E3	2.82	1.19	50th	2.41	1.42	59th	6.81	59th	L
45	E4	3.24	1.39	8th	3.41	1.23	16th	11.04	9th	M
46	E5	3.24	1.20	8th	3.24	1.20	28th	10.47	18th	M
47	E6	2.88	1.36	46th	3.41	1.33	16th	9.83	29th	M
48	E7	2.94	1.14	38th	3.24	1.15	28th	9.52	37th	M
49	E8	2.88	1.27	46th	3.41	1.28	16th	9.83	29th	M
50	E9	2.71	1.31	55th	3.41	1.42	16th	9.23	43rd	M
51	E10	2.71	1.16	55th	2.94	1.30	52nd	7.96	55th	L

No	Code	Likelihood of occurrence			Degree of severity			Safety risk level		
		Mean	Std. Dev	Rank	Mean	Std. Dev	Rank	RSIS	Rank	Risk level
52	E11	2.65	1.06	57th	2.77	1.35	54th	7.32	58th	L
53	E12	2.82	1.01	50th	2.77	1.03	54th	7.81	56th	L
54	E13	2.82	1.13	50th	3.24	1.25	28th	9.14	45th	M
55	E14	2.82	1.13	50th	2.71	1.26	57th	7.64	57th	L
56	E15	3.12	1.22	18th	3.06	1.25	41st	9.54	35th	M
57	E16	3.00	1.28	31st	3.06	1.48	41st	9.18	44th	M
58	E17	2.94	1.30	38th	3.65	1.22	3rd	10.73	16th	M
59	E18	3.12	1.36	18th	3.06	1.25	41st	9.54	35th	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	Regulatory bodies and stakeholders - related causes	2.91	4th	3.15	1st	9.18	2nd	M
2	Crane management of construction site - related causes	3.01	1st	3.14	2nd	9.45	1st	M
3	Workers and staff on construction site - related causes	2.96	2nd	3.07	3rd	9.07	3rd	M
4	Environment and equipment - related causes	2.92	3rd	2.94	4th	8.60	4th	M

M: Moderate; L: Low.

3.3. The importance of rank correlation

The value of Spearman's rank correlation coefficient facilitates evaluates the level of concordance or discordance of two parties shown in Table 7. The outcomes derived from Eq. (2) reveal the extent of alignment. Notably, there is concordance between the two distinct groups of parties. The highest degree of concurrence, approximately 67.0%, materializes between managers and crane-related workers. In contrast, the lowest level of agreement, about 51.0%, is observed between managers and crane drivers. 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 crane drivers	0.51	0.95
2	Managers and crane-related workers	0.67	0.95
3	Crane drivers and crane-related workers	0.55	0.95

4. Conclusion

The study concentrated on evaluating crane safety risk causes encountered in the Vietnamese construction industry, based on the perspectives of various participants: crane drivers, crane-related workers, and managers (government safety regulators; safety managers; equipment managers and project managers). The survey revealed unanimous identification of 59 distinct crane safety risk

causes. However, disparities in viewpoints emerged among crane drivers, crane-related workers, and managers. All managers, drivers, and crane-related workers concurred in identifying "Crane with bad manufacturing quality-R9" as the highest degree of severity. Managers suppose that "Crane workers with stress due to time pressure" cause is the most common safety risk and the highest safety risk level. Crane-related workers suppose that "Bad implementation of certificate management and graduation for crane operators" is the highest safety risk level with RSIS score of 12.82. Among the causes, safety risk causes relating to group of crane management of construction site was the most common safety risk and the highest RSIS. The group of regulatory bodies and stakeholders had the highest degree of severity. The assessment of crane safety risk causes through ranking demonstrated an evident degree of agreement between distinct groups of parties. This enhances the reliability of the research findings. This research sent questionnaires to companies in Northern Vietnam with similar sizes and in the same construction field. Future research should expand the sample size and geographic scope to improve reliability.

Acknowledgements

This research has been financially supported by Hanoi University of Civil Engineering, Vietnam (HUCE), through grant number 17-2024/KHXD.

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