An application of failure mode and effect analysis (FMEA) to assess risks in petrochemical industry in Iran

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ABSTRCT
Petrochemical industries have a high rate of accidents. Failure mode and effect analysis (FMEA) is a systematic method and thus is capable of analyzing the risks of systems from concept phase to system disposal, detecting the failures in design stage, and determining the control measures and corrective actions for failures to reduce their impacts. The objectives of this research were to perform FMEA to identify risks in an Iranian petrochemical industry and determine the decrease of the risk priority number (RPN) after implementation of intervention programs. This interventional study was performed at one petrochemical plant in Tehran, Iran in 2014. Relevant information about job categories and plant process was gathered using brainstorming techniques, fishbone diagram, and group decision making. The data were collected through interviews, observation, and documents investigations and was recorded in FMEA worksheets. The necessary corrective measures were performed on the basis of the results of initial FMEA. Forty eight failures were identified in welding unit by application of FMEA to assess risks. Welding processes especially working at height got the highest RPN. Obtained RPN for working at height before performing the corrective actions was 120 and the score was reduced to 96 after performing corrective measures. Calculated RPN for all processes was significantly reduced ($p \leq 0.001$) by implementing the corrective actions. Scores of RPN in all studied processes effectively decreased after performing corrective actions in a petrochemical industry. FMEA method is a useful tool for identifying risk intervention priorities and effectiveness in a studied petrochemical industry.
.**Key words:** FMEA, RPN, Corrective measures, Process, Petrochemical industry

INTRODUCTION
It is becoming increasingly difficult to ignore the workplace health and safety requirements to protect the workers, neighbors, and the environment from existing major hazards in petrochemical industries [1,2].

In recent years, systematic safety management methods are used to prevent accidents and adverse events and promote occupational safety in workplaces. Risk assessment is an increasingly important area in safety management systems. Hazard identification, assessment of hazards and risks, and risk control methods has been thought of as key factors in safety management systems. Recent evidence suggests that errors that occur at the design, manufacture, installation, and maintenance stages of systems may lead to major accidents and adverse consequences such as Bhopal, Chernobyl, Seveso, and Flixborough [3]. Risk assessment has been identified as a major method to assess the failures and provides the qualitative and quantitative evaluations of hazards and their consequences [4-6]. Risk assessment provides valuable information on risk- based decision-making for hazard mitigation, control measures, and providing a plan for responding to impacts of events. To date various methods have been developed and introduced to identify hazards. The selection of methods depends mainly on the complexity of the system, structural phase, organizational vision, management style, type of process, and experience and expertise of hazard identification teams [7].

FMEA is one of the more practical ways for hazard identification and risk assessment [8]. FMEA was introduced for the first time in 1949 in the United States. The purpose of implementing FMEA is to prevent accidents. FMEA is a systematic method and thus is capable of analyzing the risks of systems from concept phase to system disposal, detecting failures in design stage, and determining the control measures and corrective actions for failures to reduce their impacts [9]. FMEA increases the process reliability by preventing defects detected in systems and mitigating the adverse consequences of accidents [10, 11]. The Occurrence (O), severity (S) and detection (D) factors are important components in this method and are determined using a numerical rating scales [12]. This method consists of two phases. The first phase consists of failure identification and its associated consequences. The second phase of the analysis is related to the determination of the extent of failures using RPN [13, 14].

A number of studies have found that FMEA is a useful tool for identifying risk intervention priorities and effectiveness [15]. The findings of Ebrahimzadeh *et al*. (2011) indicated that the highest RPN obtained from risk assessment of some units of the Shiraz refinery was associated with doing some tasks such as external surface scraping (200) and handling of materials (200). After implementation of effective intervention programs, the scores of RPN for these tasks decreased to 72 and 84, respectively [16].

In the new global economy, petrochemical industries have significant effects on the economic situation in some countries. These industries have a high rate of accidents. FMEA can be considered as an effective approach for identifying risk factors for accidents in oil industries. Analyze the root causes of accidents showed that environmental conditions were the cause of failures of some systems. Previous studies have reported that working conditions of employees had effects on the rates of production of oil and gas companies [17]. The objectives of this research were to perform FMEA to identify risks in an Iranian petrochemical industry and determine the decrease of RPN scores after implementation of intervention programs.

MATERIALS AND METHODS

This interventional study was performed at one petrochemical plant in Tehran, Iran in 2014. Prior to commencing the study, relevant information about job categories and plant process was gathered using brainstorming techniques, fishbone diagram, and group decision making. The opinion of line supervisors, experienced staffs, and occupational health and safety, experts was considered in order to revise the information. The FMEA worksheet was prepared. Further information about system design, types of equipment, and standard operating guide was considered. In the first phase, the data were collected through interviews, observation, and documents investigations and were recorded in FMEA worksheets. In the second phase, the necessary corrective measures were performed on the basis of the results of initial FMEA (the intervention was the corrective actions and elimination of defects). Once the first phase was completed, the implementation of corrective actions including optimum maintenance schedule, regular inspection of equipment, installation of alarms and redundancies, and providing a system for recording and maintaining information, safety requirements, daily checklists, and safety education programs were conducted. For the purpose of assessment, different processes such as welding, milling, transportation and handling of materials, and operational and maintenance processes in a welding unit in the petrochemical industry were investigated and intervention actions for each element were done on the basis of calculated RPN. Following this, further information about organizational capital, human resources, level of employees' knowledge, organizational factors, and past accident data and their consequences were considered in determining the levels of risk in the welding unit of this industry. Fig. 1 presents FMEA flow chart used in the current study. The RPN less than 70 was defined as low-risk, RPN between 70 and 140 was defined as moderate risk, and RPN greater than 140 was considered as high risk. The RPN was obtained by multiplying three parameters including severity (S), occurrence (O), and detection (D) [18]. The severity, occurrence and detection indexes for FMEA procedure were determined according to ref. 3. The probabilities of failures and root causes were determined by occurrence criteria. The effects of potential failures were determined using severity ranking criteria and detection ranking criteria was used to detect the failures before their impacts. The occurrence ranking criteria was scaled from 1 to 10. Rate 1 was related to an unlikely probability of occurrence and rate 10 was associated with high frequency of occurrence. Severity ranking criteria were scaled from 1 (minor system damage or injury outcomes) to 10 (serious injury or death). Detection ranking criteria were scaled from 1 to 10. Rank 1 was associated with a very high probability of detection of defects and rank 10 was related to the very low probability of detection of the existing defect.

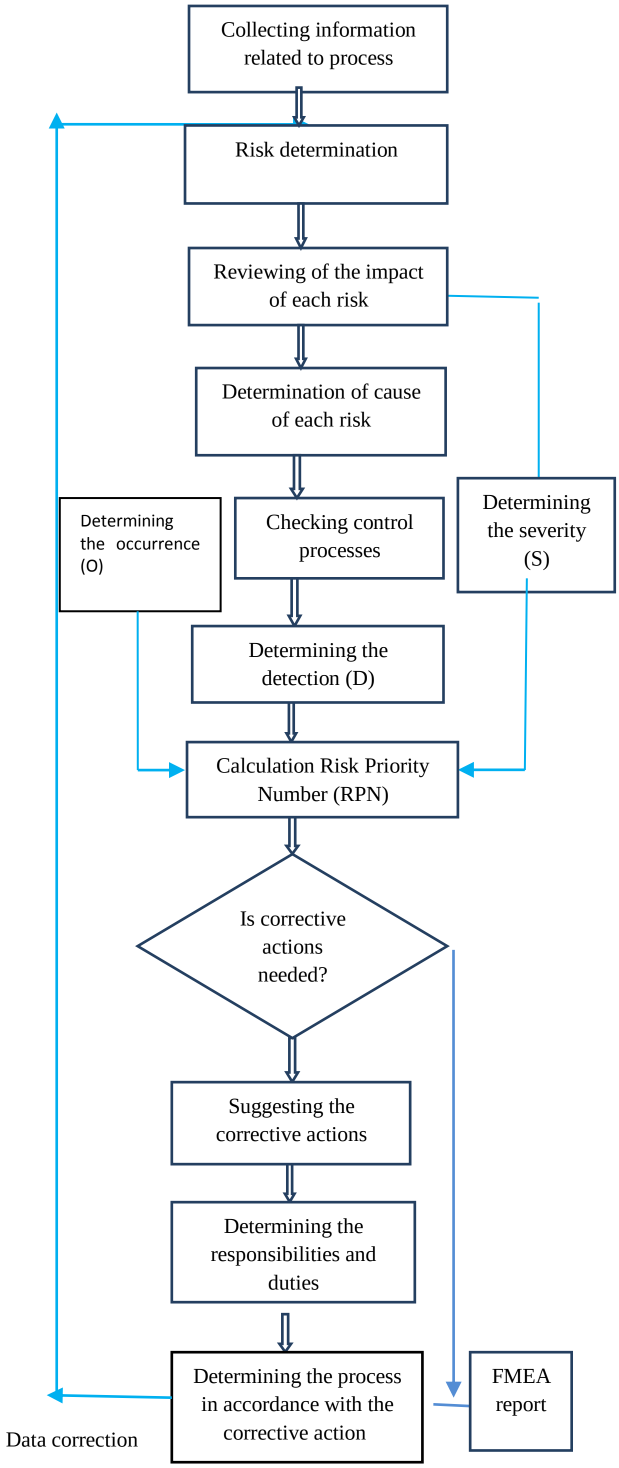

Fig. 1: FMEA flow chart used in the study

RESULTS

Forty eight failures were identified in welding unit by application of FMEA to assess risks. Thirteen failures were identified in the welding process. FMEA worksheet for assessing the failures in the welding process is presented in Table 1.

Before performing intervention programs, the lowest RPN except welding processes was calculated for cutting metal process with the score of 168. Working at height got the highest RPN score (315). After performing recommended corrective actions, electric welding process got the lowest RPN score (62) and the highest RPN was related to work at height task. Fig. 2 presents the comparison between the risk levels before and after performing intervention programs.

As can be seen in Fig. 2, the highest estimated level of risk (54.17%) before intervention was associated with a high risk level (RPN>140). After performing corrective actions, this level was reduced to 27.08%. Fig. 3 shows comparisons between calculated RPN scores before and after implementing the intervention measures at studied processes.

As showed in Fig. 3, calculated RPN for all processes was significantly reduced ($p \leq 0.001$) after implementation of corrective actions.

Table 1: FMEA worksheet in welding process

Process type	Type of defects	Cause of defects	Effects of defects	Recommended actions	Occurrence	Severity	Detection	RPN before intervention	RPN after intervention
Workig on saws	Throwing sparks	Working adjacent flammable materials	Fire	Installation and implementation of fire safety requirements	9	4	4	144	104
Argon welding	Exposure to fumes and toxic gas	Fail to use appropriate protective masks	Occupational disease	Using properly designed local exhaust hoods	8	6	5	240	168
Electric welding	Throwing sparks	The nature of process	Burning	Using personal protective equipment and installing the adsorption sheets	6	5	4	120	62
Electric welding	Fall from height	Working at height	Injuries	Usage of belts and safety net	7	9	5	315	206
Cutting metals	The explosion of cylinder	Lack of training and poor maintenance	Fire and injuries	Safety training programs	3	7	8	168	132
CO_2 welding	flash-back flame	Equipment failure	Explosion	Using flashback arrestor	5	6	5	150	142
Welding	Fire	Fail to separate full and empty cylinders	Fire	Labeling all cylinders	3	5	8	120	96
Welding	Collision with obstacles	Improper layout	Injuries	Determining passing ways	3	6	4	72	60
Welding	Collision with forklift trucks	No warning device	Injuries	Audio and visual alarms	7	6	4	168	112
Welding	Hearing loss among workers	High noise levels at workplace	Deafness and hearing loss	Using personal protective equipment	8	6	4	192	148

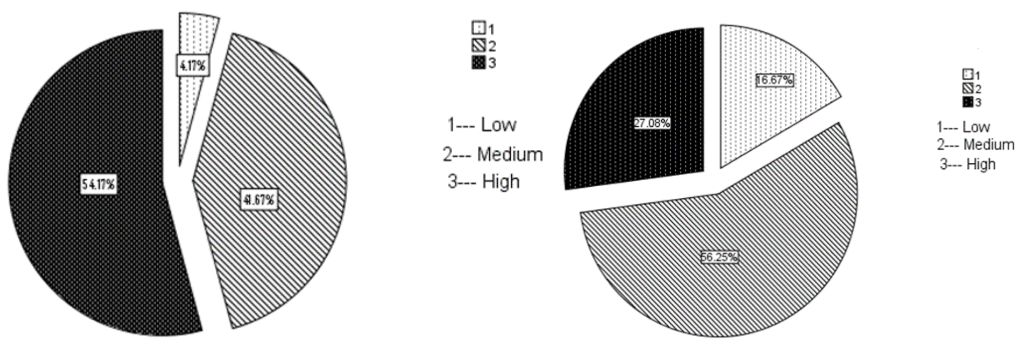

Fig. 2: The estimated levels of risk before (left) and after (right) performing corrective actions

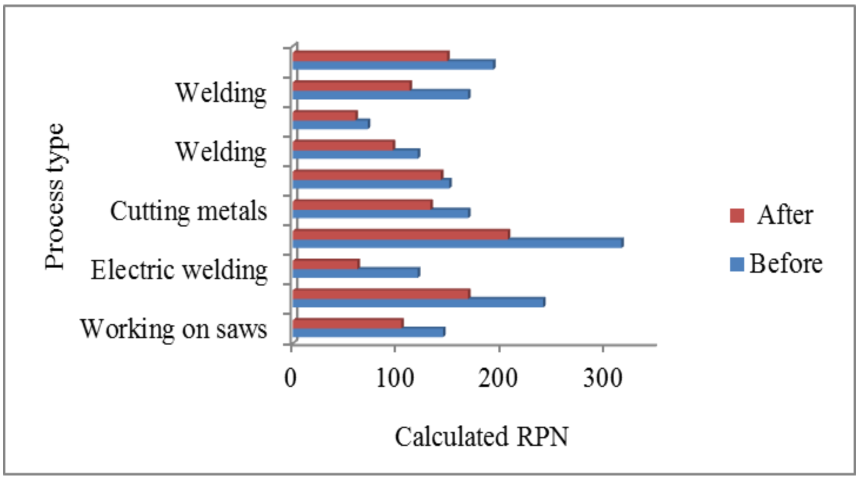

Fig. 3: Comparisons between calculated RPN scores before and after implementation of intervention measures

DISCUSSION

Hazard identification is an important component of the occupational safety and health management systems. Recent evidence suggests that hazard identification can provide the basis for risk management and possible corrective measures [16]. The objectives of this research were to perform FMEA to identify risks in an Iranian petrochemical industry and determine the decrease of RPN scores after implementation of intervention programs.

FMEA is a systematic technique for hazard identification. This is an effective tool for identifying potential hazards, root causes of failures, and corrective measures. FMEA approach has a number of attractive features. FMEA as a proactive tool provides useful information for performing corrective measures. This method is based on teamwork. Identification of team members plays a key role in the success of application of FMEA technique. The drawback of this method is that it is very time consuming. FMEA provides a preventive mechanism for improving processes in order to prevent the occurrence of deviations [19].

The current study found that welding process especially working at height got the highest RPN scores before (315) and after (206) performing corrective measures (high risk). Working at height without attention to safety requirements and using appropriate personal protective equipment may lead to fatal occupational accidents. This finding corroborates the ideas of Stellman (1998), who suggested that fall from height are one of the most common and dangerous hazards in welding process [20]. Welders were exposed to fire hazards. The calculated RPN for fire hazards before performing corrective actions in the welding process was 120 and this score was reduced to 96 after performing corrective measures. The results of assessment of the potential risks in different parts of the Shiraz refinery showed that the calculated RPN for fire hazards before and after performing corrective actions in welding process were 72 and 24 [16] which were lower than those obtained in the current study.

Another important finding was that calculated RPN for all processes was significantly reduced ($p \leq 0.001$) by implementing the corrective actions. This finding is in agreement with Hosseini's (2011) findings which showed performing corrective actions significantly reduced ($p<0.0001$) the calculated RPN scores in Bafgh steel direct reduction project [21]. This also accords with Ebrahimzadeh *et al.* (2011) investigation, which showed that implementation of intervention programs such as performing corrective measures may cause reduction in RPN scores [16].

Petrochemical manufacturing plants were exposed to hazards. This is due to the nature of the process. In general, therefore, it seems that risk assessment and management strategies for reducing accident frequency and consequences play more important roles. Given that increases in system reliability is one of the most important features of performing FMEA, recommending corrective measures for treating the cause of failures in systems can be effective in improving process reliability in petrochemical manufacturing plants. In the current study, performing corrective actions was effective in reducing the scores of RPN and improving the workplace occupational safety and health (fig.2). Even though the implementation of corrective measures effectively reduced the scores of RPN, some RPN scores were higher than those obtained in other studies [16] and high levels of risk were observed in some processes such as working at height.

It is recommended that companies should select more knowledge workers for professional work tasks. Managers should pay more attention towards the safety inspection checklists [22]. Developing a safety culture and safety climate in organizations had the greatest effect on management commitment to safety, workers' involvement and attitudes in safety, reductions in accident rates, reduction in costs of accidents, and promoting workplace safety and health [16, 23].

A variety of methods are used to assess risks in the work environment. Each has its own advantages and drawbacks. FMEA method is a useful tool for the identification and assessment risks in a studied petrochemical industry. The major disadvantage of FMEA method is special emphasis on risk number [19]. This procedure may be a reason for lack of opportunities for calculating RPN scores for a given low risk processes having high severity and occurrence with low detectability.

CONCLUSION

This study set out to perform FMEA to identify the risks in an Iranian petrochemical industry and determine the reduction in the risk priority number after implementation of intervention programs. Welding process especially working at height got the highest risk priority number. Implementation of corrective measures effectively reduced the scores of RPN in all studied processes. FMEA method is a useful tool for identifying risk intervention priorities and effectiveness in a studied petrochemical industry.

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ETHICAL ISSUES

Ethical issues have been completely observed by the authors.

COMTETING INTERESTS

The authors declared no competing interests.

AUTHORS' CONTRIBUTIONS

All authors participated in design and conduct of the study. All authors have made contributions in drafting, revising, and approving of the manuscript.

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