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Review article

Failure modes and effects analysis (FMEA) technique: a literature review

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ABSTRACT

Risk management and improve the reliability of the process, are the issues which have become more important in production and operations management literature. Risk assessment is an important tool in risk management to reduce project risks and achieve sustainable development. At present the risk assessment is concerned in planning and policy-making in most of the world countries. There are several techniques for identifying hazards and assessing risks. One of the most important of these techniques is Failure Modes and Effects Analysis (FMEA). FMEA is an efficient tool for the identification of potential failure modes and their effects in order to increase the reliability and safety of complex systems. Also this technique is useful to gather data needed for decision making and risk control. In fact, the purpose of this technique is: a. to identify failure modes and their effects; b. to specify the corrective actions to eliminate or reduce the probability of failure and ultimately c. development of efficient maintenance system to reduce the occurrence of potential scenarios. In this study, several other studies have investigated and tried to explore a range of its benefits and uses and also the method of risks computation using this technique is presented.

1. Introduction

According to the statistics reported by the oil and gas industries in 2004 in Africa, Asia and Europe, on average, 1.09 injuries occurred per million working hours. In the United States estimated that over 5,500 workers die and 80,000 workers are injured or sick due to their work and employment conditions (Omidvari 2012). According to the International Labor Organization, daily 5000 people die worldwide due to occupational accidents and diseases. Therefore the occupational accidents account a financial loss and prevention of occupational accidents is very important socially and economically. Safety experts believe that more than 80% of accidents and occupational diseases can be prevented with simple and inexpensive methods. Although traditionally is said that the causes of occupational accidents are unsafe acts or unsafe conditions, but the efforts to improve health and safety conditions in the workplace, shows that these two factors are secondary causes of accidents. In other words the root causes (primary) are defects in the management system or the lack of a safety and health management system in the organization (Ebrahimzadeh 2011; Alizadeh, Mortazavi et al. 2013; Alizadeh, Mortazavi et al. 2014).

Risk management and improve the reliability of the process, are the issues which have become more important in production and operations management literature (Parvin, Alizadeh et al. 2007; Dori 2008). Risk management is the planning, organizing, directing and controlling the activities and assets of the organization, which may have adverse effects on economic performance, in order to minimize the accidents occurrence (Noori 2008). Risk assessment is an important tool in risk management to reduce risks in workplaces and projects and achieve sustainable development. At present the risk assessment is concerned in planning and policy-making in most of the world countries. Risk assessment is a process in which the risks and vulnerability of environment analyzed quantitatively and qualitatively (Larybaggal 2011). There are many methods for risk assessment, but a useful method should be simple and proportionate to the nature of the activities, processes, culture and other aspects of the organization. Each activity has its hazards and risks that must be identified and prioritized. If the hazards and risks do not identify, organizations will face a lot of problems with high costs. This can cause to get out of the competition, lack of growth, the loss of confidence of the staff and the distance from the main objective and reduce the effectiveness and efficiency. In general, if an organization does not identify and assess the risks, it has an effective impact on its performance of the development axes (Ebrahimzadeh 2011). Risk assessment, is a decision-making tool and a basic designed methodology to help making appropriate decisions and determine their outcomes (Bolbolamiri 2010; Omidvari 2012).

The most important part of any health and safety system is hazard identification and risk assessment. In fact, this process is the engine and heart of a safety management system. If the precise hazard identification be taken, the system performance will be better. There are different methods for hazard identification and risk assessment such as safety inspection and audits, Failure Modes and Effects Analysis (FMEA), Job Safety Analysis (JSA), Hazard Operability Study (HAZOP) etc. (Cândeaa 2014).

2. Failure modes and effects analysis

Failure Modes and Effects Analysis (FMEA) is a useful tool for planning and performing preventive maintenance system in various industries. The technique for the first time by reliability engineers was based in the 1950s to assess the safety of military systems. After that using of this method quickly spread so that in the United States and France it used to evaluate safety of Concord and Airbus aircraft, respectively. In 1960, safety issues in the aerospace industry led to implementation of FMEA. The method was developed and applied in the early 1960s by NASA because of the importance of safety and prevention of accidents in space projects. Later in the 1980s, Germany used this method in its chemical and nuclear industries. In the second half of the 1980s, the Ford automobile plant implemented the quality standard ISO 9000 series in the auto industry in the United States and used this method and

caused the spread and development FMEA in the world and in the sciences especially in automotive industry. The efficiency of this method has led that healthcare centers also use it to improve patient safety and their emergency medical services system (Namdari. 2010). Also, this method is widely used in electronics, chemicals and other manufacturing sectors, to identifying, prioritizing and resolving failures, defects and potential problems (Maleki 2006; Hojjatnejad 2008).

FMEA is an efficient tool for identifying the potential failure modes and their effects in order to increase the reliability and safety of complex systems and gathering the data that is necessary to decide about how to manage risks. In fact, the purpose of this technique is to identify failure modes and their effects and corrective actions to eliminate or reduce the probability of failure (redesign) and finally the development of efficient maintenance system, to reduce the occurrence of potential scenarios (Kmenta 2000; Hojjatnejad 2008; Sedagat 2008; Narayanagounder 2009; Bolbolamiri 2010; Bahrami 2012). It is proved that this method is one of the most important primary prevention methods in system, product, process or service design (Davoodpour 2012). It's Feasibility and applicability is leading that this method considered as one of the most important risk analysis techniques. On the other hand, broad range of this method application in various fields, has revealed the weaknesses and limitations, consequently, the researchers have put many efforts in reforming and strengthening its (Cândeaa 2014).

Unlike some other hazard identification techniques, use of the FMEA is based on statistics and requires enough time and manpower. Without information about the process or product, FMEA, instead relying on facts and reality will be converted to a process based on suspicions. Basically FMEA method is used for identifying defects or deficiencies parts of a machine in a manufacturing process that includes several equipment and tools. Naturally, after identifying defects, their causes and their effects on the machine and the system will be cleared. FMEA methodology also refers to the principles of control and prevention of defects (Ebrahimipour 2009; Namdari. 2010).

Although usually one person is responsible for coordinating the process, but the basis of FMEA process is based on the team. The objective of the team building in FMEA is using diverse opinions and expertise of different people. Since each process is concerned certain aspects of a product, FMEA teams are formed when necessary and when the FMEA project is finished these teams are dissolved. Each FMEA team has a specific aim and responsibility, so there is no need to keep a permanent FMEA team. The best FMEA team forms 4 to 6 persons (Hosseinialamdavari 2011).

3. Risk priority number estimation

For calculating the risk priority number (RPN) in FMEA technique three factors are used:

a. Incident Occurrence Probability (O), b. Incident Detection Probability (D) and c. Incident Consequent Severity (S). RPN is calculated using formula 1 (Kmenta 2000; Arabzadeh 2012).

$$RPN = O*D*S \qquad \text{formula 1}$$

Incident Consequent Severity (S) reflects the scope and extent of damage, injury and death caused by the incident if occur. To assess the Incident Consequent Severity pre-designed tables usually used as a criterion. Table 1 shows the criteria to evaluate the Incident Consequent Severity in the FMEA method (SAIPA 2005; Noori 2008; Hosseinialamdavari 2011; Adl 2014).

As formula 1 shows that the risk priority number (RPN) is the product of combination of severity, occurrence and detection. Higher levels of risk priority numbers for a condition, hazard or defect indicates the priority of corrective action for that hazard, defect or condition (Narayanagounder 2009; Arabzadeh 2012). Risk priority numbers are from 1 to 1000 and are considered in order to classify the corrective measures necessary to reduce or eliminate potential failure modes. The modes of failure that have the highest RPN score should be evaluated primarily. Consideration to the severity level is very important. If severity level is 9 or 10, regardless of the RPN, its cause should be investigated immediately. Table 4 shows the criteria for deciding on the level of risk in the FMEA method. The optimization and correction continues until the new RPN reaches to an acceptable level for all potential failure modes (Hosseinialamdavari 2011).

Table 1
Criteria to evaluate the Incident Consequent Severity in the FMEA method.

Description	Scale
Complete failure (stop) of the system	10
Severe damage to the system	9
Damage to the system is too high	8
Damage to the system is high	7
Damage to the system is medium	6
Damage to the system is low	5
Damage to the system is very low	4
Minor damage to the system	3
Very minor damage to the system	2
No damage	1

Incident Occurrence Probability (O) is indicating the possibility to occur an incident in a given time period. Table 2 shows the criteria to estimate the Incident Occurrence Probability in the FMEA method (Noori 2008; Hosseinialamdavari 2011).

Table 2
Criteria to evaluate the Incident Occurrence Probability in the FMEA method

Description	Scale
Incident or failure occurrence is very likely (once or more per day)	10
Incident or failure occurrence is likely (every 3 to 4 days)	9
Incident or failure occurrence possibility is very high (once a week)	8
Incident or failure occurrence possibility is high (once per month)	7
Incident or failure occurrence possibility is medium (every three months)	6
Incident or failure occurrence possibility is low (every six months to a year)	5
Incident or failure occurrence possibility is very low (once per year)	4
Incident or failure occurrence possibility is rare (once every 1 to 3 years)	3
Incident or failure occurrence possibility is very rare (once every 3 to 5 years)	2
Incident or failure occurrence is unlikely	1

Incident Detection Probability (D) means that how likely an incident or failure is discovered after the fact at a specified time. Table 3 shows the criteria to estimate the failure or Incident Detection Probability in the FMEA method (Noori 2008; Jafari 2009).

Table 3
Criteria to estimate the failure or Incident Detection Probability in the FMEA method.

Description	Detection probability	Scale
No device control devices	No detection	10
Existing fault detection by control devices is unlikely	Negligible	9
Existing fault detection by control devices is very low	Very low	8
Existing fault detection by control devices is low	Low	7
Existing fault detection by control devices is modest	Modest	6
Existing fault detection by control devices is average	Average	5
Existing fault detection by control devices is more likely than average	More likely than average	4
Existing fault detection by control devices is high	High	3
Existing fault detection by control devices is very high	Very high	2
Existing fault detection by control devices is extremely high	Extremely high	1

Table 4
Criteria for deciding on the level of risk in the FMEA method.

Risk level	Required actions
Unacceptable	Before the risk reduction any activities should not begin or continue. If the risk cannot be reduced, the activity should be avoided.
High	Before the risk reduction any activities should not begin or continue. If the risk cannot be reduced, the emergency measures and controls to be used during working.
Medium	Efforts must be made to reduce the risk. Risk reduction measures should be applied at specified intervals. When this type of risk or consequences could be severe, evaluation of control measures is needed.
Acceptable	No further action is required. Solutions or improvements that are less expensive may be considered. To ensure that appropriate controls are establishing and maintaining, the monitoring is needed.
Negligible	There is no need to take an action or a written record.

4. Discussion and conclusion

The purpose of FMEA in a process or product is preventing the accident. In other words, FMEA with optimizing the processes and products helps to reduce the large costs. Since reducing the costs can be done in early stages of the process development, changes are relatively simple with low cost. As a result, there will be a strong process that probably will not expose to emergency conditions in the final stages of the process and require no further modification (Kmenta 2000).

The most important result of this method is determination the vulnerable elements of process and system. This method by taking failures has a significant impact on reducing the risks and costs of operation and maintenance. FMEA hardware approach provides the possibility of early detection of potential failure modes and their controls; in addition it prevents the amount of damages and helps to improve the safety and reliability of the process.

FMEA technique is easy to use. It is a powerful engineering method to identify the weaknesses in the early stage of product and process. In other words, it can reduce the catastrophic errors which cause severe damage to the organization (Alimoohamadi 2008).

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