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Contributory factors to crane-related accidents in the Thai construction industry

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Abstract: This article aims to study the key factors influencing crane-related accidents in construction operations with the objective of improving safety performance in engineering practice. A quantitative research approach was adopted using a structured rating-scale questionnaire administered to 33 experts possessing extensive experience in crane operation. Descriptive statistical analysis, including the calculation of mean and standard deviation, was performed to identify and rank the contributing factors. The findings revealed an overall mean score of 4.09 (SD = 0.94), indicating a high level of influence. The most critical factor was defective machinery ($\bar{x}$ = 4.21), followed by substandard or deformed materials ($\bar{x}$ = 4.18) and non-compliance with operational manuals ($\bar{x}$ = 4.09). Other notable contributors included inattentive workers ($\bar{x}$ = 4.06) and unsafe working environments ($\bar{x}$ = 3.93). These results suggest that mechanical defects exert the greatest impact on crane-related accidents, while human, material, procedural, and environmental aspects also play essential roles. Accordingly, the study recommends implementing proactive maintenance strategies, integrating advanced maintenance technologies, and strengthening workforce competency through continuous professional training to enhance operational reliability and reduce the likelihood of crane-related accidents in construction projects.
Keywords: *Accidents, Construction work, Cranes, Factors.*

1. Introduction

Thailand has experienced continuous development and expansion in various industrial sectors, particularly in construction and manufacturing. This growth has been largely driven by the transfer of technology from abroad through both governmental and private-sector initiatives. As a result, the advancement of machinery and equipment has progressed rapidly, significantly transforming the way of life and labor systems in the country. Increasingly, industrial machinery and labor-saving devices have been widely adopted across multiple work processes. One such piece of machinery is the crane, whose use is governed by specific legal regulations [1]. Cranes are widely employed in operations of all sizes, from small-scale enterprises to large infrastructure projects. Operators are required to possess appropriate knowledge and skills to handle cranes safely and correctly to minimize operational errors. These competencies include, for instance, Chimpradit [2], the proper selection of lifting equipment, calculation of sling tension, and secure binding or rigging of materials during lifting operations are essential. Furthermore, operators must be certified according to relevant legislation. These basic skills are critical for the safe operation of various types of cranes, including tower cranes, mobile cranes, and stationary cranes. All crane operations must adhere strictly to engineering principles and legal standards.

Research consistently underscores the importance of both knowledge and experience in crane operation, as human-made equipment such as cranes can still lead to serious accidents. Historical data

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and incident reports highlight several tragic cases. For example, on 30 August 2018 at 13:30 hours, a crane collapsed during the construction of The Rise condominium on Rama IX Road while lifting a precast slab. The operator attempted to force the lift, resulting in structural failure and the death of one worker [3]. On 23 January 2019 at 13:00 hours, a similar crane collapse occurred at the Lumpini Place Rama III construction site, causing five fatalities [4]. More recently, on 2 July 2024, a crane overturned onto a concrete truck and a temporary structure at a waste disposal plant construction site on Soi On Nut 86. The incident was attributed to an unstable and substandard crane base, resulting in two deaths and seven injuries [5]. Engineering inspection plays a vital role in determining the causes of equipment failure, structural deterioration, or collapse. It includes fault analysis, repair, and maintenance recommendations, and legal liability assessments. These procedures are crucial for generating technical evidence for legal proceedings, allowing courts to reach accurate and lawful decisions based on engineering data [6]. Efforts to mitigate crane-related accidents include the development of specialized training programs. One experimental study developed a tower crane inspection training module covering daily pre-operation checks. The program achieved a performance level of 88.16/83.92, well above the minimum benchmark of 80/80 and contributed to a noticeable reduction in crane-related incidents [7]. Legal enforcement and penalties also play a pivotal role in improving crane safety, accounting for approximately 68.92% of safety compliance outcomes [8]. Regulations mandate that crane operators strictly follow the operating manuals, with penalties imposed for non-compliance by authorized regulatory bodies. Human error in crane operations can generally be categorized into two main dimensions: "personal status" such as fatigue, stress, or physical and mental unpreparedness, and "process deficiencies" including failure to perform safety checks, misjudgment of material weight, or poor communication between crane operators and ground crews Wang and Si [9]. Herrera-Pérez et al. [10] examined 1,314 crane-related accidents in Spain from 2012 to 2021 and found that 63.3% involved inexperienced workers, particularly those employed by small enterprises with limited training resources and underdeveloped safety management systems [10]. Similarly, Chimpradit [2] emphasised the importance of specialised crane operation training. Essential skills include selecting appropriate lifting equipment, calculating sling tension, and maintaining load stability during lifting. Without continuous skill development, the risk of accidents increases, potentially leading to serious human and financial losses. Given these concerns, it is imperative to investigate the factors contributing to crane-related accidents. The findings will inform future corrective strategies and contribute to the development of effective safety protocols and operational guidelines.

2. Literature Review

A review of literature related to factors influencing crane-related accidents is essential to enhance understanding of the key variables that affect project execution, particularly in terms of legal compliance and the safety of personnel, lives, and property. This article categorizes the relevant research into five principal factors: human-related, machinery-related, material-related, procedural, and environmental. Each is discussed in detail below.

2.1. Human Factors [Hum.F]

Human involvement plays a central role in crane operation and is a frequent causal factor in crane-related accidents. Wang and Si [9] observed that operator inattentiveness is significantly associated with low motivation, fatigue, and a lack of self-discipline. These conditions often lead to poor decision-making in high-risk situations such as load weight estimation, crane rotation control, or communication among team members working in confined workspaces [10]. Operators who are over-familiar with their tasks and have never experienced accidents tend to neglect safety protocols and over-rely on personal experience, leading to non-compliance with safety standards. Alongkontaksin [7], who developed a training programme for tower crane inspection, found that post-training, participants demonstrated

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improved inspection behaviors. The programme yielded performance scores of 88.16/83.92, significantly surpassing the target threshold of 80/80. This outcome suggests that well-structured, ongoing training can meaningfully reduce accidents. According to the United States National Safety Council [11], Insufficient training is among the "Top 10 Safety Violations" globally within the construction sector and is statistically linked to repeat accidents at the same worksites.

2.2. Machinery Factors [Mach.F]

A study in Malaysia highlighted that aging machinery with inadequate maintenance poses a significant risk. Key components such as crane structures, slings, pulleys, and hydraulic systems may deteriorate, break, or collapse without timely servicing. Such failures are among the most common causes of major crane-related accidents [12]. Improper crane installation on unstable ground also contributes to incidents, including crane collapse. Further issues include corroded or deteriorated structures, loose bolts or fasteners, overloading, and a lack of maintenance under manufacturers' guidelines [13].

2.3. Material Factors [Mat.F]

The use of uncertified or unverified materials, particularly those from unregulated sources, may result in lower-than-required tensile strength, making them unsafe for bearing loads or resisting stress. Materials exposed to prolonged use without proper inspection may exhibit rust, cracking, metal fatigue, or other structural weaknesses. Inappropriate material selection also contributes to accidents. Research by Lee et al. [14] identified key defects in crane materials, such as micro-cracks, internal inclusions, and poor welding quality as contributing to unexpected failures. For instance, reinforcement plates on tower crane joints were found to have welding flaws and material inconsistencies, which led to stress concentration and early-stage cracking.

2.4. Method Factors [Met.F]

Work behaviors, operational methods, and procedural adherence directly impact crane safety. Deviating from established safety procedures, failing to follow crane installation or movement manuals, or omitting critical steps (e.g., not weighing loads before lifting or neglecting pre-operation inspections) significantly increases accident risk. According to Zhang and Fang [15], failure to use pre-operation checklists or skipping daily inspections can result in unresolved hazards at the start of operations. Additionally, Yusop et al. [16] reported that some operators failed to comply with required procedures, such as not securing loads properly or lifting in unsafe configurations.

2.5. Environmental Factors [Env.F]

Environmental conditions, particularly strong winds, rain, water, and unstable ground, are confirmed as key variables that significantly increase crane accident risk. Both real-world incident analyses (e.g., Mecca, Milwaukee) and large-scale data reviews (e.g., China, Vietnam, Spain) indicate that environmental variables often interact with human and management factors in complex ways [17]. High-rise crane operations demand enhanced visibility and well-managed working environments to mitigate accident risks and support sustainable construction site management.

3. Materials and Methods

This study investigates the factors influencing the occurrence of crane-related accidents through the use of a five-point rating scale questionnaire. The conceptual framework for examining these influencing factors comprises five primary categories, each with four sub-factors, as follows: These factors are illustrated in Figure 1.

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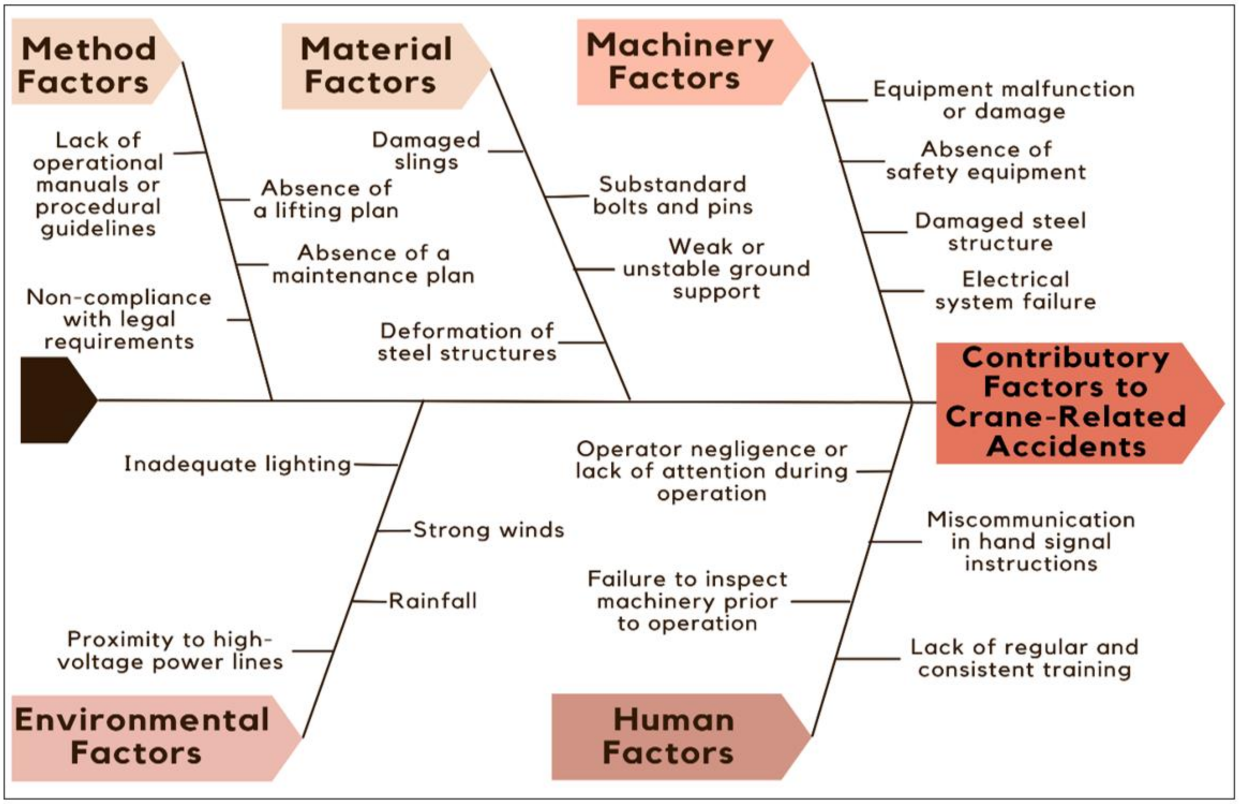

Figure 1.
Analysis of Factors Contributing to Crane-Related Accidents.

This study employed a quantitative research design to investigate the factors contributing to crane-related accidents. A structured questionnaire was utilized, comprising three main sections: (1) primary factors affecting crane-related accidents, (2) sub-factors contributing to such incidents, and (3) respondents' comments and recommendations [18]. The questionnaire was based on a 5-point Likert scale, ranging from 1 = Strongly Disagree to 5 = Strongly Agree.

The sample consisted of 33 participants who were knowledgeable and experienced in operating tower cranes within the Bangkok Metropolitan Area. The sample size was determined following the Krejcie and Morgan [19] sampling table [19], and participants were selected using simple random sampling. Data were collected through both online questionnaires and face-to-face interviews. The data analysis was conducted using SPSS [20] employing both descriptive statistics, including $\bar{x}$, SD, frequency, and percentage, and inferential statistics, namely the Pearson Product-Moment Correlation Coefficient and One-Way Analysis of Variance (ANOVA). The interpretation of mean scores is based on the criteria proposed by Best [21] which classifies the levels of opinion into five categories as follows: 4.51–5.00 indicates the highest level (VH), 3.51–4.50 indicates a high level (H), 2.51–3.50 indicates a moderate level (MO), 1.51–2.50 indicates a low level (L), and 1.00–1.50 indicates the lowest level (VL) [22].

The reliability of the questionnaire was verified using Cronbach's Alpha Coefficient [23], which yielded a coefficient of 0.90, indicating high internal consistency. The questionnaire was developed and its alignment with the research objectives was evaluated through the Index of Item–Objective Congruence (IOC) by three subject-matter experts, with only items achieving an IOC score of ≥ 0.80

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retained. Content validity was further examined by three crane-operation specialists from both public and private sector organizations. The interpretation of the Pearson correlation coefficient was based on the criteria suggested by Best [21] where a value between 0.81–1.00 indicates a very high correlation (VHC), 0.61–0.80 a high correlation (HC), 0.41–0.60 a moderate correlation (MC), 0.21–0.40 a low correlation (LC), and 0.01–0.20 a very low correlation (VLC). A coefficient of 0 indicates no correlation (NC), while a negative value reflects an inverse relationship [21]. All collected data were systematically processed and analyzed following the predetermined research procedures.

3.1. Step 1: Analysis of Primary Factors Contributing to Crane-Related Accidents

The key factors contributing to crane-related accidents comprise the following: (1) Human Factors, particularly lack of attention during operations, (2) Mechanical Factors, (3) Material Factors, (4) Method Factors, and (5) Environmental Factors. The data were analyzed using descriptive statistics, with findings presented in the form of frequency distribution tables, percentages, mean values, and standard deviations.

3.2. Step 2: Analysis of Sub-Factors Associated with Crane-Related Accidents

This phase involved a detailed examination of the sub-factors underlying each primary factor: (1) Hum. F– negligence or lack of attention during operation. This includes four sub-factors: operator negligence, miscommunication or errors in hand signal interpretation, failure to inspect machinery before operation, and lack of regular training. (2) Mech. F– This category encompasses four sub-factors: equipment malfunction, absence of safety devices, structural defects in steel frameworks, and electrical system failures. (3) Mat. F– The sub-factors in this domain include damaged slings, deformed steel structures, unstable ground support, and substandard bolts or pins. (4) Met. F– This comprises four sub-factors: absence of a lifting plan, lack of manuals or standard operating procedures, non-adherence to legal safety regulations, and absence of a maintenance schedule. (5) Env. F– This includes four sub-factors: insufficient lighting, rainfall, strong winds, and proximity to high-voltage power lines. The results of this sub-factor analysis are also presented through frequency distribution tables, percentages, mean values, and standard deviations (SD).

3.3. Step 3: Analysis of the Relationships Between Primary Contributing Factors

The relationships between the primary factors contributing to crane-related accidents were examined using the Pearson Product-Moment Correlation Coefficient. The following relationships were investigated: the correlation between Hum. F and Mach. F; between Hum. F and Mat. F; between Hum. F and Met. F; and between Hum. F and Env. F. This analysis provides insights into the strength and direction of correlations between these variables, which may serve as a basis for strategic planning and policy development aimed at reducing accident risks in crane operations.

4. Results and Discussion

4.1. Result

4.1.1. Results of the Analysis of Primary Factors Contributing to Crane-Related Accidents

The analysis of primary factors contributing to crane-related accidents revealed that the overall mean ($\bar{x}$) across all factors was 4.09, with a standard deviation (SD) of 0.94, indicating a high level of concern. Upon examining each factor individually, it was found that mechanical failure had the highest average score of 4.21 (SD = 0.92), categorized as very high. This was followed by substandard or deformed materials, which recorded a mean of 4.18 and an SD of 0.76, also rated as high. The factor human error, specifically operator negligence or lack of attention during operation, had a mean of 4.06 (SD = 1.08), while non-compliance with standard work guidelines was rated at 4.09 (SD = 0.87); both

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were also classified as high. Lastly, working environment conditions yielded a mean of 3.93, with an SD of 1.08, likewise considered high. In summary, mechanical failure emerged as the most significant factor affecting crane-related accident occurrence, while other factors such as human error and material inadequacies also demonstrated considerable impact. These findings are summarized in Table 1.

Table 1.
$\bar{x}$ and SD of Key Factors Affecting Crane-Related Accidents.

Contributing Factors	Mean ($\bar{x}$)	SD	LF
Hum. F	4.06	1.08	H
Mach. F	4.21	0.92	VH
Mat. F	4.18	0.76	H
Met. F	4.09	0.87	H
Env. F	3.93	1.08	H
Overall	4.09	0.94	H

4.1.2. Results of the Analysis of Sub-Factors Contributing to Crane-Related Accidents

The analysis of sub-factors contributing to crane-related accidents revealed that issues related to human error had an overall average score of 4.01, with a standard deviation (SD) of 0.79, indicating a high level of concern. Upon examining individual items, it was found that operator negligence or lack of attention during operation received the highest average score of 4.27, with an SD of 0.76, categorised as very high. This was followed by both miscommunication in hand signal instructions and failure to inspect machinery prior to operation, each with an average score of 3.96, with SDs of 0.88 and 0.80, respectively, both rated as high. Lastly, lack of regular and consistent training had a slightly lower average score of 3.87, with an SD of 0.73, but was still considered to have a high level of impact. These results are summarised in Table 2.

Table 2.
$\bar{X}$ and SD of Hum. F Influencing Crane-Related Accidents.

Hum. F	$\bar{X}$	SD	LF
Operator negligence or lack of attention	4.27	0.76	VH
Miscommunication in hand signals	3.96	0.88	H
Failure to daily inspect machinery prior	3.96	0.80	H
Lack of regular and consistent training	3.87	0.73	H
Overall	4.01	0.79	H

The analysis of sub-factors contributing to crane-related accidents revealed that issues related to machinery had the highest average rating, with a mean ($\bar{x}$) of 4.29 and a standard deviation (SD) of 1.01, indicating a very high level of concern. Upon examining individual items, it was found that malfunctioning machinery received the highest score, with a mean ($\bar{x}$) of 4.39 and an SD of 0.86, also categorized as very high. This was followed closely by damaged steel structures, which had a mean ($\bar{x}$) of 4.39 and an SD of 0.96, similarly rated at the very high level. The absence of safety equipment recorded a mean ($\bar{x}$) of 4.30 and an SD of 1.04, likewise considered very high. Meanwhile, electrical system failures had a slightly lower mean ($\bar{x}$) of 4.09, with an SD of 1.18, but still ranked at a high level. These results are summarized in Table 3.

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Table 3.
$\bar{X}$ and SD of Mach. F Influencing Crane-Related Accidents.

Mach. F	$\bar{X}$	SD	LF
Equipment malfunction	4.39	0.86	VH
Absence of safety equipment	4.30	1.04	VH
Damaged steel structure	4.39	0.96	VH
Electrical system failure	4.09	1.18	H
Overall	4.29	1.01	VH

The analysis of sub-factors related to material issues contributing to crane-related accidents revealed that this category had an overall mean of 4.27 with a standard deviation (SD) of 0.83, indicating a very high level of impact. An item-by-item analysis showed that the factor of unstable ground support had the highest mean of 4.51 with an SD of 0.61, categorized as very high. This was followed by damaged wire ropes, with a mean of 4.39 and an SD of 0.78, also at a very high level. The factor of deformed steel structures recorded a mean of 4.12 and an SD of 0.99, classified as high. Lastly, the issue of non-standard bolts and pins had a mean of 4.06 with an SD of 0.96, also rated at a high level. These findings are summarized in Table 4.

Table 4.
$\bar{X}$ and SD of Mat. F Influencing Crane-Related Accidents.

Mat. F	$\bar{X}$	SD	LF
Damaged slings	4.39	0.78	VH
Deformation of steel structures	4.12	0.99	H
Weak or unstable ground support	4.51	0.61	VH
Substandard bolts and pins	4.06	0.96	H
Overall	4.27	0.83	VH

The analysis of Met. F sub-factors contributing to crane-related accidents revealed that this category had an overall mean ($\bar{x}$) of 3.91 with a standard deviation (SD) of 0.82, indicating a high level of impact. Item-level analysis showed that the absence of a maintenance plan had the highest mean ($\bar{x}$) of 4.09, with an SD of 0.80, categorized as high. This was followed by the absence of a lifting plan, with a mean of 3.93 and an SD of 0.78, also rated as high. The factor of non-compliance with legal regulations had a mean of 3.90 and an SD of 0.80, again indicating a high level of concern. Finally, the lack of standard operating procedure manuals recorded a mean of 3.75 and an SD of 0.93, also classified as high. These results are summarized in Table 5.

Table 5.
$\bar{X}$ and SD of Met. F Influencing Crane-Related Accidents.

Met. F	$\bar{X}$	SD	LF
Absence of a lifting plan	3.93	0.78	H
Lack of operational procedural guidelines	3.75	0.93	H
Non-compliance with legal requirements	3.90	0.80	H
Absence of a maintenance plan	4.09	0.80	H
Overall	3.91	0.82	H

The analysis of environmental sub-factors associated with crane-related accidents showed an overall mean ($\bar{x}$) of 3.77 with a standard deviation (SD) of 1.03, indicating a high level of impact. Item-specific analysis revealed that the factor proximity to high-voltage power lines had the highest mean of 4.12 with an SD of 1.29, classified as high. This was followed by the factor strong winds, which recorded a

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mean of 3.78 and an SD of 0.99, also at a high level. The factor rainfall had a mean of 3.63 with an SD of 1.05, while insufficient lighting had a mean of 3.57 and an SD of 0.79. Both were likewise classified as having a high level of impact. These findings are summarised in Table 6.

Table 6.
$\bar{x}$ and SD of Env. F Influencing the Increased Risk of Accidents.

Env. F	$\bar{x}$	SD	LF
Inadequate lighting	3.57	0.79	H
Rainfall	3.63	1.05	H
Strong winds	3.78	0.99	H
Proximity to high-voltage power lines	4.12	1.29	H
Overall	3.77	1.03	H

4.1.3. Correlation Analysis of the Primary Factors Influencing Crane-Related Workplace Accidents Using the Pearson Product-Moment Correlation Coefficient

The analysis revealed that Hum. F exhibits a low positive correlation with accident occurrence, with a statistically significant p-value of less than 0.05 and a Pearson correlation coefficient (r) of 0.42. This indicates a low-level positive relationship, suggesting that when workers possess knowledge and understanding of crane operation, machine efficiency improves and the risk of crane-related accidents on construction sites is reduced. However, the strength of this relationship remains low. Further analysis showed no correlation between Hum. F and Mat. F. Conversely, the correlation between Hum. F and both Met. F and Env. F was statistically significant ($p < 0.05$), indicating that Hum. F is correlated with Met. F and Env. F aspects, albeit at a low level. These findings are summarized in Table 7.

Table 7.
Correlation Coefficients between Hum. F, Mach. F, Mat. F, Met. F, and Env. F.

Hum. F	Mach. F	Mat. F	Met. F	Env. F
Correlation Coefficient (r)	0.42	-0.05	0.38	0.34
p-value	0.015	0.778	0.026	0.048
Correlation Level	LC	NC	LC	LC

The analysis revealed that Mach. F exhibits a moderate positive correlation with material-related factors, with a statistically significant p-value of less than 0.05 and a Pearson correlation coefficient (r) of 0.55. This indicates that when cranes are properly maintained and materials such as lifting gear are used appropriately, the likelihood of crane-related workplace accidents can be reduced. Moreover, the correlation between machinery-related factors and method-related factors was also statistically significant ($p < 0.05$), although the strength of the correlation was low. Additionally, the analysis showed a statistically significant ($p < 0.05$) moderate correlation between machinery-related factors and environmental factors. These findings are summarized in Table 8.

Table 8.
Correlation between Mach. F, Mat. F, Met. F, and Env. F.

Mach. F	Mat. F	Met. F	Env. F
Correlation Coefficient (r)	0.55	0.35	0.54
p-value	0.001	0.040	0.001
Correlation Level	MC	LC	MC

The analysis indicated that Mat. F does not correlate significantly with Met. F, as reflected by a p-value greater than 0.05 and a Pearson correlation coefficient (r) of 0.25. This suggests that the use of high-quality materials in compliance with engineering standards can help reduce the likelihood of crane-

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related accidents in construction operations. Further analysis revealed that the correlation between material-related factors and environmental factors was found to be statistically significant ($p < 0.05$), with a low positive correlation, indicating that material considerations are weakly associated with environmental conditions in crane operations. These results are summarized in Table 9.

Table 9.
Correlation between Mat. F and Met. F, and Env. F.

Mat. F	**Met. F**	**Env. F**
Correlation Coefficient (r)	0.25	0.46
p-value	0.157	0.007
Correlation Level	NC	LC

The analysis revealed that Met. F exhibits a moderate positive correlation with Env. F, with a statistically significant p-value of less than 0.05 and a Pearson correlation coefficient (r) of 0.50. This indicates that a well-maintained and safe working environment can support the implementation of safer work procedures, thereby helping to reduce crane-related workplace accidents. The analysis of the relationship between Met. F and Env. F revealed a statistically significant correlation (p-value < 0.05). This indicates that working methods are moderately positively correlated with environmental conditions. These results are summarized in Table 10.

Table 10.
Correlation between Met. F and Env. F.

Met. F	**Env. F**
Correlation Coefficient (r)	0.59
p-value	0.000
Correlation Level	MC

4.2. Discussion

The findings revealed that among the individual factors examined, mechanical failure emerged as the most critical, receiving the highest mean score of 4.21 (SD = 0.92), which is classified as very high. This indicates the essential need for proper maintenance and upkeep of machinery to ensure operational readiness. Furthermore, it underscores the importance of selecting appropriate lifting machines, tools, and equipment that are in safe and serviceable condition. These results are consistent with the study by Kongsong et al. [8] which emphasizes that the proper selection of lifting equipment and the correct rigging methods, based on engineering principles, play a crucial role in preventing crane-related accidents, due to equipment malfunction, breakdowns in hydraulic or brake systems, and defects in safety mechanisms concerns that were repeatedly observed in both field inspections and previous research conducted by Chimpradit [24]. These mechanical failures often lead to catastrophic incidents, particularly when preventive maintenance is neglected or when outdated equipment is used without proper retrofitting.

5. Conclusion and Suggestion

5.1. Conclusion

The findings indicate that malfunctioning Mach. F is the most significant factor contributing to crane-related accidents. Cranes are designed to lift and transport heavy loads; therefore, failure of any key component, such as slings, pulleys, hooks, pivot points, main structural columns, or hydraulic systems, can immediately result in dropped materials or crane collapse. Certain parts, including electrical control systems, safety sensors, and rotating winches, may deteriorate over time [25] without clear visible signs. These issues can be overlooked in the absence of regular inspections, particularly

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when preventive or predictive maintenance is not in place, leading to operational failures and consequent accidents. The second most influential factors were found to be substandard Mat. F and improper work practices, including Met. F who do not comply with established safety guidelines. These findings are consistent with the research of Hinze and Teizer [26], which focused on accidents in the construction sector and identified a strong correlation between major incidents and the use of machinery. Another notable factor is worker attentiveness, which, despite showing only low to moderate correlation with other variables, plays a critical role in overall safety. This underlines the importance of fostering individual awareness and responsibility regarding safety practices. The correlation analysis revealed low to moderate interrelationships among the key factors, indicating that no single factor operates in isolation. Rather, these variables are interrelated and may reinforce one another, particularly in the case of machinery, materials, and environmental conditions. Without appropriate controls, such overlaps can escalate operational risks.

While other elements, such as worker negligence or substandard materials, also contribute to crane-related accidents, malfunctioning machinery represents a non-compensable risk; caution alone cannot eliminate the threat. When mechanical failure occurs, the consequences are often severe in both human and economic terms. Based on these findings, the following preventive measures and strategies are proposed to reduce and mitigate crane-related accidents:

5.2. Suggestion

5.2.1. Implementation of Artificial Intelligence for Predictive Maintenance in Crane Operations

To enhance safety performance and reduce the risk of crane-related accidents in construction, the adoption of predictive maintenance technology powered by Artificial Intelligence (AI) represents an effective approach and is highly recommended. This approach involves integrating various sensors, such as those monitoring vibration, temperature, and pressure, into critical crane components to enable real-time data collection. The AI system then analyzes these data to detect anomalies that may indicate early signs of mechanical failure, for example, abnormally high vibration levels, delayed brake response, or motor temperatures exceeding standard limits. Once a potential issue is identified, the system can automatically alert operators or maintenance personnel to conduct further inspections or undertake timely preventive actions. This not only minimizes the risk of accidents due to undetected machinery faults but also supports a sustainable and intelligent safety management system in crane operations.

5.2.2. Development of Checklists and Maintenance Schedules

A daily pre-operation checklist system should be established and rigorously implemented to ensure that all crane components are inspected before each use. Results of these inspections must be properly documented. In addition, a comprehensive maintenance plan should be enforced in accordance with manufacturer guidelines, including scheduled monthly and annual servicing to ensure the continued safe operation of cranes.

5.2.3. Ongoing Safety Training for Personnel

Personnel involved in crane operations should receive regular safety training as mandated by law, with a strong emphasis on practical, hands-on training in the field. This is essential to develop operational skills and expertise.

Remark

This article is a part of the dissertation for the Ph.D Program in Engineering Law and Inspection, Faculty of Engineering, Ramkhamhaeng University, Bangkok, Thailand [24].

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Transparency:
The authors confirm that the manuscript is an honest, accurate, and transparent account of the study; that no vital features of the study have been omitted; and that any discrepancies from the study as planned have been explained. This study followed all ethical practices during writing.

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