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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