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Original

Application of FMEA and AHP in Elevated Highway Construction Project Risk Assessment

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Abstract

Background: By investigating accidents in industries, it can be concluded that a significant proportion of work-related accidents occur in the construction industry. The present study aimed to apply a hybrid model in identifying and prioritizing risks in a construction project with new machinery. **Methods:** In this study, the methodological shortcomings of the traditional failure mode and effects analysis (FMEA) method and the need to prioritize control measures were modified by the analytical hierarchy of process (AHP). The FMEA was used for risk identification and risk assessment in the elevated highway construction project, then AHP accidents were prioritized according to their physical, psychological, economic, and socio-political burden. **Results:** In the AHP structure, several sub-criteria for each criterion were considered and weighted for each item. The five activities included crane collapse, falling from a height, collapse, and electrocution devices that their risk priority number is more than 250 weighted by the AHP. **Discussion:** Based on the literature, the traditional FMEA has many shortcomings that need to be corrected by other methods. This study aimed to modify the traditional FMEA method using a hybrid model. **Conclusion:** The findings of this study showed that in urban projects, hazards threaten workers, citizens, and company properties. In addition to accidents, deaths, and injuries, they have negative consequences, such as health, psychological, economic, and socio-political impacts. Accidents cause loss of human life, worker's mental health problems, damage to equipment or property, worker's productivity loss, and affect the profit and reputation of the organization. Due to many deficiencies of the conventional risk priority number (RPN) in the FMEA method, it was criticized, and to enhance the performance of the FMEA in risk analysis, various risk priority models have been proposed.

Keywords: Launching Gantry Crane; Elevated Highway; Risk Assessment; Analytical Hierarchy

Introduction

Many job opportunities for millions are provided by the construction sector worldwide.[1] It is a high-risk industry containing many potentially dangerous factors for workers. In many construction companies, safety has been an important issue, and they have aimed to protect their employees from injuries and fatalities.[2, 3] In the construction sector, 60.000 fatal accidents are reported worldwide each year. One worker dies every 10 minutes due to an occupational accident. High risks of the construction sector are due to its labor-intensive characteristics and production processes. Occupational accidents have created a large scale of financial loss in this sector. The costs and

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environmental impacts of occupational accidents are crucial for the sustainability of enterprises.[4] The analysis of occupational accidents and injuries in the construction industry can improve its health and safety.[5]

Occupational safety and health challenges are mainly tied to the construction industry. One of the significant roles undertaken by a project manager is managing the risk of a project.[6] Highway construction projects have higher capital investments and more complexity and depend on economic, social, and political challenges. Therefore, compared to other construction projects, they are subject to higher risks and uncertainties.[7] Risk Matrix,[8] Monte Carlo Simulation (MCS),[9] Sensitivity Analysis, Event Tree,[10] Fault Tree,[11] AHP,[12] TOPSIS,[13] FMEA have been used to develop various risk analysis techniques by specialists and researchers in the construction industry. Given that most of the mentioned methods were applicable for processing risk[14] and were not appropriate for construction projects, the FMEA method was used to identify accidents and risks in this study. The experts' opinions were applied using the AHP method to modify the shortcomings of the FMEA.[15] These risk management techniques were used to improve the construction industry efficiency during practice and add value to project delivery. Therefore, research studies aimed at examining risk management practice in the construction industry have been increased. The FMEA is a structured and systematic approach to identify the potential failures in designing a product. It examines the effects of malfunctions on the system and provides qualitative assessment. Then, the method takes necessary measures and prevention methods, taking to account the existing problems in the systematic reliability. It is a standard method that has been widely accepted in Japanese, American, and European manufacturing companies.[16]

In the 1960s, the FMEA was first developed by the aerospace industry as a formal design methodology.[17] This analysis technique is used to define, identify, and modify the potential failures in a system. Service, before they reach the customer, questioned the calculation of RPN.[18] Some other methods, such as Level of Risk, Criticality Score Evaluate, Matrix, and Critical Analysis, have been used to improve traditional RPN calculation methods. Some new methods have been recently proposed to improve the default of subjective appreciation of each factor in the RPN. For instance, in the study by Davidson & Labib [2003], they integrated the AHP methodology with the FMEA applied in the Concorde accident; Chang et al. [2001] applied the Grey theory to the FMEA, and Bowles [1998] explained multi-criteria Pareto ranking as an alternative method for calculating the classical risk priority number. However, the mentioned methods did not study the effect of each failure after the accident.[19] Thus, this study was conducted to estimate the weights of detection, occurrence, and severity and calculate the RPN and then prioritize high-risk activities by AHP to decide on control measures.

Methods

This study was conducted in 3 phases as follows:

Establishing the decision group

The decision group consisted of 10 safety professionals, 5 civil engineering technicians, and 5 workers. First, risk identification and risk assessment were made by the FMEA method; then, activities were prioritized according to their RPN. For prioritization, only activities with more than 250 RPN were considered high-risk activities (according to the experts' opinions).

Collecting the initial data

Pair-wise comparisons based on the evaluation index system were made by the decision group for the factors and the sub-factors within the same index Figure 1.

Weight calculation

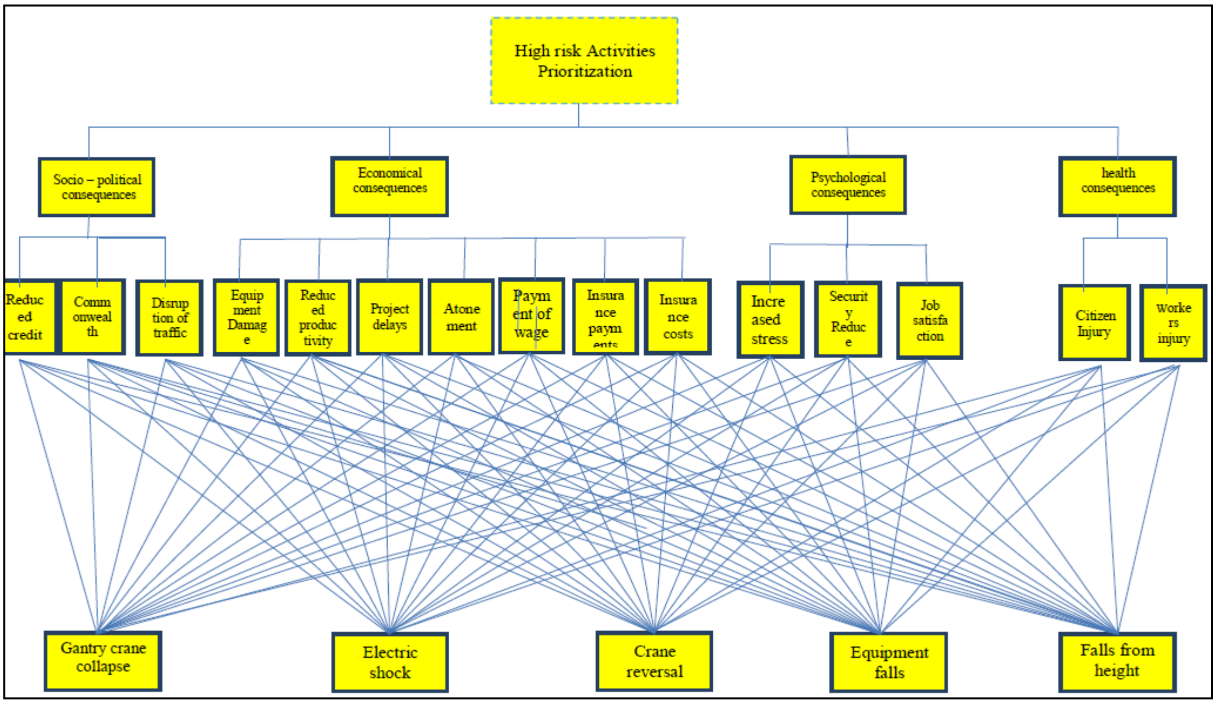

Figure 1. Analytical hierarchy structure of the process

The experts' group calculated the activities of the high risk RPNs as a result of FMEA application weights using Expert choice 11 software. The comparison matrixes consistency was checked before calculating the weights, and all of the comparison matrixes were consistent. The results of pair-wise comparisons and processes of the consistency check were not provided in the present study due to space limitation. The RPNs intervals given in the worksheet can be utilized in the AHP model with the 95% confidence interval according to the FMEA results.

Results

After reviewing the FMEA worksheet, it was concluded that activities in elevated bridge construction projects by launching gantry crane with more than 250 risk priority numbers are divided into five categories as follows:

1. Activities with falling from height hazard
2. Activities with falling objects hazard
3. Activities with crane reversal hazard
4. Activities with electric shock hazard
5. Activities with a crane of gantry fall hazard

The criteria and sub-criteria pair-wise results showed that the highest weight was for a gantry crane fall whit .450; after that, crane collapse was .244, equipment fall .131, electric shock.099, falling from height.076, and overall consistency was 0.4 Table 1.

Table 1. The weight of alternatives

Alternative	Weight
Gantry crane Collapse from the height	0.450
Movable crane collapse	0.244
Equipment fall from the height	0.131
Workers electric shock	0.099
Workers falling from the height	0.076

Overall inconsistency= 0.4

According to the final results of the pair-wise comparison, the activities were prioritized concerning their risk weight. After investigating the FMEA worksheet, it was concluded that some activities might include several hazards. For prioritization, the weights of each activity hazard were summed. Finally, after investigating the activities, it was concluded that the nose truss connection to the main truss is a hazardous activity and has the following hazards:

Gantry crane collapse

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Movable crane collapse
Equipment fall
Falling from height

Discussion

In urban construction projects, accidents, in addition to threatening workers, also pose risks to citizens. Moreover, accidents can cause death, injury, and many negative consequences from health, psychological, economic, and socio-political perspective. The accidents also cause loss of human life; worker's mental health problems, damage to equipment or property, worker's productivity loss, and affect the profit and reputation of the organization.[20] The conventional RPN method has been criticized due to its shortcomings. Thus different risk priority models have been suggested in the literature[21-26] to improve the FMEA performance. In a study,[27] FMEA and fuzzy AHP model were applied to identify occupational safety and health risks in the process industry. However, in the present study, FMEA and AHP were used in construction safety risks. In another study,[28] the AHP method was used to prioritize the corrective actions suggested in the FMEA; while, in the current study, AHP was applied for prioritizing high-risk activities according to their RPNs in the result of FMEA. In this study, a new approach was developed to prioritize risks using the AHP method. Given the deficiencies and shortcomings in the FMEA method, such as uncertainty, taste, failure to consider multiple options in decision making, and lack of distinction between high-risk RPNs, these shortcomings were overcome using this method. This methodology provides a new scientific method for occupational safety risk assessment and early warning in construction projects and makes the evaluation results more reasonable and comprehensive. With the evaluation index system development, officials, managers, and evaluators have used the proposed method, early warning system, and safety grade as powerful tools in accident prevention.

Conclusions

The risk assessment in expressway highway construction in urban areas will greatly identify the work-related hazards and their negative consequences for the company, citizens, and workers. In this study, the AHP method based on the FMEA was developed for safety risk assessment in elevated expressway construction using a launching gantry crane. In the analytical hierarchy of process, four factors and 15 sub-factors were included in the index system. The findings of this study showed that in urban projects, hazards threaten workers, citizens, and company properties. In addition to accidents, deaths, and injuries, they have negative consequences, such as health, psychological, economic, and socio-political impacts. Accidents cause loss of human life, worker's mental health problems, damage to equipment or property, worker's productivity loss, and affect the profit and reputation of the organization. The conventional RPN in the FMEA method has been criticized for its drawbacks, and to improve the FMEA performance in risk analysis, different risk priority models have been proposed.

Conflicts of Interest

The authors declare that there is no conflict of interest.

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