International Journal on Advanced Science Engineering Information Technology

Vol.13 (2023) No. 2
ISSN: 2088-5334

Safety Risk Factors for Tower Cranes Used by Small and Medium-Scale Contractors on Construction Sites

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***Abstract*— Considering a large number of Small and Medium-Scale Contractors (SMSCs) dominating the construction industries of many developing nations and the increasingly high rate of tower crane accidents in the industry, this paper seeks to methodically determine the safety risk factors that are significant in influencing construction site safety, especially on sites where the SMSCs operate tower cranes. The paper will further assess the extent to which each safety risk factor affects safety on construction sites. Data for the study was obtained through a literature search, site visual observations, discussions with site operators, and structured questioning of safety and equipment managers of leading construction companies. The study's findings reveal that the *operator's low experience level* was the most significant factor influencing construction site safety, particularly when operating tower cranes. This paper systematically investigates the key safety risk factors that influence construction site safety when operating tower cranes. The paper presents a clear methodology for identifying and prioritizing the safety risk factors, which may readily apply to other construction equipment. The findings of this paper are expected to play an important role in promoting and enhancing a safety culture for operating tower cranes in construction sites, particularly the project sites operated by the SMSCs.**

***Keywords*—Construction site; construction safety; risk factors; small & medium-scale contractors; tower cranes.**

Manuscript received 11 Feb. 2022; revised 12 Sep. 2022; accepted 15 Feb. 2023. Date of publication 30 Apr. 2023.

I. INTRODUCTION

The construction industry of Saudi Arabian is considered one of the most significant pillars of the nation's economy, and it generates 9.5% of the Kingdom's Gross Domestic Product [1]. About 18% of the country's population is gainfully employed in construction [2]. This corroborates the fact that the construction industry in Saudi Arabia is an indispensable sector of the Kingdom's economy [3], [4]. However, construction projects in Saudi Arabia have been synonymous with accidents despite the industry's significant impact on the nation's economy and the considerable improvements in safety through the years [2]. Remarkably, the rate of accidents in construction projects is second to none compared to any other sector of the economy [5], [6]. The construction industry singlehandedly accounted for over 50% of the reported 69,241 job-related accidents in 2014 [7]. These accidents could be related to various factors and causes, among which crane-related accidents remain prominent.

Cranes, one of the most operated equipment on construction sites, can be dangerous. In the last decade, there have been over a thousand reported cases of crane accidents worldwide [8]. As Song [9] pointed out, working with tower cranes to lift loads during construction is among the major causes of accidents and loss of lives in the construction industry. For instance, in 2015, a tower crane collapsed onto the Grand Mosque in Makkah, Saudi Arabia, killing over one hundred persons. About four hundred sustained various injuries while many pilgrims got trapped under the debris [10].

Considering their structure and configuration, operating tower cranes on construction sites is a complex and hazardous task that depends on experienced and proficient operators considering the safety risk factors [11]. Thus, safety remains the key driving force for the successful operation of tower cranes on construction sites [12]. To seek a sustainable solution to this, it is essential to closely look at the activities of construction companies, especially the 'small and medium-scale contractors (SMSCs)', regarding how they handle safety risks related to tower crane operation on their project sites [13].

Therefore, an attempt was made in this paper to determine the key safety risk factors that influence site safety in which the SMSCs operate tower cranes. The paper aimed to measure how each safety risk factor influences project-site safety. The

safety risk factors with a higher influence level should be considered, and allocated sufficient project resources to ensure that construction site safety is enhanced.

II. Materials and Method

In many developing nations worldwide, small & medium-scale contractors (SMSCs) outnumber the big construction companies [13]. The SMSCs play some essential roles in the economies of developing nations. The most predominant construction companies in developing countries are the SMSC, which operates within the local context [14]. In Saudi Arabia, a large proportion of the local construction contractors are SMSCs. As evidenced in developed countries, the safety performance of SMSCs is lower than that of larger construction companies [15]. When faced with issues like scarcity of project resources, the SMSCs are not likely to provide adequate funds for managing construction safety [14]. Alizadeh [15] observed that SMSCs usually have a safety plan and safety professional on board, not because the companies have a real safety commitment. Still, for the reason that top management feels that it is an essential evil. He further stated that though not all SMSCs operate this way, many do so. This is because construction projects normally operate with a small profit margin, which leads to sharp practices and cutting corners. Thus, if a project owner fails to enforce safety, then the contractor is not motivated to prioritize safety.

With most SMSCs, construction safety risks are often wrongly considered to have a low impact [14]. The owners, project engineers, and managers mostly misconstrue the extent of the safety risk of their construction projects and hardly involve their employees in making key safety-related decisions [16]. Given the large number of SMSCs in the construction industries of many developing countries around the world, the low safety performance of most SMSCs, and the increasingly high rate of tower crane accidents and fatalities in the industry. It is obvious not to overlook the safety risks posed by activities of SMSCs especially the safety risk factors that have a significant influence on-site safety where tower cranes are operated.

Over the past few years, there have been tremendous technological advancements in the manufacture, assembly, erection, operation, and disassembly of tower cranes [17], [18]. These cranes are easily noticeable in many construction sites; they are mostly used to help achieve the requisite work capacity and for the project to remain on schedule. It is hard to see a construction site without a tower crane to lift and pull heavy loads to the appropriate heights [19]. It is common to see tower cranes in city centers and in residential and public buildings. Tower cranes have indeed come to serve a crucial role in developing the built environment. Tower cranes are commonly operated in constructing high-rise and overcrowded metropolitan buildings worldwide [20].

Working with tower cranes on construction project sites poses many threats to health and safety [18], [21]. A review of related literature suggests that few published research works focus mainly on tower crane safety risk factors on construction sites [11], [18], [20]–[24]. Consequently, the preliminary list of the safety risk factors was obtained from reviewing a few available pieces of literature. There seem to be few quantitative works undertaken that focus on the subject at the project site. While some studies advocate for using quantitative models in assessing safety management on-site, these quantitative models are typically inferential, incapable of reflecting the real site risks, and do not suggest the risk causes. Therefore, this paper seeks to methodically ascertain the main safety risk factors that significantly influence the site safety in which the SMSCs operate tower cranes. The paper will seek to assess further how each safety risk factor affects safety on construction sites.

Given the main goal of this study, this section seeks to describe the method used to methodically determine the key safety risk factors that significantly influence safety on sites where SMSCs operate tower cranes. Figure 1 presents the methodology adopted. The author embarked on a desk study to meticulously obtain some of the safety risk factors under study. This process involved an extensive review of related literature on the subject, and the author produced a preliminary list of the factors. As shown in Figure 1, the next step led to the visual observations at various construction sites in Dammam, Khobar, Dhahran, and Jubail, where the SMSCs and the big and reputable contractors operate tower cranes.

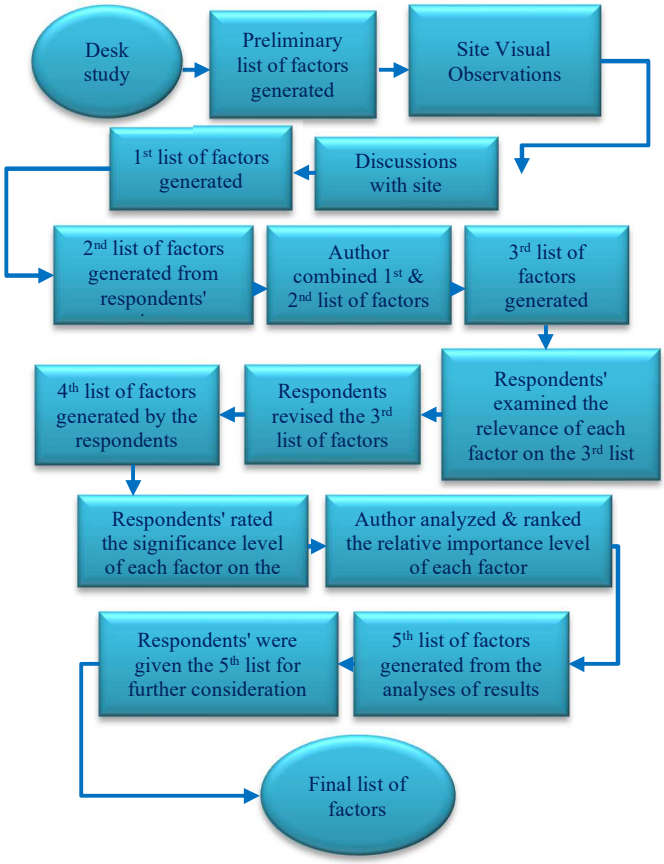

Fig. 1 Methodology Flowchart

These site visits aimed to observe the operations of the tower cranes and to engage the site managers, crane operators, superintendents, signalpersons, safety managers, and equipment managers in valuable discussions on safety management in the operation of tower cranes in construction sites. The site visits were fruitful as some safety risk factors associated with operating tower cranes on construction sites were explored, which the author did not capture earlier during the desk study. As a result, the site visits helped to expand the

preliminary list of factors the author had compiled, and the first list of the factors was generated.

The next step in the methodology framework involved obtaining more safety risk factors and confirming the validity of the factors already identified from the literature, site observations, and discussions with site operators. Thus, to get more knowledge sources to identify the safety risk factors, the author turned to the professionals (through face-to-face interviews) to tap into their wealth of experience. This was essential because accurate data for tower crane-related accidents in construction sites hardly exist, but even where the records are available, they hardly provide the root causes of the accidents examined [23].

The sample of professionals that provided more knowledge sources for this study consists of 63 specialists, mostly equipment or safety managers in some big construction companies in Riyadh and Eastern Province. The companies in which these specialists operate are known for operating large fleets of tower cranes on their construction sites and are equally famous for their involvement in many high-profile projects, managerial efficiency, safety culture, and good use of automation in construction.

Of the 63 specialists, 27 are safety managers; 21 are equipment engineers and the remaining 15 double as safety and equipment managers in their respective companies. Thirty-six specialists have been in their present positions in the companies for over twenty years, while the others have served for over ten years. Thus, it could be inferred that the specialists have the satisfactory working experience to provide the required information, especially that concerned with identifying and assessing safety risk factors of using tower cranes on construction sites. Their overall competencies add validity to the findings of this study.

In the first part of the interview with the specialists, they were requested to shed more light on managing safety risks on construction sites. In the second part, they identified the key safety risk factors that significantly influence safety on construction sites where the SMSCs operate tower cranes. Thus, the list of factors compiled from the specialists' contributions is known as the '2nd list'. In the third part of the interview, the author combined the two lists (the list generated by the specialists and the one generated by the author from literature, site observations, and discussions with site operators). The combined list is referred to as the '3rd list'. Thus, the specialists then examined the relevance of each factor on the 3rd list, renamed and removed some factors, and modified the list. The modified list is referred to as the '4th list'.

At this stage, having already established contact with the specialists, the author designed a structured survey questionnaire seeking the specialists (now the respondents) to rate the significance level of each factor listed on the '4th list' based on the extent to which it influences site safety when working with tower cranes on project sites. The evaluation was established by a five-point Likert scale.

- One = Very low importance; if the respondent feels the factor has very low influential
- Two = Low importance; if the respondent feels the factor has a low influence
- Three = Moderate importance; if the respondent feels the factor has a fair influence
- Four = High importance; if the respondent feels the factor has a strong influence
- Five = Very High importance; if the respondent feels the factor has a very strong influence

The Relative Importance Index (RII) was used to analyze the data obtained [25]. After that, the analyzed results (prioritized safety risk factors) were presented in the '5th list', which was sent to the respondents along with their assessment of the factors for further consideration. The respondents were then requested to examine the analyzed results and consider modifying their initial assessments, especially where there was a significant deviation from the mean assessment of other respondents to the survey. Eventually, a few more revisions were made, and the final list of factors was compiled, which ended this study's knowledge extraction stage.

Furthermore, the key safety risk factors that significantly influence safety on construction sites where the SMSCs operate tower cranes are presented in Table 1. The safety risk factors are classified into three primary groups, namely managerial, behavioral, and site-based factors. Other notable factors like crane configuration, crane procurement strategy, and frequency of crane assembly and dismantling cycles, were unanimously excluded by the specialists considering their level of influence on safety and the fact that the factors are predominantly one-time operations that will cease to be present right through the construction stage on site.

TABLE I
SAFETY RISK FACTORS

Behavioral Factors
Operator's low level of experience
Operator's mindset & mental capacity
Rigger's poor level of experience
Signalperson's low level of experience
Superintendent's mindset & mental capacity
Managerial Factors
Frequent replacement of crane operators
Insufficient training for personnel
Nature of employment
The poor accident investigation process
Poor maintenance management of crane & lifting accessories
Poor safety culture
Site Conditions Factors
Contact with energized overhead power lines
High fatigue due to overtime
Improper rigging & handling of loads
Lack of operation devices
Poor cab condition
Poor visibility conditions
Severe weather conditions
Use of different languages during irregular load lifts

The Relative Importance Index (RII) is a non-parametric process generally used for analyzing responses containing an ordinal evaluation of opinions [26]. This technique uses weighted scores to compare the relative importance of the factors under study. The rating scale was converted to relative importance indices for each factor to determine the ranks of the different factors [14]. The rankings provided a cross-comparison of the relative importance of the factors as rated by the respondents. The scores of the RII varied from zero to one and were obtained using the following equation:

$$RII = \frac{\sum w}{A \times N} = \frac{5n_5 + 4n_4 + 3n_3 + 2n_2 + n_1}{5 \times N} \quad (1)$$

From the equation above, *w* is the weighting assigned to every factor by the experts, and it varies from one to five, where one signifies not at all important and five is considered extremely important. "A" stands for the highest weight, "N" refers to the total number of experts in the survey while n_1 indicates the number of experts that selected 'very low importance' and n_5 for those that selected 'very high importance'.

III. Result and Discussion

The evaluation of the safety risk factors related to personnel behavior performed by each group of respondents and the 'weighted average' of both groups are presented in Table 2. The *operator's poor experience* and the *operator's mindset & mental capacity* were the topmost rated factors having a Weighted Average RII of 0.953 and 0.915, respectively. This suggests that the two factors have a 'very strong influence on the safety of using tower cranes on construction sites.

TABLE II
RII AND RANKS (R) FOR SAFETY RISK FACTORS RELATED TO BEHAVIOR

Behavioral Factors	Safety Managers		Equipment Managers		Weighted Average	
	RII	R	RII	R	RII	R
Operator's low level of experience	0.945	1	0.960	1	0.953	1
Operator's mindset & mental capacity	0.909	2	0.920	2	0.915	2
Superintendent's mindset & mental capacity	0.873	3	0.880	3	0.876	3
Rigger's poor level of experience	0.818	4	0.740	5	0.779	5
Signalperson's low level of experience	0.727	5	0.840	4	0.784	4

Considering the significance of the *operator's low level of experience* and its influence on on-site safety, it is logical to infer that the less the experience of the crane operator, the lower the level of his competency and the higher the safety risk. This factor plays a vital role in influencing the operator to make errors, timely prevention of unsafe situations, and responding to the errors made by other workers once an unsafe situation comes up. As emphasized by Danel et al. [27], the experience of the crane operator is one of the leading safety risk factors that influence safety when working with a crane during construction.

Another leading safety risk factor that has a very high safety influence when operating a tower crane during construction is the *mindset and mental capacity of the operator*. This factor undoubtedly focuses on the character of the operator that may determine his behavior, e.g., rationality, persistence, self-control, and attentiveness. When operating a tower crane, the operator's mindset and mental capacity significantly and directly impact the probability of accidents occurring on site.

Still, in Table 2, it could also be noted that the s*uperintendent's mindset & mental capacity* has *a* 'high' level of influence (Weighted RII = 0.876). This factor focuses on the character of the superintendent, which may play a decisive role in maintaining safety on site or neglecting it. Moreover, the superintendent always has a link with the operations of the tower crane, which is an essential component of the construction works on site. The superintendent's authoritativeness, sense of responsibility, and alertness may likely have an effect on the crane operations as well as on the crane operators. On the other hand, the *signalperson's low level of experience* and the *rigger's poor level of experience* have a considerably 'moderate' level of influence (Weighted Average RII = 0.784 and 0.779, respectively) on-site safety when operating tower cranes. Irrespective of the Weighted RII of these factors, they are also considered key safety risk factors that should be given due priority whenever the issue of safety of using tower cranes on construction sites arises.

A closer look at the rankings obtained in Table 2 would reveal that the two categories of the respondents (Safety Managers and Equipment Managers) have separately ranked the *operator's low level of experience*, the *operator's mindset & mental capacity* and the *superintendent's mindset & mental capacity* in a similar fashion as 1st, 2nd and 3rd respectively. This suggests some level of agreement in the rankings of the two respondents. On the other hand, there is an indication of disagreement in the respondents' rankings, particularly where the Safety managers ranked the rigger's *poor level of experience* in the 4th position. In contrast, the Equipment Managers ranked it in the 5th position. Similarly, the *signalperson's low level of experience* was ranked in 5th position by the Safety Managers and 4th position by the Equipment Managers. Despite the disagreement in the rankings among the respondents, both factors have been recognized and rated by the respondents as having a significant level of influence on safety in construction sites when operating tower cranes.

Table 3 presents the evaluation of the safety risk factors related to management performed by each group of respondents and the 'weighted average' of both groups. P*oor maintenance management* and *poor safety culture* were the topmost rated factors having Weighted Average RII of 0.924 and 0.895 (≈ 0.9000), respectively. This suggests that the two factors have a 'very strong influence on the safety of using tower cranes on construction sites.

TABLE III
RII AND RANKS (R) FOR SAFETY RISK FACTORS RELATED TO MANAGEMENT

Managerial Factors	Safety Managers		Equipment Managers		Weighted Average	
	RII	R	RII	R	RII	R
Poor maintenance management	0.927	1	0.920	1	0.924	1
Poor safety culture	0.909	2	0.880	2	0.895	2
Nature of employment	0.873	3	0.840	4	0.856	3
Frequent replacement of crane operators	0.836	4	0.860	3	0.848	4
The poor accident investigation process	0.782	5	0.740	6	0.761	6
Insufficient training for personnel	0.764	6	0.780	5	0.772	5

Like any other construction equipment, a Tower crane requires proactive maintenance to ensure its safety and efficiency and extend its service life [11]. A corrective or reactive maintenance management approach for the tower crane and other lifting accessories affects its on-site safety operations. The chances of accidents significantly increase, thereby causing more spending that could increase the overall project costs. The *safety culture* of a construction company comprises the safety policies, standards, attitudes, insights, competencies, and forms of behavior that define adherence to the style and proficiency of managing safety in the company [27].

Managing safety on construction sites is deeply rooted in management at the company site level. At the company level, safety management deals with assigning sufficient resources to prepare, implement, monitor, and control safety improvement plans. It also seeks to provide an organized process for investigating accidents, ensuring the active participation of workers, and training as well as capacity development of workers [24]. Safety management at the company level may not necessarily cause accidents directly on the construction site; however, it affects construction works. Also, the perception of personnel and workers at the construction site impacts their conduct. At the site level, safety management focuses more on strategies to raise awareness, provide training, hazard recognition, accident prevention, daily inspections etc. The safety environment on site, which is usually influenced and governed by the general superintendent, also impacts the crane operations since he is largely considered the crucial linkage between the workers and top management in enhancing a positive safety environment. Thus, it is correct to assert that poor site management significantly increases the chances of crane-related accidents.

Still, in Table 3, it could also be noted that the *nature of employment* and *frequent replacement of crane operators* h*ave a* 'high' level of influence (Weighted RII of 0.856 and 0.848, respectively), while *insufficient training for personnel* and *poor accident investigation process* has 'moderate' levels of influence (Weighted RII of 0.772 and 0.761 respectively). It should be noted that the Weighted RII scores of these factors do not make them any less significant; rather, they are also considered vital safety risk factors that should be given due priority whenever the issue of the safety of using tower cranes on construction sites arises.

A closer look at the rankings obtained in Table 3 would show that the two categories of the respondents (Safety Managers and Equipment Managers) have separately ranked *poor maintenance management* and *poor safety culture* similarly as 1st and 2nd. In contrast, their rankings for nature of employment and frequent replacement of crane operators differ entirely. The Safety Managers ranked the *nature of employment* as the 3rd place factor, while their counterparts ranked it as 4th. Similarly, in other factors like *poor accident investigation process* and *insufficient training for personnel*, the Safety Managers ranked them 5th and 6th, respectively, while the Equipment Managers ranked them 6th and 5th. This seems to indicate some level of disagreement in the respondents' rankings. Notwithstanding the disagreement in the rankings among the respondents, both factors have been recognized and rated by the respondents as having a significant level of influence on safety in construction sites when operating tower cranes.

Table 4 presents the evaluation of the safety risk factors related to site conditions performed by each group of respondents and the 'weighted average' of both groups. The *severe weather conditions*, *improper rigging & handling of loads*, and *poor visibility conditions* were the top-rated factors having Weighted Average RII of 0.879, 0.848, and 0.810, respectively. This suggests that the two factors have a 'strong' influence on the safety of using tower cranes on construction sites.

Severe weather condition mainly deals with conditions that affect safety when operating crane. Hyun [8] noted that this factor also considers the quick changes in temperatures, sudden wind gusts, and other weather conditions that influence the workers' bodies. The significance of this factor influencing safety is attributed to the fact that in extreme weather conditions like high-intensity winds, working on construction sites can be hazardous, as severe strong winds could topple over the tower crane. Thus, the crane operator and the ground crew workers would normally be more concerned about protecting themselves due to the harshness of the weather than paying full attention to the crane operation.

TABLE IV
RII AND RANKS (R) FOR SAFETY RISK FACTORS RELATED SITE CONDITIONS

Site Conditions Factors	Safety Managers		Equipment Managers		Weighted Average	
	RII	R	RII	R	RII	R
Severe weather conditions	0.878	1	0.880	1	0.879	1
Improper rigging & handling of loads	0.836	2	0.860	2	0.848	2
Poor visibility conditions	0.800	3	0.820	3	0.810	3
High fatigue due to overtime	0.782	4	0.720	7	0.751	6
Poor cab condition	0.764	5	0.740	6	0.752	5
Lack of operation devices	0.745	6	0.780	4	0.763	4
Use of different languages during irregular load lifts	0.727	7	0.700	8	0.714	8
Contact with energized overhead power lines	0.709	8	0.760	5	0.735	7

Another significant safety risk factor that influences safety on construction sites under this category (Safety Risk Factors related to Site Conditions) is the *improper rigging & handling of loads*. This factor deals mainly with the nature of the load being lifted and the rigging method. Lifting some loads can be more dangerous than others, considering the load's weight, dimension, and rigging method. Other considerations include whether the load is regular or irregular and the configuration and packaging. Usually, loads do not cause any danger when rigged and handled correctly. The danger is obvious when the loads are improperly rigged and handled and there are obstacles on-site or strong winds. The remaining factor that has a 'high' level of influence on on-site safety when using tower cranes on construction sites in this category is *poor visibility conditions*. This highly important factor deals with

mainly the poor visibility of the crane operators, superintendent, signalperson, and other on-site workers. The visibility problems could be linked to night work, working in a dark shaft or weather, which increases chances for errors and accidents as images may be unclear, the eyes are stressed, and exhaustion sets in much faster.

Of all the factors observed to be having a *moderate* influence on on-site safety when using tower cranes on construction sites in Table 4, it is noteworthy that *contact with energized overhead power lines* received a much lower rating from the respondents despite being considered a major hazard on construction sites. During the interview, most of the respondents argued about this rating, insisting that it is a well-known hazard for all construction workers, as such; adequate preventive measures are always provided on construction sites to mitigate its risk impact.

Looking at the rankings obtained in Table 4 closely, it could easily be seen that the two categories of the respondents (Safety Managers and Equipment Managers) have separately ranked the *severe weather conditions*, *improper rigging & handling of loads*, and *poor visibility conditions* in a similar fashion as 1st, 2nd, and 3rd. In contrast, their rankings for the remaining five factors in the category were entirely different. This seems to suggest some level of disagreement in the respondents' rankings. Notwithstanding the disagreement in the rankings among the respondents, the factors have been recognized and rated by the respondents as having a significant level of influence on safety in construction sites when operating tower cranes. Kendall's concordance test was applied to ascertain the agreement level between the Safety Managers and Equipment Managers rankings.

Kendall's concordance test was applied to ascertain the agreement level between the Safety Managers and Equipment Managers rankings. The concordance coefficient approximates the variance of the row sums of ranks R_i Divided by the highest possible score, the variance can take [28]. This happens only when there is total agreement among the entire variables. The coefficient varies from zero to one, where zero indicates no agreement, and one indicates perfect agreement. The concordance values for this study were calculated using the below equation, and the values are presented in Table 5.

$$w = \frac{12\left(\sum_{i=1}^{n}(R_i - \bar{R})^2\right)}{m^2(n^3 - n) - mT} \quad (1)$$

Where R_i= sum of ranks between judges, $\bar{R}$= average of the ranks assigned across all factors, m = number of sets of ranking, e.g., number of judges, n = number of factors being ranked, and T_j= correction factor is used when there is a rank tie [29].

TABLE V
KENDALL'S CONCORDANCE COEFFICIENT (W) BETWEEN THE RANKINGS OF THE RESPONDENTS

Safety Risk Factors	Rankings		CC (W)
	SM	EM	
Behavioral Factors			
Operator's low level of experience	1	1	0.95
Operator's mindset & mental capacity	2	2	
Superintendent's mindset & mental capacity	3	3	
Rigger's poor level of experience	4	5	
Signalperson's low level of experience	5	4	
Managerial Factors			
Poor maintenance management	1	1	0.94
Poor safety culture	2	2	
Nature of employment	3	4	
Frequent replacement of crane operators	4	3	
The poor accident investigation process	5	6	
Insufficient training for personnel	6	5	
Site Condition Factors			
Severe weather conditions	1	1	0.86
Improper rigging & handling of loads	2	2	
Poor visibility conditions	3	3	
High fatigue due to overtime	4	7	
Poor cab condition	5	6	
Lack of operation devices	6	4	
Use of different languages during irregular load lifts	7	8	
Contact with energized overhead power lines	8	5	
Average Concordance Coefficient (w)			**0.92**

Key: SM = Safety Managers; EM = Equipment Managers. CC = Concordance Coefficient

On the other hand, a relatively lower agreement level (86%) was observed in the respondents' rankings of the safety risk factors related to site conditions, which suggests differing opinions among the respondents due to the nature of their jobs on-site. While the safety managers were more concerned about the general safety of management, the equipment managers were so obsessed with equipment operation safety on site. Overall, the average level of agreement observed is 92%, which is considered very high. It can be concluded that there is a very high level of agreement among respondents in their rankings of the important safety risk factors that influence construction site safety when using tower cranes.

It is duly acknowledged that this research was likely to be affected by certain constraints and biases, which is common for mixed-mode-based research works. Adopting the judgmental sampling method in selecting the sample also helps reduce bias by offering the author some control. Even though the study sample size may seem relatively small, the findings of this paper produce useful guidance that could be used to promote tower crane safety culture, particularly in project sites being operated by small and medium-scale contractors.

The other limitation of the study centers on using construction accident records as a reliable knowledge source for this type of research. However, obtaining data on construction accidents is nearly impossible as the records are simply unavailable. Where the records are available, they hardly establish the basic causes of the accidents being investigated [6, 9, 12, 30, 31]. Thus, the accident investigation records are mostly incomplete and inaccurate in serving as a safety hazard source and the predominant project site conditions that cause them. Consequently, the author had to rule out the use of construction accident records and resorted to using alternative knowledge sources to determine the safety risk factors that influence construction site safety when using tower cranes.

IV. Conclusion

This part presents the main conclusions from the preceding sections. It draws together the major themes of the paper. A list of nineteen significant safety risk factors influencing construction site safety when using tower cranes has been presented. The list was produced and further strengthened as per the sheer knowledge and proficiency of the high-ranking safety and equipment managers in some of the leading construction companies in Riyadh and Eastern Province that operate large fleets of tower cranes on their construction sites and are well-known for their involvement in many high-profile projects. The specialists examined the relevance of each factor on the list and eventually modified the list. After that, the specialists evaluated the significance level of each factor based on the extent to which it influences construction site safety when operating tower cranes. This was necessary to be able to ascertain the contribution of each factor to site safety.

On a general note, findings of the study reveal that the *operator's low level of experience*, *poor maintenance management*, *operator's mindset & mental capacity*, *poor safety culture*, and *severe weather conditions* were the most significant factors that have the highest degree of influence on construction site safety, particularly when operating tower cranes. Thus, the construction industry regulatory authorities, enforcement agencies, small and medium-scale contractors, and other relevant key stakeholders in the industry should emphasize those safety risk factors prioritized as having a strong influence on construction site safety, particularly when operating tower cranes.

This paper provides an original contribution to knowledge through a systematic investigation to determine the key safety risk factors that influence construction site safety when operating tower cranes. The paper presents a clear methodology for identifying and prioritizing the safety risk factors, which may be readily applicable to other construction equipment, as well as identification and determination of the significance or severity of some criteria or factors in the field of construction project management. The findings of this paper are expected to help promote and enhance a safety culture for operating tower cranes in construction sites, particularly the project sites being operated by small and medium-scale contractors.

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