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Research Article

IMPROVINGPROJECTECONOMICSBY PROVIDINGAPROCEDURETO DEAL WITHENVIRONMENTAL RISKSIN INDUSTRIAL ANDCONSTRUCTIONPROJECTS, USING FMEA & QFD INTEGRATION

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ABSTRACT
Nowadays, strict controls and careful supervision is done on projects for environmental protection, so protection or lack of protection of the environment, in industrial and construction projects, will have a significant impact on the project economics; because in case of damaging the environment caused by the contractors, government or employer impose them to redress environmental damages. It even may be cause to the contractor bankruptcy. In addition, it should never be forgotten that the environmental protection as a human value and a vital human need, should always be considered. In order to protect this vital human need and the need to maximize profits in industrial and construction projects, we used integration of FMEA & QFD methods in a real project, and recorded the results in this article. In the first step we used QFD method to accurately evaluate the employer's needs and the mandated standards in the field of environmental protection. Then in the second step using the FMEA to identify failure modes those prevent the realization of these objectives and determine their effectiveness. In the third step, according to the employer's needs and priorities that had been obtained from the previous steps, present an approach to prevent the environmental risks occurring or redress them. At the end, the practical results of implementation of this method are provided as at able can be used for later or similar problems in other projects. Implementation of this method will reach quality and customer satisfaction to the maximum level and reduce the amount of damages to the environment, to the minimum level; also it strongly reduces resources and time wasting in the industrial and construction projects and increased the final profit.

Keywords*: Project Economics, Environmental Risks, FMEA, QFD*

INTRODUCTION
One of the problems that caused the project to produce heavy losses is Compensation for damages caused by the lack of early attention to employer needs and the mandated standards in the field of environmental protection; those are included by the employer in terms of the contract. This concern led to a lot of wasted time and money in many industrial and construction projects and the factors that are unresponsive to these issues. Redressing sometimes is so costly that will lead to bankruptcy of Contractor or severe losing project profit or reduction of time or incurring additional penalties due to delayed delivery of the contracts. And these highlight the importance of studying ways of confronting with this danger.
The present study attempts to integrate FMEA and QFD methods to protect the environment as a valuable heritage of humanity. And also help the project managers to deal with environmental risks by providing a procedure. The procedure learns them how despite the limitations in resources, using a scientific approach to deal with the environmental risks (However, this method is extensible to other cases and can solve all of the project problems).
QFD is a systematic tool to identify and establish quality requirements of customers in every stage of service development. In other words, QFD is a developed quality instrument that its ultimate goal is winning the market through customer (or employers) satisfaction (Jeong M., 2001). QFD is a systematic

approach consisting of a continuous chain that activities of customer identification, collecting customer, service design based on these demands and timely delivery of customer services, is done in it (Chaplin E and Terninko J., *2004*). To achieve quality goals and what is called QFD objectives, different tools and techniques are used in QFD. The main tool for implementing QFD is the House of Quality (HOQ) or the same elements. And there are different ways to implement each element. This method not only considers tangible and intangible factors, but also determines the importance of each of these factors in the final decision (Zare Mehrjerdi and Radaei, 2011).

In 1975, the Computer Research Committee (headed by myself and later named the QFD Research Group in 1978) was appointed by the Japanese Society for Quality Control (JSQC). The committee devoted the next 13 years to ongoing research of QFD methodology. In 1987, it published a final survey report on the status of QFD application among 80 Japanese companies (Akao, 1997).

QFD received very little interest in the beginning until 1972 when the publications of the articles by Mitsubishi Heavy Industry and me paved the way for more QFD related articles to be published later. Following 1978 publication of "*Quality Function Deployment*," the first book on the topic, the number of QFD applications leaped (Akao, 1997).

Nowadays the use of this technique has grown to such an extent that in most of construction and industrial projects, used extensively in the early stages of the design process and the various stages of implementation. (Zeyghami et al, 2011).

FMEA is a procedure that is performed to classify each potential failure effect according to its severity and probability of occurrence (Mohammad D. AL-Tahat, et al., 2013). Failure modes and effects analysis (FMEA) first emerged from studies done by NASA in 1963. It eventually spread to the car manufacturing industry where it served to identify and quantify possible potential defects at the design stage of a product (Allen H. Hu et al., 2009). FMEA is a method that examines potential failures in products or processes and has been used in many quality management systems. One important issue of FMEA is the determination of the risk priorities of failure modes (Kwai-Sang Chin et al., 2009). An FMEA should be the guide to the development of a complete set of actions that will reduce risk associated with the system, subsystem, and component or manufacturing/assembly process to an acceptable level (Carl S. Carlson, 2012).

Failure mode and effects analysis (FMEA) is a very powerful and effective analytical tool which is widely used in engineering projects to examine possible failure modes and eliminate potential failure during system designs (Ningcong Xiao et al., 2011). FMEA, designed to provide information for risk management decision-making. It was first developed as a formal design methodology by NASA in 1963 for their obvious reliability requirements and then, it was adopted and promoted by Ford Motor in 1977. Since then, it has become a powerful tool extensively used for safety and reliability analysis of products and processes in a wide range of industries especially, aerospace, nuclear and automotive industries (Ahmet Can Kutlu, and Mehmet Ekmekcioglu,2012).

Generally we can say that FMEA is a systematic method used for the following reasons:

1) Identifying and prioritizing the potential failure modes in a system, product, service or process.
2) Defining and implementing measures to eliminate or reduce the occurrence of potential failure modes.
3) Recording the results of the analysis carried out, in order to provide a complete reference for future problems (Robin et al, 2009).

METHODOLOGY

Given the global importance of environmental degradation and its severe negative impact on the environment and economy of the project, we did an extensive research on reliable information sources, Internet sites, field studies, and used experienced experts, then used this integration method in a real project (in Iran, Karaj) and this paper is the results. In this method, QFD is used to coordinate the needs of the customer (employer) and the technical requirements and also for accurate assessment of performance standards. Using this method will cause to implement all requirements in a commitment.

But sometimes errors occur during the QFD implementation. These makes the efforts to meet the standards and requirements of the employer do not eventuate. Therefore this study also used FMEA to identify effective failure modes damage to the environment, in massive civil and industrial projects. Using FMEA help the project managers to identify failure modes and rank them according to their efficacy. So they will be able to manage the limited resources to deal with environmental degradation, due to the importance of the failure modes (RPN (Risk Priority Number)). Using this method will prevent environmental degradation caused by the identified failure modes. In addition, it will reduce the project costs, resulting in increased productivity and profitability of the project.

Correct FMEA analysis can:

1. Identify existing and potential failure modes.
2. Determine the cause sand effects of each mode.
3. Rank the failure modes according to their preference and risk.
4. Identify the correct operation in future.

DEFINITIONS

Risk: The combination of the probability of occurrence of a hazardous event and its severity or extent of Costs that will be imposed when it occurs.

Environmental risks: The source, situation or action that has the potential to damage the environment.

Risk Priority Number (RPN): a numerical factor that determines the importance of each risks and rank them according to their severity of the effects, likelihood of occurrence of the cause and likelihood of detection of the cause.

Technical requirements: Official standards set by regulatory authorities, for the different stages of industrial and civil projects.

Customer needs: the constraints which the customer (employer) in addition to the official standards, stipulated in the project contract and demands them.

Failure modes: Risks, potential problems and defects in the design, implementation and etc. that there are in projects and prevent meeting the predetermined goals.

QFD: Quality Function Deployment is a method that is used for coordinating the needs of the customer (employer) and the technical requirements, and evaluating them accurately.

FMEA: Failure mode and Effects Analysis is a method that identifies existing and potential failure modes and determines the effects of each mode, then ranks the failure modes according to their preference and risk.

THE PROCEDURE

The objective of this paper is to achieve a system and a procedure for the implementation of environmental requirements by integrating QFD and FMEA methods. Ultimately it provides appropriate solutions those are implemented to redress the identified risks. It is important to know that integrating these two methods can be used for eliminating risks and improving the quality in all different processes and activities in the industrial and civil projects.

- The implementation of this method in the field of safety and environmental risks could be responsible for the director of HSE (Health, Safety, Environment**)** in the project.
- In this method the expert and experienced staffs in each unit determine the requirements and Identify and assess the risks.

The proposed structure consists of 4 steps. The first step is to input customer (employer) needs. The output is determining the importance of qualitative characteristics of these demands. This stage is named HOQ (House of Quality). In the second, optimum combination of the measurable executive functions are determined, according to the limitations of the system. This step is needed for implementing the qualitative characteristics of customer needs and technical requirements. In the third, determine the

potential failures due to the implementation of the most important executive activities which had caused the customer (employer) dissatisfaction and reduced the quality of services provided in the second step. The fourth step is to reduce the most important effects of potential failures in the output of the third step. Therefore, implement the FMEA and determine the severity of each risk, and the corrective and preventive actions necessary to eliminate or reduce the effects of the system are programmed.

The method of determining the customer needs and the environmental requirements specifications in the HOQ matrix:
In the first step of QFD that complete the HOQ, in fact we try to design tests for every qualitative customer needs and the environmental requirements. Test designing, is based on the experts opinions and the consented written requirements between the employer and contractors. They usually include questions about how and the quality of the needed applications.

How to quantify the communications between the customer needs and the environmental requirements specifications:
For this purpose, 4 numbers are used:
9 for the strong communications
3 for the medium communications
1 for the weak communications
0 for cases that there was no communication

It is obvious that the technical characteristics and environmental requirements are on the influence of each other. In order to quantify the effects use asymmetric matrix that the rows and columns are different requirements. The severity of these effects was determined with the following four numbers:
9/13 = 0.692 for the strong communications
3/13 = 0.231 for the medium communications
1/13 = 0.077 for the weak communications
0 for cases that there was no communication

How to determine the real amount of communications between customer needs, technical specifications of environmental requirements:
The interacting matrix with technical specifications of environmental requirements and the customer needs is named as Am×n and its elements will specify by aij; and the interacting matrix with technical specifications with themselves is named as Bn×n and its elements will specify by bjk. Cm×n matrix is the result of multiplying Am×n × Bn×n, and shows the full impact of technical characteristics and environmental requirements in achieving customer needs. The formula number (1) shows this calculation.

$$C_{ik} = \sum_{j=1}^{n} (a_{ij} \times b_{jk}) \quad (1)$$

This means that to determine the communications between customer needs and each one of the technical specification environmental requirements, two factors are considered:
1- The communications of customer needs with the technical specifications of the environmental requirements.
2- The communications of the technical specifications with themselves.

Determining the weight of customer needs:
To determine the weight, calculate the sum of each Cm×n matrix rows. Finally, the total number of rows summation divides by the calculated number, so the weight of each on will obtain (Kauffmann, 2005).
Table 1 shows the calculating of the weight of customer (employer) needs.

Table 1: Calculating of the weight of customer (employer) needs

	Technical specifications			Rows summation X_i	Weight of customer (employer) needs
customer (employer) needs				a	c = a/b
	Total rows summation			$\sum X_i = b$	

How to make numbers dimensionless (normalize):
The only thing left to complete the QFD method is normalizing the calculated numbers in the various stages. This is due to the different scales and units for each determined parameter. For example, the cost unit is $, and the customer satisfaction is a concept that can be expressed as a percentage without a specific unit. Therefore, in order to integrate the numbers obtained in each of these stages, it is necessary to perform this process after the calculation of each index.
Linear method is used to normalize the numbers. Each number obtained by dividing the maximum number into an index. The formula number (2) shows how to do this process:

$$(2) \qquad n_{ij} = \frac{r_{ij}}{Max_i(r_{ij})} \quad j = 1, 2, 3 \ldots n$$

If put indexes into the matrix columns and put the components that can be linked to any index into the matrix rows, the normalized number of each component shows by 'nij'. So the 'nij' is the normalized number of the component 'i' that is linked to the index 'j'. In this method, after the normalizing process, the components of an index will turn into a number between 0 and 1 (if it is as a percentage, it will be between 0 and 100).
In this method, it is important to convert the zero components to an acceptable value. Because, if you assign the zero to a total index the result of multiplying indexes will be zero. Therefore, the zero component of an index will neutralize the others.
To avoid this problem we decided to convert the zero normalized components to 0.01. Because the acceptable considered error in this method, is 0.01. Therefore, the smallest possible number to assign a zero component of an index would be 0.01.
Finally, given the above description, after normalizing the component of each index, the number value can be assigned to each index will be between 0.01 and100.

How to identify environmental risks and hazards, using FMEA:
To be all the project environmental risks in accordance with OHSAS 18001:2007andISO 14001:2004standards, they were identified and reviewed in all work areas, specific courses, in participation with managers, HSE officers and the relevant staffs. Also to implement the standards and the optimal use of change management, in case of any changes in the organization, work units, operation procedures, work equipment ,personnel changes, changes in the design, work units development, changes in materials, changes in the environment around the project area, changes in contractors or any changes such as changes in regulatory requirements which could result in increase, decrease or change in the risk of danger and environmental aspects of the project, are identified and assessed by the HSE officers and participation of relevant staffs, before applying the changes.
To identify the risks in the FMEA, first all the jobs in the project accurately identified, then determined the location of those activities in the project. Because specific activity in different places, can has

different risks. In the next step, identify, assess, and then rank the risks related with these occupations by the FMEA. Finally an accurate analysis of the risks is done to present the key solutions in order to redress or provide occurring risks.

How-to assess environmental risks:
All environmental risks must be identified and assessed under the supervision of the HSEManagement; and then their risk degrees should be determined according to the procedure in the same way. To do this, HSE manager should conducts surveys and use the opinions of the relevant staffs.

Determine the Risk Priority Number(RPN):
Determining the Risk Priority Number(RPN) in FMEA method is based on combining the probability of risk occurrence, severity of damages and the probability of detecting it. These variables in the (3) formula are shown by 'S (Severity)','O (Occurrence)' and 'D (Detecting)'.

(3) $RPN = S \times O \times D$

Therefore, each of these factor numbers is determined by experts, using the tables 2, 3and4 and actuarial records of the project accidents and individual work experiences.

Table 2: Determining the number of severity of damages

score	Severity of the environmental damage	Severity of financial losses
1	No damage	No loss
2	Very Small damage	Financial losses less than500 $
3	Small damage	Financiallossesbetween500 to5000 $
4	Medium damage	Financiallossesbetween5000 to50000 $
5	Severe damage	Financiallossesbetween50000 to500000 $
6	Very severe damage	Financial losses more than 500000 $

Table 3: Determining the number of the probability of risk occurrence

score	Type of incident	frequency rate of the incident
1	Very high frequency	Once or several times a week
2	High frequency	Once or several times in1months
3	Frequent	Once or several times in3months
4	Average	Once or several times in6months
5	Few	Once or a few times a year
6	Rare	Once or less duration the project

Table4: Determine the number of probability of detecting

score	probability of detecting
1	There is probability to detect the risk and the current measures are sufficient
2	There is probability to detect the risk and the current measures are almost enough
3	There is probability to detect the risk and the current measures are slightly enough
4	There is probability to detect the risk and the current measures are not enough
5	There is no probability to detect the risk and requires specialized equipment
6	There is no probability to detect the risk and requires subspecialty equipment

Environmental risk assessment to insert in the database:

The risks arising from the activities of each process in the project will be recorded in a special form of environmental risks identification. Then the impacts on air, water, soil, and natural resource will be identified and the number of risk assessment importance will be carried out by using the segmentation table 5.

The table5willbe reviewed according to the records of the recent events. Records of risk assessment will be archived in the master database of the HSE office, in order to improve the accuracy of this method and use them in future events.

Table 5: Risk Assessment Matrix

Score	Severity of damages	probability of risk occurrence					
		A	B	C	D	E	F
	Environmental impact	Never been reported	Occasionally reported in similar projects	Occasionally reported in this project	Several times a year reported in this project	Several times a year reported in a certain area of this project	Several times a month reported in a certain area of this project
0	No effect	LOW					
1	Very slight effect						
2	slight effect						
3	medium effect			MEDIUM			
4	Severe effect				HIGH		
5	Very severe effect						

FINDINGS OFTHE CASE STUDY:

For case study, this procedure came into force in the Karaj-Tehran water tunnel project, in Iran. According to investigations conducted by the experts, the most important part of the environment in the project area is the river named Kondor.

Given the importance of environmental standards in this project, there were great deal of attention by the employer and the employer's counsel about the existence of any harmful environmental impacts on the river comes from the tunnel operations. So the main focus on environmental principles about the river and its margins was performed.

The research Result indicates that overall the water pollution sources are divided into two categories:

A -Pollution sources due to the operations of the tunnel construction

B-Pollution sources due to the establishment of personnel in the site

A -Pollution sources due to the operations of the tunnel construction

One of the main pollution sources in this category is the effluent from the tunnel excavation. This is due to the tunnel excavation progress and activities such as cleaning the tunnel walls, segmentation, injection,

periodic maintenance of the TBM machine and etc.. So, there are always significant amount of sediment and hydrocarbons (oil and grease) in the effluent of tunnel.
To avoid adverse environmental impacts, periodically every two months sampling from the river water and the effluent of tunnel carried out and sent to trusted laboratory of the environment organization (Laboratory of Mineral Processing Research Center, Iran).

B-Pollution sources due to the establishment of personnel in the site:
Due to the construction of two series of prefabricated dormitories and the office, and establishment of a large number of employees on the site, significant amount of the workshop effluent and human waste are produced in this area. Therefore the contractor proceeded to install a15 m^3wastewater treatment package in the site to prevent the water pollution. For optimum performance of the wastewater treatment package, there was always careful monitoring of the HSE office, and periodically every six months physicochemical and biological tests are done from the output of the package.

Table 6: Environmental risks, Remediation programs and the Results

RPN	Ranking	Description of environmental risk	Description of the remediation programs	Results
150	1	Waste generated by more than 500 workers	installing a15 m^3 wastewater treatment package in the workshop	BOD and COD reduction in waste water effluent to meet the standards for entry in to surface waters
120	2	Significant outflow of water with high concentrations of suspended solids resulting from tunnel excavation	Design, construction and installing the tunnel effluent treatment system	Reach the standard level in water turbidity and TSS (suspended solids solution) caused by tunnel excavation
96	3	Produce a large amount of waste from the foods and etc. by more than 500 employees in workshop	Plan for the collection and disposal of waste by the authorized centers	100% hygienic disposal of waste
64	4	Rivers polluted by human sewage those works in tunnel and the waste related with TBM machine	Treatment plant for human sewage and TBM waste to prevent the river pollution	Complete purification and disinfection of pollutions resulting from human sewage and tunnel excavation
60	5	Penetration of gasoline, oil and its derivatives into the soil near the river because the parking and car repair of the heavy machinery are nearby the rivers	Relocation the parking and car repair of the heavy machinery away from the river	Removing the risk of soil around the river
48	6	Pouring gasoline on the traditional method of handling or improper Depot	Plan diesel fuel Center to avoid pouring gasoline into the riverbed	Prevent pouring gasoline into the riverbed during transmission and fuel
36	7	Lack of staff awareness about the environmental hazards and how to prevent them	design and installation of 5boards and posters about the environmental requirements associated with the project and trained50personnelabout the environmental rules and requirements	Reach to higher levels of culture and skills to protect the environment and reduce risky behavior in the environment

After identifying and weighting to employer demands and environmental requirements stipulated in the contract, in order of importance, the following were obtained as the final environmental requirements in this project:

Maintaining the standard level of BOD (up to a maximum limit of 30 mg per liter) and COD (up to a maximum limit of 60 mg per liter) in Kondor river that is located within the workshop of tunnel.
Maintaining the standard level of TSS (Total Suspended Solids) in the river up to a maximum limit of 40 milligrams per liter.
Prevention of river pollution and its environs by solid waste and liquid waste permeable in soil. Cultural and skills training for personnel to protect the environment.

After performing the above steps, the project's environmental risks were identified and evaluated by the experts and relevant personnel. The risks are then ranked based on RPN (Risk Priority Number), and arranged in descending order in Table 6, and consequently the required remediation program designed and implemented, by HSE experts.
The results of implementing corrective solutions confirm that all the above operations have been performed correctly. According to the results, specified that the implementation of this method is quite effective to protect the environment and consequently lead to increase productivity and improve project economics through to avoid the waste of financial resources.

CONCLUSION AND DISCUSSION

This article attempted to integrate FMEA and QFD methods and provide an executive scientific method to protect the environment as a valuable of humanity. Using this method, in the massive industrial and civil projects in addition to help better preservation of this precious heritage, also can has a significant impact on development of the project economics. Using this integration method can be a suitable solution to manage, prioritize, control and prevention of environmental risks, in accordance with the determined requirements, and prevents the heavy financial losses resulting from non-compliance to it.
Although in the studies, did not observe integrating the two methods to solving environmental problems, but the implementation of these methods in the case study that we had done, was quite beneficial. It identified and prioritized the requirements and risks and achieved its predefined financial and environmental objectives, also totally adjusted the project activities with the environmental requirements. Using this method eliminates the risks that had been existed previously and also forecasts the risks and prevents them from occurring in the future.
The results of this research are stored as a table (Table 6), in a master database to use in future of this project or the others, in the same risks. In occurrence of the new risks, it is possible to complete and up to date the table. If the HSE manager changes, this database will be the best help and guide for the next one.
However, this procedure has achieved100%targets in the case study project, but in order to increase the accuracy of this method, it is suggested for the next researches to use the 'Pareto _ Ishikawa' and 'Fuzzy' methods to combine and integrate whit it. Except using this method to remove environmental risks and enhance project benefits, it is possible for the future researches, using QFD and FMEA integration method to solve the other problems of massive projects.
Due to the large variation in the factors causing environmental risks in different projects, unfortunately, in many cases you can see similar problems and risks are repeated indifferent projects. Because of the importance of environmental protection as a global issues, and in order to reduce the cost of large projects will be implemented in the various countries in the future, it is necessary that the contractors have sufficient information to deal with these dangers. If there will not be enough information to protect them, definitely they will cause to a lot of environmental risks and financial losses for people all around the world.
As offering a strategic suggestion for the large industries and massive construction projects, recommended to establish an international (or national) center, for sharing the best practices in dealing with the environmental risks. It seems essential that the experienced experts, give their experiences about the environmental risks have encountered in projects and their successful strategies for confronting them, to such an international (or national) center. It is more useful to transform these experiences into simple

and understandable tables such as the Table6. Establishing this database can certainly prevent wasting huge amounts of time and money caused by ignorance of the experiments done by the others, around the world.

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