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Full Length Research Paper

The application of FMEA in the oil industry in Iran: The case of four litre oil canning process of Sepahan Oil Company

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Failure modes and effects analysis (FMEA) is an effective technique for preventing the potential problems and actions needed in eradicating the cause of error in oil industries. On the other hand, oil producing companies play a critical role in the oil industry in Iran as a developing country, out of which Sepahan Oil Company has a significant contribution. The aim of this research is to show how FMEA could be applied to improve the quality of products at Sepahan Oil Co. For this purpose, the four litre production line of the company has been selected for investigation. The findings implied that the application of FMEA has reduced the scraps from 50000 to 5000 ppm and has resulted in a 0.92% decrease of the oil waste.

Key words: FMEA, Iran, Sepahan Oil Company, canning, waste, scrap.

INTRODUCTION

Selecting the most effective improvement programs, including risk management techniques, is the main challenge of business managers to achieve superior operational performances (Hajirezaie et al., 2010). Failure modes and effects analysis (FMEA) is one of such effective techniques. FMEA is a technique used to identify potential problems "before the event", and to determine what actions can be taken to prevent them (Shahin, 2004). It is an analytical technique through which all possible "potential failure" modes, the effects that will occur if the failure actually happens and all the causes which can bring about the failure are determined (Slinger, 1992; Healey, 1994; Slack et al., 2001). It is a group-oriented, structured and stepwise approach to quantify the effects of possible failures, thus allowing a company to set priorities for action (Vandenbrande, 1998). The main benefits of implementing the FMEA are to improve the product/process quality and reliability and satisfy the customers (Tang and Ho, 1996).

Traditional supply chain design models typically assume that facilities will never fail. However, in real world cases, facilities are always vulnerable to disruptions of various sorts (Aryanezhad et al., 2010; Wu et al., 2007). Generally speaking, disruption risks of a supply chain may be classified into two types: risks arising from within the supply chain and risks external to it (Miao et al., 2010). In this paper, the internal supply chain problems are analyzed. Nowadays, since the business paradigm is moving from individual enterprise centric to supply chain centric oriented, the implication to develop FMEA as a quality assessment tool within the supply chain framework is apparent (Vanany et al., 2009; Sinha et al., 2004). There is also a necessity to develop service reliability assessment techniques to access product quality in which the products design, development and manufacturing are distributed among outsourced suppliers. Sinha et al. (2004) used FMEA as a means to access the criticality of risk factors within the aeroplane manufacturing supply chain. Kumar et al. (2009) presented FMEA examination to assess the risk of each steps in reverse logistics activities within the pharmaceutical industry. Van Leeuwen et al. (2009) used FMEA to identify the rankings of the risk in analytical screening of drugs, while Chiozza and Pozzenti (2009) pinpointed the key points learnt from applying FMEA in the medicinal sectors. Chuang (2010) analysed the impact of disservice

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using Bayesian probability and concluded that there is need to extend his work to quantify the impact of intangible disservice effects, such as customer complaints and loss of market share. Sonntag et al. (2010) developed a modified FMEA based on the four critical resources required to sustain the lean systems as personnel, equipment, materials and schedules. They found that the practical methodologies needed to improve the reliability of the lean systems are non-existent. Segismundo and Miguel (2008) proposed a systematization of the technical risk management through the use of FMEA to optimize the decision making process in new product development (NPD). The result had a positive influence on the product development decision-making process, evidenced by better allocation of resources among projects at the program. Ookalkar et al. (2009) utilized FMEA at one of the leading Hospitals in Central India, providing kidney care and dialysis. The aim was to identify areas in the haemodialysis unit that needed special attention, in order to improve the process quality and ensure better patient welfare. The results obtained were the reduced process errors and mitigating overall risks, which eventually resulted to effective patient care.

By FMEA, many world class companies have gained great benefits. On the other hand, while oil has become a dominant element within the power capability profile of every nation (Ugoh and Ukpere, 2010), Iran and its oil industry play a major role in the Middle East and in the global economy. Therefore, although FMEA might be employed as a part of the improvement toolboxes, such as those of Six Sigma projects, it is expected that conducting the approach individually will also provide considerable advantages to the country and its stakeholders. As one of the world's leading oil producing country, Iran's importance in the world's oil market is both indisputable and indispensable. Iran presently ranks as fifth in the world in terms of proven oil reserves and second in natural gas. Based on the latest estimations released in 2008, it holds 96.4 billion barrels of oil. In Iran, according to preliminary estimates, GDP at basic price grew by 5.2% at constant prices and amounted to $ 44.9 billion in 2008. The value-added of the manufacturing and mining, services, oil and agriculture sectors grew by 8.5, 6.5, 3.0 and 4.7%, respectively and the shares of these sectors in GDP were 17.1, 48.8, 26.5 and 10.4%, respectively, at current prices (OPEC, 2008).

Organisations have to manage their resources effecttively due to the limited resource available, and one of the effective strategies for managing the available resource is to reduce the cost of operations. In other words, managers have to find ways for resources to be used effectively by reducing work defect, shortening the time taken to complete a particular process, or reducing waste (Yaacob, 2010). Therefore, it is expected that preventing oil's waste provides advantages, such as cost reduction, quality improvement, higher productivity, and higher satisfied customers.

According to Tiku (2005), the oil and gas industry is riddled with risk and uncertainty at almost every stage of the business from exploration through production to downstream marketing. They addressed FMEA as an effective approach in studying the factors that lead to risks, in which manufacturers and suppliers of oil and gas, as well as electronics, must address while developing products for use in the proper completion and continuous monitoring operations. It is important to note that risk management techniques are used in a wide range of fields and applications (Demir and Bostanci, 2010). Moghaddam (2010) studied risk management in the National Iranian Oil Company (NIOC) and did propose a portfolio management for improvement of financial resources' allocation. The causes of failures might not only relate to machinery or processes, but can also include environmental conditions. Based on the investigation of Taiwo (2010), in the oil industry of Nigeria, improvement of the working environment can lead to higher productivity of employees and bad working conditions can contribute to low productivity of employees, which in turn can influence processes and machinery conditions. Meanwhile, oil producing companies play a critical role in the oil industry of Iran, out of which, Sepahan Oil Co. has a considerable contribution. Therefore, the aim of this research is to show how FMEA could improve the quality of products at Sepahan Oil Co. In the following, FMEA is demonstrated and applied to the four litre oil production line of Sepahan Oil Co.

FAILURE MODES AND EFFECTS ANALYSIS

The QS 9000 FMEA manual defines FMEA as a group of activities aimed at recognizing and evaluating the potential failure of a product/process and its effects, identifying actions that may eliminate or reduce the likelihood of a potential failure mode occurring, and documenting the analysis process (Estorilio and Posso, 2010). FMEA is a systematic procedure enabling designers to identify potential failures, evaluate them, investigate them and take action to prevent them. Through the use of a simple rating method, specifically constructed to serve the company's requirements, a risk priority number (RPN) is established for each cause of failure. Those potential causes, with high RPN values, are selected for the corrective action to reduce the risk of failure occurrence. Attention is also given to those parts of a system, where failure would produce adverse customer reaction and loss of company image.

In order to define the potential failure modes, all ways in which it could conceivably fail to perform its intended function must be considered and described. A good starting point is to look at past FMEAs, tests and quality, warranty, durability and reliability reports. The team must anticipate how the part or process might fail to meet engineering requirements. For potential failure effects, it is necessary to describe the effects of the failure in terms of what the customer might notice or experience, by listing both the "local" and "overall" effects of failure. Of course, one failure mode could have more than one effect and the same effect could apply to a number of different failure modes. Moreover, all possible causes of failure must be listed. Once the list is complete, the causes of failure must be ranked in order to calculate the risk priority number.

Severity is an assessment of the seriousness of the effect of the potential failure mode on the customer after it has occurred. The severity of the failure should be predicted and recorded on a 1 to 10 scale, which is called severity rating. Since the severity rating is based solely on the effect, and not the cause of the failure, it always remains the same, regardless of its possible causes.

When considering "occurrence of failure", one must evaluate the risk, that is, the probability that the failure mode will occur as a result of a specific cause. A design change is the only way a reduction in the occurrence can be affected (Alam, 2009). After considering the failure mode and its possible causes, the estimate of the probability of the failure actually occurring must be recorded, using all available knowledge, and then the probability of occurrence would be ranked on a 1 to 10 scale. The probability that a potential failure will be detected before it reaches the customer should also be estimated based on a scale of 1 to 10. This is called 'detection rate'.

Finally, risk priority number (RPN), which is the product of the occurrence, severity and detection ratings is calculated as $\mathrm{RPN} = \mathrm{O} \times \mathrm{S} \times \mathrm{D}$. The RPN must be calculated for each cause of failure. RPN shows the relative likelihood of a failure mode, in that the higher the number, the higher the failure mode. From the RPN, a critical summary can be drawn up to highlight the areas where action is mostly needed. Regardless of the resultant RPN, special attention must be given to any cause of failure with a severity rating of "9" or "10".

After calculation of RPN, the company should ensure that the main hazards are removed from the specification by re-engineering. The three remedies in order of desirability, include: (1) To eliminate the problem altogether through a design change; (2) to reduce the probability that the failure would occur; and (3) to improve the chances of detection through improved quality control. Finally, following the improvement actions, re-evaluation of severity, occurrence and detection must be carried out, and a new RPN should be calculated. The higher the RPN, the higher the chance that the mode will fail, and subsequently, this mode demands higher priority for corrective action (Chang and Sun, 2009).

The results of the analysis help managers and engineers to identify the failure modes, their causes and correct them during the stages of design and production (Sharma and Sharma, 2010). Timely uses of FMEA can avoid expensive modifications to design elements by identifying potential failures and preventing them, assessing which risks will or must be taken, and determining ways to mitigate their consequences (Tanik, 2010).

METHODOLOGY

This work uses the case-based research as its methodological approach. The rationale behind this is due to the various aspects of the research, such as the importance of the context, the nature of variables (both quantitative and qualitative in nature) and the approach to data collection and analysis. The company that was used in this study was selected based on its history in waste management and accessibility of data. It is important to note that while the company has plans for waste reduction, it has never experienced systematic approaches, such as FMEA for failure analysis and improvement. In addition, this project is a part of the toolbox of a larger project of Six Sigma, in which FMEA is an effective technique of the toolbox. The FMEA approach includes the following steps:

1. Creating a multidisciplinary team and its functions.
2. Identifying potential failure mode(s) for various functions in the process.
3. Assessing the potential effects of this failure and evaluating the severity (S).
4. Determining the possible cause(s) of the potential failure and checking the occurrence (O) (failures that occurred during the defined period).
5. Determining the present controls for prevention and detection and verifying the effectiveness of the control(s) implemented (D).
6. Calculation of risk priority number (RPN).
7. Deciding and implementing the action plan.
8. Recalculation of RPN after taking necessary actions.

The study team includes an administrator, consultant (the authors through a university-industry research contract), production planner, quality control manager, housekeeping incharge and the maintenance supervisor.

Sepahan Oil Co. was funded and established by the National Iranian Oil Company Employees' Pension in April 2002. The company trades in petroleum and petrochemical products in the world. Today, this company operates in most of the world's countries and is well known by brand names like Exxon, Esso and Mobil. Sepahan Oil Co. makes products that drive modern transportation, power cities, lubricate industries and provide petrochemical building blocks that are vital to thousands of consumers. Ever since its establishment and with regard to the type of design and anticipated capacity, Sepahan Oil Co. has been considered as the major supplier of engine oil in the country. The company is capable of securing over 30% of approximately 600 million litres of engine oil used domestically. "Alvand" and "Arzhan" engine oils share most of the market for years, and at present, special trade names of Sepahan Oil Co., such as "Speedy" and "Jey" are ranked as first among domestic and foreign suppliers. It produces almost all types of engine oils required domestically including those for gasoline, diesel, gas, dual fuel, two-stage and four-stage engines, tractors, locomotives, generators, gear boxes, as well as manual and automatic differentials. Oil canning can be defined as a perceived waviness in the flat areas of metal roofing and metal siding panels. Generally, the period and amplitude of the wave depend on the continuous width of the flat. Oil canning is an inherent part of the light gauge that could form metal products, particularly those with broad flat areas. Profiles, having wide flat surfaces, are often referred to as "architectural" roofing and sliding panels. Such panels are distinguished from corrugated shapes as the latter are more

Table 1. Percentage of waste in canning and filling processes of Sepahan Oil Company.

	Wastage line		
Production line (L)	**Canning (%)**	**Filling (%)**	**Total (%)**
1	1	0.1	1.1
4	6	1	7
20	-	0.001	0.001
210	-	0.002	0.002

fluted in the design, which have much narrower flats, and are less likely to exhibit oil canning. As shown in Table 1, the most crucial line is the four litre can among the four production lines of the company. The waste values are mostly related to a period of time starting from August, 2005 to August, 2007. It is important to note that the production of the four litre has the highest rate among the mentioned production lines. Therefore, it is reasonable to target this line as having the highest waste in terms of canning with 6% waste and filling with 1% waste, leading to huge loss of totally 7% of the total production of this line. The FMEA is adopted to improve the quality of this production line, respectvely.

The data, used for the improvement project, were collected from the internal complaint records and files in the historical documents. Data, in forms of downtime, were gathered from the documents of the maintenance department. Also, some information were gathered from the Sepahan Oil Co. websites, such as annual reports and the company's internal documents, in describing the work approach and economical statistics. In addition, information was also gathered within the company from conversations with employees.

With regard to the fact that the four litre canning and filling production line includes most of the scraps in the selected company, the improvement team seeks to attain the following targets by the implementation of the proposed methodology:

1. Cost reduction and increasing production speed through scrap reduction.
2. Improvement of teamwork culture towards the improvement of management functioning.
3. Income increase through production increase and cost reduction.
4. Determination of a set of solutions resulting to the scrap reduction of the four litre can production line.

To monitor the production line and evaluate the improvements, the scrap rate index, which is the product of the division of the number of scrap cans by the total number of the cans, is produced, and the percentage index of wasted oil which is the product of the division of the wasted oil by the total oil produced multiplied by 100, are determined. After the preparation of the index and with regard to the registered data for the identification of the existing situation, the trend of this index is examined four months prior to the project and is compared with the present condition. The can scrap rate is considered as 6% (60/1000) and the oil waste as 1% before the implementation of the improvements.

Also, six failure modes with the highest share in the scraps were selected and emphasized by the company's chief manager. These modes include: cutting, welding, bottom seamer, towards the filling, filling and top seamer.

RESULTS

Identifying CTQs

After determination of the six major failure modes, their associated critical to quality (CTQ) factors are identified. These CTQs are factors which cause scraps in the canning and filling sections. The most important factors which cause the scrap cans in the cutting section are imprecision of the dimensions of the plate, low and high hardness, plate thickness and the unadjusted device with regard to the type of plate. Furthermore, due to the unadjusted feeder, the worn out parts in the welding section during production, inappropriate thickness, hardness of the bare electrode, and unadjusted crown of the device are considered as the most important factors causing scrap cans in this line.

In the bottom seamer production section, important factors, such as unadjusted side pressure and the perpendicularity of the reels' exit, result in the production of scrap cans. From the seamer production section to the filling section, which includes many conveyor devices and due to the lack of precise study of this section and on the factors, such as can cripple before filling and can dirtiness, a number of cans are scrapped and low-quality oil is produced. In the filling section, important and varied factors, such as overflowing of the oil from the cans, entry of air into the filled cans and crippling of the cans in the filling section, resulted to scrap cans and oil waste. For the last mode, that is, the top seamer, due to inappropriate sewing of the filled cans and the cripple in its path, both the oil and the cans were wasted. The measured values of the CTQs are illustrated in Table 2.

With regard to the obtained CTQs, the highest and least scraps at the plate cutting section are 0.6 and 0.09 for the high and low thickness and hardness of the plate, respectively. The factors, which produce the highest scraps at the welding section, are the unadjusted feeder, worn out parts during production, inappropriate thickness and hardness of the bare electrode and the unadjusted device crown, which comprise 0.1, 0.4, 0.5 and 0.6 percentage of the scrap, respectively. The unadjusted side pressure and perpendicularity of each reel with 0.75% of the scrap are also observed in the seamer section. The scrap is calculated as 0.15% from the seamer to the filling section, with cripple and dirty cans before filling. In the fifth mode, the CTQ is divided into two groups of filling and canning. The most important factors include oil overflow, entering of air into the can, and crippling of the can in the filling section with 0.2, 0.3 and 0.05% for the filling section, respectively, while the percentage of the canning scrap for canning is calculated as

Table 2. The measurement of the identified CTQs at the 4-litre line.

Section	CTQ	Scrap (%)
Plate cutting	Imprecise plate dimensions	0.11
	Low and high hardness of the plate	0.09
	Low and high thickness of the plate	0.60
	Unadjusted device regarding the type of plate	0.15
Welding	Unadjusted feeder	0.60
	Worn out parts during production	0.50
	Inappropriate thickness and bare electrode hardness	0.40
	Unadjusted device crown	0.10
Bottom seamer	Unadjusted side pressure	0.75
	Perpendicularity of the reels	0.75
From seamer to filling	Can crippling and dirtiness of the cans	0.15
Filling	Oil overflow (filling)	0.20
	Entering of oil into the can (filling)	0.30
	Crippling of the can (filling)	0.05
	Canning scrap (canning)	0.30
Top seamer	Crippling of the can (filling)	0.05
	Inappropriate sewing of filled can lid (filling)	0.40
	Crippling of the can (canning)	0.75
	Inappropriate sewing of filled can lid (canning)	0.75

Table 3. FMEA for plate cutting.

Potential failure mode	Potential failure effect	S	Potential causes of failure	O	Current process control	D	RPN
Imprecision of the plate dimensions	Can scraps	5	Providers	5	No control	2	50
High and low hardness of the plate	Can scraps	3	Providers	2	No control	2	12
High and low thickness of the plate	Can scraps	4	Providers	4	No control	2	32
Unadjusted device regarding plate type	Can scraps	8	Operator	6	No control	6	288

0.3%. In the top seamer section, there exist two groups of scraps of the filling and canning sections. The most important CTQs are can crippling and inappropriate sewing of the filled can lid with 0.05 and 0.4% of scrap in the filling section, respectively and it is calculated as 0.75 and 0.75% for the canning section.

Considering the fact that in the production line, plate cutting and welding sections are prior to the next sections, and their problems will cause more waste in those sections, these two modes are considered for further analysis. This is compatible with the argument of Tiku et al. (2005) on the possibility of common mode failures. They argued that failure can affect a set of functionally identical components or systems as a direct result of the common or shared root causes.

Plate cutting

Table 3 shows the FMEA of the plate cutting. As it is observed, four modes of potential failures are considered to result in can scraps. Three of these four modes of potential failures are relevant to sending of unsuitable plates by the providers that result in can scraps and some problems in the production line. At the present situation, the company does not impose any control over sending the plate, but the fourth mode of potential failure is pertinent to the absence of system adjustment with due attention to the type of applied plate. This mode has the maximum RPN and the highest degree of importance. The cause behind this problem is the imprecision of the operator and lack of any effective control. As addressed by Sharma and Sharma (2010), with respect to man, inadequate training, operators' errors and attitude can contribute to unreliability, whereas with respect to machine, problems such as, poor calibrations or misalignments may result to loss in operational efficiency. The severity of this mode of potential failure is high, and it is almost of high frequency. Therefore, teams of eight and six members are respectively assigned to them.

Welding

Table 4 displays the FMEA of the welding section. The problems of this welding section result to scraps in can bodies. Maximum RPN is related to the nonalignment feeder that originates from the lack of operator skills and the imprecise tools. However, daily, weekly and monthly controls on the feeder are not completely fruitful. The second RPN is pertinent to the erosion of the system segments, where it is manufactured. Additionally, unfit diameter and the severity of bare electrode, as well as the unfit system crown are respectively, the next cases of the RPNs of 60 and 27.

Improvement

Improvement starts after the analysis of the root causes of the problems. For this purpose, the improvement team identifies ways to remove the root problems through brainstorming and taking advantage of the creativity and innovation of the members in the meeting. Then, the approaches suggested for the solution are evaluated with regard to the cost-benefit analysis for each of the approaches and finally, the optimal approaches are addressed for the improvement of the process. Subsequently, the solutions are completely revaluated for their risk factors in execution, after which the improvement plan is implemented with regard to its effectiveness in the improvement of the process and in the reduction of scraps. In Tables 5 and 6, the solutions recommended for the six failure modes by the improvement team are presented with priorities of importance.

Basically, the suggested improvements in Tables 5 and 6 are mostly related to operator training, and control and prevention of processes, which are similar to the suggestions made in the available resources on the application of FMEA (Ookalkar et al., 2009; Estorilio and Posso, 2010; Sawhney et al., 2010; Tanik, 2010).

DISCUSSION AND CONCLUSIONS

In this paper, failure modes and effects analysis (FMEA) were applied for improving the quality of four litre production line of Sepahan Oil Co. as a key player in Iran's oil industry. This production line consisted of two important sections of can making and can filling. Therefore, the two important wastes investigated were the percentage of the wasted cans and the percentage of the wasted oil. The caning process was more emphasized in this research.

The results implied that the application of FMEA led to loss reduction, which in turn led to profitability. However, most of the improvements were related to the welding section. CTQs were measured in different specified parts. The percentages of scrap in the canning section, consisting of plate cutting and weld points, were 9.86 and 1.6, respectively. The processes were analysed to identify existing problems. In this analysis, the convergence of the views of the problem-solving team members for discovering the causes of the problems and testing to validate the views of the problem-solving team was beneficial. At this stage, FMEA was used to find the root causes of the problems. In the "Cutting mode" based on the analysis of RPN values obtained from FMEA, most scraps in the cutting section resulted from the unadjusted machinery, that is, RPN = 9.5 × 10 × 3 = 285. In fact, the value of 9.5 was the total value of scrap percentages at the plate cutting section multiplied by 10, which was the maximum subjective value of occurence. Severity and detection rate were weighed with a maximum of 10 and 3 by the improvemnent team, respectively. The investigation by the improvement team indicated that the operator's negligence to adjust the device has resulted in the production of scrap. This has also been confirmed by field research and statistical analysis. In the "Welding mode", the values obtained from RPN in FMEA showed that unadjusted feeder and worn out parts during production had the most effect on the production of scraps, that is, RPN = 10 × 6 × 4 = 240. In fact, the occurrence value of 10 was considered because the total value of scrap percentages at the welding section multiplied by 10 was 16, which was more than the maximum subjective value of occurrence. Therefore, the value of 10 was assigned to it by the team. Severity and detection rate were also weighed as 6 and 4 by the improvemnent team, respectively. The results obtained by the improvement team showed that the device problems resulted in scrap, with due consideration of the welding section devices. This was confoirmed by field research and statistical analysis. The improvement team embarked on the identification of possible solutions by enjoying many brainstorming meetings and after studying all the solutions, they announced the most important improvement methods for the intended sections. In the plate cutting section, training of the operator and employing expertise were conducted, while in the welding section, special attention was given to the maintenance plans. However, after implementation of the improvement actions, the can scrap percentage was reduced from 50000 to 5000 ppm and the percentage of the oil waste was reduced from 1 to 0.08%.

What is clear in this study is the significant improvement

Table 4. FMEA for welding.

Potential failure mode	Potential failure effect	S	Potential causes of failure	O	Current process control	D	RPN
Unadjusted feeder	Number of scrap bodies	8	Operator of precision tools	6	Daily, weekly, and monthly control	5	240
Part wear and tear	Number of scrap bodies	5	Operator of precision tools	5	Weekly control	5	125
Unfit hardness and thickness of the bare electrode	Number of scrap bodies	4	Operator of precision tools	5	Daily control	3	60
Unadjusted device crown	Number of scrap bodies	3	Operator of precision tools	3	Daily control	3	27

Table 5. Solutions suggested by the improvement team at plate cutting.

Improvement	CTQ	Before FMEA	After FMEA
Operator training and use of expertise	Imprecise dimensions of the plate	0.11	0
Sensor preventing double-sheet lifting	High and low hardness of the plate	0.09	0.01
Calibration of the device every day	High and low thickness of the plate	0.60	0
Checking the plate before unloading and making the provider committed	Unadjusted device with regard to the type of the plate	0.15	0

Table 6. Solutions suggested by the improvement team at welding.

Improvement	CTQ	Before FMEA	After FMEA
Preventive maintenance schedule	Unadjusted feeder	0.60	0.09
Part defect finding	Wearing of the parts during production	0.50	0.10
Hardness control and its surface alloy for the electrical conductivity during production for every 2 h, since the two ends of the wire are different	Inappropriate thickness and hardness of the bare electrode	0.40	0.08
Rechecking hardness and thickness of the plate before entering the feeder	Unadjusted device crown	0.10	0.02

improvement in each of the criteria made after the implementation of FMEA, highlighting the fact that the new methodology has significant effect on the oil production line. However, one of the most important criteria of the FMEA project, which justifies the application of the proposed methodology, is the monetary savings. The calculation of the project team shows that the net profit of implementing FMEA reached 558726$. This is derived by calculating of cost savings due to the reduction of wastes.

In addition to the aforementioned summary of results, it is concluded that the number of CTQ criteria depends on the number of products and the extent of the manufacturing processes and whether the quality improvement approaches have been implemented previously. Readiness and willingness of managers to use advanced quality engineering techniques might not be similar in every country. In this research, FMEA was customized for the oil canning companies and was applied in the Sepahan Co. as a sample. It is important to note that there might be challenges in applying the methodology in other companies of the oil industry and with more confidence in other industries (Teng and Ho, 2006). Some of the problems are associated with the methodology of FMEA and the calculation of RPN (Shahin, 2004; Chang and Sun, 2009).

However, there seems to be a high demand for quality development in Iran's oil industry, as energy is becoming increasingly important and this importance will continue to grow over this century. The application of techniques, such as FMEA, can be further developed and applied to the entire oil industry of Iran. Regarding the achieved results, advantages such as increased return rate, increased process capacity, increased efficiency, reduction of process time cycles, and reduction of scraps are expected to be gained by other companies involved in Iran's oil industry. The results at each stage of implementing the technique should be compared with the intuitive views of the team members. Where a divergence is noted, analysis can be directed at identifying the factors responsible. The appropriate changes can then be made to the results of different stages of the technique.

The application of FMEA as discussed in the study will help managers to model, analyze and predict the behavior of industrial systems in a more realistic manner (Sharma and Sharma, 2010). However, there are certain limitations in the application of FMEA. The criteria for severity and detection evaluation are subjective, for example, the distinction between “high” and “very high” in the detection evaluation criteria is not sharp. Thus, there may be a measurement bias (Ookalkar et al., 2009). The critically debated disadvantage of FMEA based on RPN analysis is that various sets of failure occurrence probability, severity and detectability may produce an identical value; however, the risk implication may be totally different which may result in high-risk events going unnoticed. Another disadvantage of the RPN ranking method is that it neglects the relative importance among the three factors. The three factors are assumed to have the same importance, but in real practical applications, the relative importance among the factors exists (Sharma and Sharma, 2010). Estorilio and Posso (2010) argue that there are inconsistencies in the way the technique is applied. They identified such irregularities and proposed a strategy to minimize them. Their findings highlighted seven factors that contributed to these inconsistencies. The strategy included a partially preconfigured FMEA form.

In this study, the importance of the improvement team was emphasized. It is important to note that many enterprises limit the productivity enhancement of employees to the acquisition of skills. However, about 86% of productivity problems are found in the work environment of organizations. The work environment has effect on the performance of employees (Taiwo, 2010). In this respect, team management is an essential strategy needed to aid business performance (Azeez et al., 2009). On the other hand, as addressed by Ooi (2009), TQM as a team working quality system together with knowledge management (KM) contribute significantly to the improvesation of performance for any organization. In addition, Afrazeh (2010) conducted an investigation in selected oil companies of Iran and found that applying KM in work processes, including customer related processes, resulted in more efficiency in the performance of these works. Kuen et al. (2009) demonstrate empirically that project personnel competency and project mission are critical factors influencing the micro project success. Moreover, as for macro project success, top management support and project mission are two main critical factors. In conclusion, in order to enhance the effectiveness of FMEA programs, KM and team-working should be overemphasized.

While in this investigation, FMEA was implemented in specific sections of the production line of Sepahan Oil Co., the approach could be further examined and investigatred in the other remaining sections of the production line. It is important to note that the size of companies may affect the application of FMEA; therefore, an investigation about the relationship between the size of organizations and the efficiency and effectiveness of the technique is recommended. Applying FMEA in the oil industry of other countries and comparing their results with those of the present study could provide great research opportunities and outcomes. It seems more research work remains to be undertaken in order to make FMEA more robust. For example, mathematical tools such as optimization theory and other associated quality techniques could be applied during the implementation process to further enhance its applicability. Davidson and Labib (2003) used analytical hierarchy priority (AHP) as a basis to prioritise the corrective action upon critical failure assessment. However, the mitigation impact of critical failure should also consider the constraints on the resource owned by the firm. Under such situation, the use of theory of constraint (TOC) can be a basis toward the more realistic risk mitigation strategy. The integration of FMEA and other quality and improvement methodologies such as lean manufacturing (for example, lean sigma), could also be studied further as a few researchers have attempted to provide some solutions (Naslund, 2008; Sawhney et al., 2010).

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