ORIGINAL ARTICLE

Evaluation of Safety Indexes of the Tower Crane with the FMEA Model (A Case Study: Tower Cranes Mounted in the City of Mashhad in 2016)

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ABSTRACT

Background: Tower cranes play a major role in numerous construction accidents, with 116 accidents in the world in 2009, resulting in more than 44 deaths and countless injuries. Therefore, the safety assessment of the equipment for preventing accidents and maintaining the construction industry staff health is essential.
Aim: To evaluate the tower crane safety indicators using the FMEA risk assessment model.
Methods: This descriptive-analytic study was conducted on 150 tower cranes in Mashhad in 2016. Initially, a tower crane was selected, and after the formation of the team, all failure modes were evaluated and their initial RPN was calculated using the FMEA technique. In the next stage, after the implementation of corrective measures, the secondary RPN was calculated and the effectiveness of the measures was evaluated.
Results: In total, 30 failure modes were analyzed. Of which, the base sections, the trolley body, and the jib retaining split pins with 720, 480, and 360, respectively, had the highest RPNs, which the high work height and the heavy weight of the loads are some of the major risk factors of these devices.
Conclusion: Tower cranes are highly risky as a result of the severity of the possible consequences. Therefore, periodic training for riggers, periodic visits of cranes, obtaining a crane health certificate, and risk assessment of hazards to reduce the risks, are some of the solutions presented in this study in order to lessen the risks and accidents of the tower cranes.
Keywords: Safety index; Tower crane; Risk assessment, FMEA technique

INTRODUCTION

Work-related accidents are the third leading cause of death in the world. The construction industry is introduced as a high-risk industry because of the high accidents and the risk of people's health[1]. Reports indicate that the construction industry in Iran accounts for about 40% of the workplace accidents for 29% of the total industrial workers. Recent studies on workplace accidents by the Ministry of Labor showed that the construction industry has the most accidents and injuries among all the industries in the country[2]. According to the development of the construction industry and the urgent need to use the machinery to quickly achieve the stated goals, industry experts believe that the tower crane is one of the most important construction machinery that is placed in a privileged position due to the diverse capabilities and low costs compared to similar machines[3].

The tower crane was widely used for the first time for lifting and moving materials in the construction industry in Hong Kong[4]. Statistics of high occupational accidents caused by tower cranes indicate the widespread and the central role of these types of machinery in countless construction accidents. In the year 2000, 872 accidents occurred by tower cranes in the world, resulting in more than 668 deaths and numerous injuries, and these numbers reached more than 116 accidents and 44 deaths in 2009[1]. According to the reports of the accidents caused by the tower crane in the country, in a construction project in Mashhad in 2014, an accident occurred during the installation of a mobile tower crane that killed two people and injured another two. Furthermore, in September of 2014, the crash of a tower crane in a street in the city of Mashhad caused three injuries and several billion dollars in financial damage due to the lack of attention to the tower crane capacity and disregarding the technical inspection instructions[5]. Damage and injuries can be prevented if the tower crane safety is approved in accordance with the ISO 12100 standard[6].

By using risk assessment methods in the tower cranes, including quantitative and quantitative methods and accident analysis, we can examine crane parts, identify unsafe measures and conditions as well as deficiencies in safety management, and implement control measures to prevent accidents[7]. Safety analysis is carried out in a variety of ways, including energy analysis, hazard analysis and the capability of operation, error analysis, occupational safety analysis, deviation analysis, analysis of potential failure scenarios and their effects, task analysis and immunity analysis.

The Failure Modes and Effects Analysis (FMEA) is widely adopted for identifying, assessing and eliminating known potential risks, problems and system errors in design and pre-production (8). This method is well-designed and is in accordance with various international standards[9]. The FMEA is primarily a reliable tool for identifying failure modes that identify the system's negative performance. One of the capabilities of this system is determining the failure rate for each failure mode in order to achieve a quantitative analysis. In addition, the FMEA can be used to extend the failure modes, such as system risks and hazard analysis, which may be unintentionally entered into the system (10). The Machinery Failure Modes and Effects Analysis (MFMEA) supports the machine tool design process, from design phase to project approval, and is considered as a complete revision of any stage or function in the final performance of a machine and is a design output to evaluate and improve reliability, flexibility, and durability of the machine used. In this method, unlike others, three variables; the severity of the outcome, the number of detections, and the probability of occurrence of failure are used for estimating the risk number, which is its main advantages compared to other methods of risk detection. Therefore, the purpose of this study was to evaluate the reliability of the tower cranes in the city of Mashhad in 2016[11,12].

MATERIALS AND METHODS

This descriptive study was carried out in 2016 to identify and assess the risks of 150 tower cranes in Mashhad using the MFMEA method and the *tower crane inspection checklist*. In this research, data recording was performed using the FMEA worksheets proposed by *the standard SAE J1739* and the *tower crane inspection checklist*. In the first phase, 15 sessions with the FMEA team were completed. After the completion of the necessary studies, 30 final papers of the FMEA were completed and then finalized. In the second stage, thanks to the access granted by and cooperation of the project authorities, all 150 active tower cranes in the city of Mashhad were inspected using the standard checklists of the *tower crane inspection checklist*, and the safety and health status of the active tower cranes at Mashhad level was investigated. To this end, the first stage of MRMEA risk analysis requires the collection of information, extensive knowledge and sufficient experience in the studied system by the study team (13). The team is responsible for all the relevant activities from the initial stages until the implementation of the proposed actions and reviewing the results.

The study team in this study included an engineering supervisor, an HSE engineer, an electrical engineer, a crane operator and a rigger. In the present study, it was attempted to organize special sessions for different parts of the crane to identify its dangers and consequences. Also, the project executive was present and was responsible for guiding the meeting.

In the current research, in order to collect information, a tower crane was first selected by the study team and then, with the help of the team members, the information required to prepare the FMEA worksheets and the analysis of the device was collected through device diagrams, operating instructions, risk analysis reports along with other safety reports, the results of the risk analyses carried out in other similar systems, maintenance records, system-constructing data and its components, crane inspections and observations, interviews with riggers, and brain storming. In the second stage of this technique, after the data was collected by the operating team, the potential of the component failure modes was determined in all operating modes of the system and a list of failure modes causing the machine failure, in accordance with its intended functions, was provided. At this stage, with regard to the activation of 150 tower cranes in the city of Mashhad, and due to the access granted by and cooperation of the project authorities, all 150 active tower cranes were inspected using the standard tower crane inspection checklist.

In the next step, the risk matrix was determined using the severity of the outcome, the probability of failure occurrence and the detection of each failure. By establishing the risk matrix, the risk priority number was obtained. The causes or potential mechanisms and the controls in the relevant columns were also completed. In the present study, the ten-digit ranking guidelines proposed by the SAE J1739 standard have been used to rank the severity. Table 1 shows the selection rating for the final severity in this study[16]. Also, in Table 2, the probability of occurrence of the cause or potential mechanism of a failure at a given time was calculated using the proposed table of probability of occurrence of SAE.J 1739 by making changes as a result ranking table.

Table 1: A guidance for selecting the severity ranking (using the standard SAE.J 1739)

Effect	Criterion: the effect severity	Ranking
Being risky with previous warning	Very high severity: Effects on the safety of the operator, tower crane or personnel or in contravention of government regulations.	10
Being risky with prior warning	Very high severity: Effects on safety of the operator and personnel and or in contravention of government regulations	9
Too much stop time	Stop of the crane for more than a month	8
Long stop time	Stop of the crane for 10 days to one month	7
Average stop time	Stop of the crane for 24 hours to 10 days	6
Low stop time	Stop of the crane for 10 hours to 24 hours	5
Very little effect	Stop of the crane for 1 hour to 10 hours	4
Negligible effect	Stop of the crane for less than 1 hour	3
Very effect negligible	The parameter fluctuations are within the control range. Setting or other control of the process is required.	2
Ineffective	The parameter fluctuations are within the control range. The adjustment or other control of the process is not required. Or, we can check the device between two shifts or in the usual repairs of the organization.	1

Table 2: Guidance on the selection of occurrence ranking (using the standard SAE.J 1739)

Possible number of failures in work cycles	Ranking
1 in 5	10
1 in 50	9
1 in 200	8
1 in 450	7
1 in 850	6
1 in 300	5
1 in 1600	4
1 in 2500	3
1 in 4000	2
1 in over 4000	1

The detection ranking is, in fact, a ranking that indicates the ability of the existing controls to detect each potential failure mode. Table 3 shows the ranking of the detection of failures used in this study.

Table 3: Guide for selection of detection ranking (using the Standard SAE.J 1739)

Likelihood of detection	Likelihood of detection by design or control of machines	Ranking
Almost impossible	Controls of the machine cannot detect the causes or mode of failure, or there is no control of design or machine.	10
Very remote	It is very remote that controls of design or machines can detect the causes or mode of failure.	9
Remote	It is remote that controls of design or machines can detect the causes or mode of failure.	8
Very low	Controls of design or machines cannot prevent failure occurrence. Controls of the machine will isolate the cause and mode of failure after the failure.	7
Low	There is a low chance that controls of design or machines can detect the cause and mode of failure. Controls of machine prevent imminent failure.	6
Moderate	There is a moderate identification that controls of design or machines can find the causes or mode of failure. Controls of machine prevent imminent failure and isolate the cause of failure.	5
Moderately high	There is a moderately high chance that controls of design or machines can find the causes or mode of failure. Controls of machine prevent imminent failure and isolate the cause of failure.	4
High	There is a high chance that controls of design or machines can find the causes or mode of failure. Controls of machine prevent imminent failure and isolate the cause of failure.	3
Very high	There is a very high chance that controls of design or machines can detect causes or modes of failure.	2
Almost certain	Controls of design or machines definitely detect the causes or mode of failure.	1

Acceptable RPN values may vary from one industry, organization, or plant to another; for example, in the study of the safety analysis of the spherical liquid gas reservoir by Nezhadali, the tolerable RPN class was set at 100. Tolerable RPN is determined based on the engineering decision making, regulatory requirements, safety-related standards, safety and health commitments, the level of income of the organization, and so on. Therefore, in this study, RPN = 150 was considered as tolerable, and taking into account the above argument and the consensus of the team, it was accepted that it will be in need of the planning and implementation of corrective, preventive and control measures. However, in this study, attempts have been made to recommend corrective actions for most RPNs less than this value.

After detecting and implementing the required precautionary or corrective measures, the values of severity, occurrence, and detection were estimated under the new conditions and the secondary RPN was calculated. Finally, after completing the inspection checklists of all the active tower cranes in Mashhad city, the results were analyzed using the 2013 Excel statistical software.

RESULTS

The number, capacity, and characteristics of the studied cranes are presented in Table 1. The initial RPN was determined for each failure mode and the failure modes were prioritized according to the RPN value as shown in Table 1. Moreover, the final RPN values and the acceptable or unacceptable determination of risk are shown in this table. Given the FMEA team meetings and reviewing the existing conditions, and consulting with team members, the acceptable RPN was considered to be 150.

Table 4: Information on active tower cranes in city of Mashhad

Crane features	The existing number of it in the city of Mashhad
Capacity	70 cranes have a 4-8- ton capacity. 50 cranes have an 8-ton capacity. 30 cranes have a capacity of more than twelve tons
Manufacturing Country	85 cranes are made in France. 50 cranes are made in China. 15 cranes are assemblies and no information is available.
Arrow length	30 cranes are with a 55- meter arrow length 95 cranes with a 45-meter arrow length25 cranes with a 65-meter arrow length

Table 5: A list of priorities of detecting failure modes by MFMEA method based on RPN values

Row	Failure mode	Initial RPN value	Acceptable or unacceptable risk	Final RPN after recommended actions	Acceptable or unacceptable risk
1	Basic section	720	Unacceptable	90	Acceptable
2	Trolley body	480	Unacceptable	240	Unacceptable
3	Jib-retaining split pins	360	Unacceptable	108	Acceptable
4	Defect in fixture base reinforcement network	320	Unacceptable	120	Acceptable
5	Jib-boom Stops-inhibiting bar	300	Unacceptable	144	Acceptable
6	Load indicator	300	Unacceptable	60	Acceptable
7	Overload Stopper	280	Unacceptable	100	Acceptable
8	Trolley Stopper	280	Unacceptable	140	Acceptable
9	Inappropriate quality of base fixation Concrete	270	Unacceptable	120	Acceptable
10	Hook Stopper	256	Unacceptable	100	Acceptable
11	Equilibrium Weight	250	Unacceptable	90	Acceptable
12	Section parts welding	240	Unacceptable	120	Acceptable
13	Derrick section	240	Unacceptable	120	Acceptable
14	Jib fittings welding	200	Unacceptable	120	Acceptable
15	Winch and pulley construction	200	Unacceptable	72	Acceptable
16	Defects and fractures in pulleys and winches	200	Unacceptable	72	Acceptable
17	Main Sections ladder	180	Unacceptable	100	Acceptable
18	Jib bolts and fittings	168	Unacceptable	96	Acceptable
19	Anemometer	160	Unacceptable	96	Acceptable
20	Bolt and fittings of the rotation system	160	Unacceptable	64	Acceptable
21	Bolts and pine fittings and pine constructions	160	Unacceptable	60	Acceptable
22	Access step to the cabin	160	Unacceptable	48	Acceptable
23	Access corridor to the flash cone	135	Unacceptable	45	Acceptable
24	Chariot lock front	126	Unacceptable	54	Acceptable
25	Rear Chariot Lock	126	Unacceptable	54	Acceptable
26	Power transmission Cables of Spinning system	126	Unacceptable	54	Acceptable
27	Central stopper	90	Unacceptable	18	Acceptable
28	Work radius indicator	90	Unacceptable	50	Acceptable
29	Screws	72	Unacceptable	24	Acceptable
30	Pin, split-pin, and screws related to the derrick	72	Unacceptable	24	Acceptable

According to the results of Table 2, after the presentation and implementation of corrective actions, 21 of the identified unacceptable risks became acceptable and only 1 in the "body of the trolley" of the risk with a value of 240 remained unacceptable. According to the statistical analyses of the relationship between failure modes and RPNs in the tower crane, the majority of failure modes has an RPN greater than 100, with the highest failure rates as shown in Table 6.

Table 6: Relationship between Failure Modes and RPNs in the tower Crane

Ranking	Failure modes	RPN
1	Base parts	720
2	Trolley body	480
3	the jib retaining split pins	360
4	Defect in fixture as reinforcement network	320
5	Jib-boom Stops-inhibiting bar	320
6	load indicator	300

DISCUSSION

Among the detected failure modes, the ones related to the base sections, trolley body, and jib retaining split with 720, 480, and 360, respectively, had the highest RPN. Furthermore, failure modes such as the work radius indicator, screws, pins and split pins related to the derrick with 90, 72, and 72 RPN, respectively, had the lowest RPN. High levels of RPN in this study and other similar studies are due to high work height and heavier weights, combination of which causes the risk and increase in the risk of these devices[16,17].

In the study of Vivian et al., the highest values of RPN were in the base sections and crane foundation, which is consistent with the results of this study. These results indicate the importance of the foundation and the strength of the base structure as one of the most important safety factors of the crane. Vivian also referred to four main factors affecting the safety of a crane operation, including negligence or incorrect judgments about the tower crane operation, inadequate training, small tower crane operation and pressure due to time constraints, which are more likely to express relationship to the safety and skill attitude of the operator of the crane[16].

In another study, Shapira et al. (2000) identified major safety factors in the industry with a tower crane such as the site safety management, operator skills, storms, project manager characteristics, maintenance management, company safety management, the overlap of cranes, load lifting, and operator work shift lengths. Shapira et al.'s study also shows that in order to achieve the appropriate safety status and to perform the safe loading, in addition to the parameters of the crane safety, attention should be paid to other parameters of attitude, skill, culture, safety of the workshop, and its atmospheric conditions when lifting the load. Therefore, its results are consistent with the present study[17].

In a report by the Ministry of Labor's Work Safety and Health Council, entitled "Human error review", 23 crane crashes were shown using error tree analysis. Three main causes of accidents include inadequate knowledge and information, often attributed to inadequate training, error of a person, which is often a result of exceeding the capacity of the crane, and violating the rules and instructions, including ignoring the limiting switches, ignoring alarm alarms, failing to check the load chart, and executing non-conforming safety procedures. Of course, other issues such as inaccurate judgment about the load weight also leads to accidents (18). In the present study, 73% of the identified risks were initially unacceptable and were reduced to 3% after corrective actions. Hosseini et al., Using the FMEA technique, in the case study of the construction phase of oilfield platforms achieved the low risk of 62.7%, average risk of 31.6%, and high risks of 5.7% after corrective actions and management solutions by specialists. Moreover, low risks increased by 30.6%, moderate risks and high risks decreased by 72% and 53%, respectively[19].

Hosseini et al. (2012) also assessed the potential hazards of the Shiraz refinery through the FMEA method and its effects, and concluded that the RPN score in some of the activities, such as transportation and handling of objects and milling can be done using effective control measures such as safety classes, internal audit, execution of the 5S Kaizen (Continuous improvement), continuous maintenance and installation of process instruction panel in order to control or eliminate risks, indicating the usefulness and efficiency of the FMEA method[20].

According to the results of statistical analysis, the relationship between failure modes and RPN in a tower crane has the most failure modes with an RPN greater than 100 which is due to the high risk of the tower cranes and the consequences of its failure. Also, based on the relationship between failure modes and severity in the tower crane machines, most failure modes have a severity rating of 10, which indicates a risk with the previous warning, and the severity of the effect is very high, which affects the safety of the operator, the tower crane or the personnel. The need for corrective or preventive action is determined by reviewing critical properties, control, safety, or severity and a tolerable RPN (21). According to the results, the sensor indicates the load and radius of work, as well as the status of access to the cabin with 16, 38.67 and 52%, respectively, were the most common defects in the tower cranes in the city of Mashhad. In his study, Neitzel et al. described the most safety-related failures of cranes due to the inadequate functioning of sensors and the inappropriate condition of wire rope, which suggests that in similar studies, lack of the safety of tower crane sensors and disregarding them are some of the major reasons for accidents related to them (22). In an example of the fall of a tower crane in Mashhad in 2014, the lack of a micro switch stopper of the load of the tower crane was a major cause of the accident.

Therefore, in the present study, due to the high percentage of unacceptable risk identified in the pre-corrective stage (73%), control methods have been presented to eliminate or reduce identified risks. A set of corrective actions provided by the FMEA team, which reduced RPN and subsequently improved the safety of the tower cranes are as follows:

Soil strength testing prior to installation of a tower crane, the use of suitable bar and fittings in accordance with the instructions for the basic structure of the barrier, the testing of welding fittings by qualified persons and obtaining approvals from authorized companies, leveling the sections, as well as using healthy sections without folding or fluctuation, determining the weight and dimensions of the load before being loaded by a rigger and communicating it to the driver, performing loading operations in the appropriate atmospheric conditions and suitable wind speed, daily checking of micro switches and reporting their failure to predetermined units, the establishment of an on time reporting system and keeping track and entrusting competent people to discontinue operations in hazardous conditions, the selection of qualified persons for the maintenance and creating an organizational relationship between the project manager, responsible for the safety of the project and the operator of the machine, to create a reporting system on system errors by the rigger and the operator to the competent person for troubleshooting and tracking it until complete elimination.

Considering the risks and significance of the crane issue in occupational accidents, suggestions for further research, such as assessing the effectiveness of existing training on the performance of operators and riggers of tower cranes by using JSA forms and designing training courses to reduce individual errors, checking the time schedule delays of the project and its relation to the accidents and errors of the power crane, the effect of the program of regular maintenance of the tower crane on the amount of damages caused to the tower crane, the connection of the safety atmosphere of the construction workshop with accidents and errors caused by the tower cranes.

CONCLUSION

One of the obstacles to research in the present study is the interest of several organizations, including Engineering Organization, the Municipality and the Department of Labor and Social Welfare as well as insurance, and the lack of coordination among these organizations affects any research activity. One of the reasons for organizations' reluctance is due to gross and non-negligible defects in the work processes that organizations prefer to remain internally and within the organizations themselves, and no action is taken to remove them from the other organization. The second limiting factor of the study, which is very significant, is the existing policy of insurance so that insurance companies ignore the cost of the risk and provide services under different nomenclature. In one such case, having a health certificate is a standard requirement for all organizations for tower cranes, but insurance can provide services to the tower crane without any safety visit. Moreover, the Engineering Organization has a poor monitoring of the performance of tower cranes and has no leverage on the employer due to the choice of tower cranes.

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REFERENCE

1. Hoła B, Szóstak M. Analysis of the Development of Accident Situations in the Construction Industry. Procedia Engineering. 2014;.34-91:429
2. SH G. Optimization of safty process in construction industry with using a decision support system. quarterly journal of business management perspective (mANAGEMENT Perspective). 2009;8(31):.78-159
3. Online TS. World-Wide Tower Crane Accident Statistics 2000 through 2009.[Accessed April. 17, 2016] .Available from: http://towercranesupport.com/09article.php.
4. hang J, editor Study on the Lifting Weight Detection of Tower Crane. Applied Mechanics and Materials; 2013: Trans Tech Publ.
5. khabaronloin. Tower crane crashed in Mashhad 2016 [Accessed April, 17. 2016]. Availablefrom:http://www.khabaronline.ir/print/384636/society/events?model=WebUI.Models.Details.DetailsPageViewModel BS EN 14439:2006: Cranes: Safty: tower Cranes. The European Standard EN 14439:2006has the status of a British Standard. Available From: tps://law.resource.org/pub/us/cfr/ibr/003/bs.en-14439.2006.pdf.
6. Wang Q, Xie L, editors. Safety analysis of tower crane based on fault tree. Applied Mechanics and Materials; 2012: Trans Tech Publ.
7. Stamatis DH. Failure Mode and Effect Analysis, Milwaukee, WI: ASQ Quality Press; 1995: 102-121.
8. Lars Harms R. Safety analysis. UK: Taylor & Francis. .81-2003:170
9. El MSBAA, El Nawawy OAM, Abdel-Alim AM. Identification and assessment of risk factors affecting construction projects. HBRC Journal. 2015
10. Jafari MJ, Gharari N. TBM Risk Analysis using FMEA, Proceeding 8th Iranian Tunneling Conference, 18-20 May 2009, Tehran: 456-465.
11. Jafari MJ, Gharari N, Sheikhi HR. The Reliability of a Tunnel Boring Machine, IJOH, 2009; 1: 19-24.
12. Jafari MJ, Gharari N-a, Sheikhi HR. The reliability of a tunnel boring machine. International journal of occupational hygiene. 2009;1(1):.5-20
13. Sheridan-Leos N, Schulmeister L, Hartranft S. Failure Mode and Effect Analysis (TM): A Technique to Prevent Chemotherapy Errors. Clinical journal of oncology nursing. 2006;10(3):.393
14. Wilcox R. Risk-informed regulation of marine systems using FMEA. US Coast Guard Marine Safety Center Washington Available online at www uscg mil/hq/msc/fmea htm. .1999
15. Tam VWY, Fung IWH. Tower crane safety in the construction industry: A Hong Kong study. Safety Science. 2011;49(2):.15-208
16. Shapira A, Simcha M, Goldenberg M. Integrative model for quantitative evaluation of safety on construction sites with tower cranes. Journal of Construction Engineering and Management. 2012;138(11):.93-1281
17. crane safety analysis and recommendation report. This Report is published by the Workplace Safety and Health Council, the Ministry of Manpower and the National Crane Safety Ashore. September .2009
18. Khosravirad F, Zarei E ,Mohammadfam I, Shoja E, Majidi Daryani M. Explosion risk analysis on Town Border Stations (TBS) of natural gas using Failure Mode & Effect Analysis (FMEA (and Fault Tree Analyses (FTA (methods. Iran Occupational Health Journal. 2016;12(6):.27-16
19. Hosseini H DT, Arjmandi R, Shirianpour I. Safety and Occupational Health Risk Management in construction phase of oil field and presenting Management strategies improve (Case study construction phase of platform's Reheat oil field). Journal of Human and Environment 2012;10(22):.67-39
20. Shim K-H, Rie D-H. A Quantitative Risk Analysis of Related to Tower Crane using the FMEA. Journal of the Korean Society of Safety. 2010;25(6):.9-34
21. Neitzel RL, Seixas NS, Ren KK. A review of crane safety in the construction industry. Applied Occupational and Environmental Hygiene. 2001;16(12):..17-1106