Archives of Materials Science and Engineering

Volume 65
Issue 1
January 2014
Pages 37-44

International Scientific Journal
published monthly by the
World Academy of Materials
and Manufacturing Engineering

# Evaluation of FMEA methods used in the environmental management

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Received 26.10.2013; published in revised form 01.01.2014

## ABSTRACT

**Purpose:** The aim of the study is to present a newly developed methodology for the E-FMEA analysis. The importance and implementation of the FMEA analysis to the effective management of the environment are discussed.

**Design/methodology/approach:** In this paper the concepts of the E-FMEA methodology presented in the literature and proposed by the authors are presented. The developed conception is based on the FMEA method used in the quality management.

**Findings:** The detailed analysis of the quality FMEA is described. A new approach to the E-FMEA analysis is discussed.

**Research limitations/implications:** The paper presents the methodology for the FMEA analysis carrying out in relation to the environmental aspects.

**Practical implications:** The result of the analysis and the developed E-FMEA methodology is a proposal of management tools for the manufacturing processes. The development tool would allow the management of the environmental aspects in the productive process in an efficient manner. The improvement of the environmental management using the developed E-FMEA tool allows to increase in the productive of the process in relation to the requirements of the law, maintaining the machinery and the equipment and their impact on the environmental aspects.

**Originality/value:** The methodology of E-FMEA suggested in the paper is a part of the scope of the eco-management methods dedicated to the manufacturing processes.

**Keywords:** Industrial management and organisation; FMEA; Environmental management; Environmental FMEA; E-FMEA methodology

**Reference to this paper should be given in the following way:**

A. Kania, M. Roszak, M. Spilka, Evaluation of FMEA methods used in the environmental management, Archives of Materials Science and Engineering 65/1 (2014) 37-44.



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## 1. Introduction

FMEA (Failure Mode and Effects Analysis) is a method in which prevention of errors is the most important [1,2]. The research in the enterprises showed that 75% of the errors result from irregularities in the preparation stage of production but their detection in the design phase is small. Approximately 80% of the errors are detected during the production and control phase, as well as during operation [3,4].

The FMEA method is also known as: FMECA (Failure Mode and Criticality Analysis) and AMDEC (Analys des Modes de Defaillace et Leurs Effets). It began to be used in the 60s of the twentieth century in the United States for the construction and preparation of the complex manufacturing processes and responsible products in the aerospace, nuclear engineering and aerospace industry. From this time, it began gradually extend to other industries, providing products, which are required to particularly high reliability due to a safety of the users (e.g. car industry) [5]. Increasingly, it is also used as a tool for the threats analysis in the HACCP system in the food industry and in the medical industry as a way to study the risks associated with a medical practice [2]. FMEA is used not only by the final product manufacturers, but also by their suppliers, for whom, in many cases, carrying out FMEA projects is a condition for receiving the contract for production of the components or elements [5].

In the professional literature and in the practice one can distinguish many kinds of FMEA in the various areas of management. There are: FMEA in the quality management, FMEA in the occupational health and safety management and the environmental FMEA (E-FMEA) [6-11].

## 2. Characteristics of FMEA

The FMEA method is used to identification of potential defects and causes which in the large extent can restrict the proper use of the product, decreasing the efficiency and effectiveness of the product realization processes. The defects can also expose the products users or service recipients for material losses, loss of health, and in particular cases even life. It consists in estimation (by use of knowledge and experience of the FMEA project team) of the risk of a product or process defects appearance (inconsistencies, errors, etc.), describing their causes and significance (consequences) and proposing, on this basis, preventive or corrective solutions [5].

It is used for [2,10]:

- designing of a new product, process, technology,
- modification of an existing product or process,
- use of an existing product or application of existing process in a new environment, location and functionality.

There are two types of FMEA: product/construction FMEA and FMEA of the process (Table 1).

FMEA of the product/construction and FMEA of the process are differ in respect of an application area, criteria and subject of the analysis, a kind of problems (questions), a way of describing the defects, causes and consequences.

The objective of the product/construction FMEA is a cognition of the weak and strong parts of a product already in a designing phase. This makes possible creation of optimum construction in a phase of construction works and in a conceptual phase. The carrying out product/construction FMEA is recommended in case of a new product which is introduced on the market, a product in a considerable part is modified, new technologies or materials are used, new possibilities of use of the product appear, appearance of any product failure is unacceptable, a product is used in the difficult conditions, production of a product is connected with considerable investments.

The production FMEA concerns processes of product and their parts production and usage or service processes. Its aim is to identify the factors making difficult the fulfilment of construction requirements or disorganization of production processes. These factors are associated with processing methods, processing parameters, using means of measurement and control, with use of machines and equipment and the impact of the environment.

The FMEA of the process is applicable in the initial phase of design of the production process, before starting the production, during series production in order to improve the unstable and inefficient processes [5,10]

The actions related to the FMEA analysis (both product and process) are shown in Table 2 and in Figure 1. They are implemented in three main stages: preparation, proper analysis, implementation and monitoring of the preventive actions.

FMEA is an universal and flexible method, which is used to the analysis of various phenomena and problems occurring in the enterprise [2]. It can be implemented properly in any organization regardless of its size and business profile. The adequate type of FMEA can be used depending on which process in the organization is a critical stage of the product realization. One can choose:

**DFMEA** – Design Failure Mode and Effects Analysis – for product/project;
**SFMEA** – System Failure Mode and Effects Analysis – for system;
**PFMEA** – Process Failure Mode and Effects Analysis – for manufacturing process or service;
**LFMEA** – Logistic Failure Mode and Effects Analysis – for logistic processes;
**EFMEA** – Environmental Failure Mode and Effects Analysis – having an impact on the environment;
**SWFMEA** – Software Failure Mode and Effects Analysis – for software;
**MFMEA** – Machine Failure Mode and Effects Analysis – for machines and devices;
**RFMEA** – Reversed Failure Mode and Effects Analysis.

Table 1.
Comparison of FMEA product/construction with FMEA of the process [4]

| | **Product/construction FMEA** | **FMEA process** |
|---|---|---|
| **The analysis of objectives** | • Determination of defects and failures that can appear in a product<br>• Determination of product points being its sensitive places, determination of means and methods for their removal<br>• Gaining necessary information for better planning of testing and developmental programs making possible the elimination of needless control<br>• Creation of a list of potential defects | • Decision about a process usability<br>• Identification of weak points and process variables on which must be concentrated control<br>• Using means preventing appearance of weak points in processes<br>• Creation of a list of potential hazards ranged according to their influence on a client |
| **Scope of application** | • Introduction of a new product to production<br>• Introduction of the new or changed components to a product<br>• Introduction of the new materials<br>• Use of the new technologies<br>• Appearance of the new possibilities of product use<br>• High hazard for a man in case of appearance of an accident<br>• Exploitation of a product in very difficult conditions | • Starting of the new production series<br>• Introduction of technological processes in early phase of designing<br>• Planning of production in order to possible the best process planning<br>• Introduction of the new products or production processes<br>• Rationalization of unstable processes |
| **Used solutions** | • Assistance of an objective evaluation of design requirements and design alternatives<br>• Inclusion of the preliminary design stage production requirements of detail and assembly<br>• Increase of the probability that the potential defects and their consequences for the operation of a vehicle will be considered during the design and product development<br>• Provide additional information that enables thorough planning of effective testing and development programs | • Identification of a product exposed on defects appearance<br>• Evaluation of potential defect results and their influence on client/user<br>• Identification of potential causes of defect in a production process, assembly or production variables on which tools making possible the decrease of occurring degree or detectability of defect conditions degree should be directed<br>• Making possible of ranged specification of potential defects carrying out |

Table 2.
Stages of FMEA method realization [5]

| 1 Stage<br>Preparation<br><br>Defining the problem and its causes | 2 Stage<br>Proper analysis<br><br>Calculation of numerical indicators for causes definition | 3 Stage<br><br>Implementation and supervision of preventive action |
|---|---|---|
| Team appointment<br>Definition of the problem and problem consequences<br>Definition of the area of including FMEA<br>Definition of the system boundaries in which problems will be analyzed; decomposition of the system<br>Selection of the components and functions of a product or activities in a process which will be analyzed | Indication for selected elements and functions of a product or actions in the process, potential defects, defects causes and effects<br>Determine the relationship:<br>defect → effect → cause<br>Description of the operations used to detect of defects and their causes<br>Attributing defects, effects and causes creating relations of total numbers in the range of 1-10 defining:<br>defect significance – S<br>occurrence of risk defect/cause – O<br>possibility of detection defect/cause – D<br>Calculation of risk priority number:<br>RPN = S x O x D | Carrying out a ranking of defects and defects causes<br>Planning and undertaking the preventive actions with respect to defects, which received the highest rank<br>Supervision of the planned activities implementation |

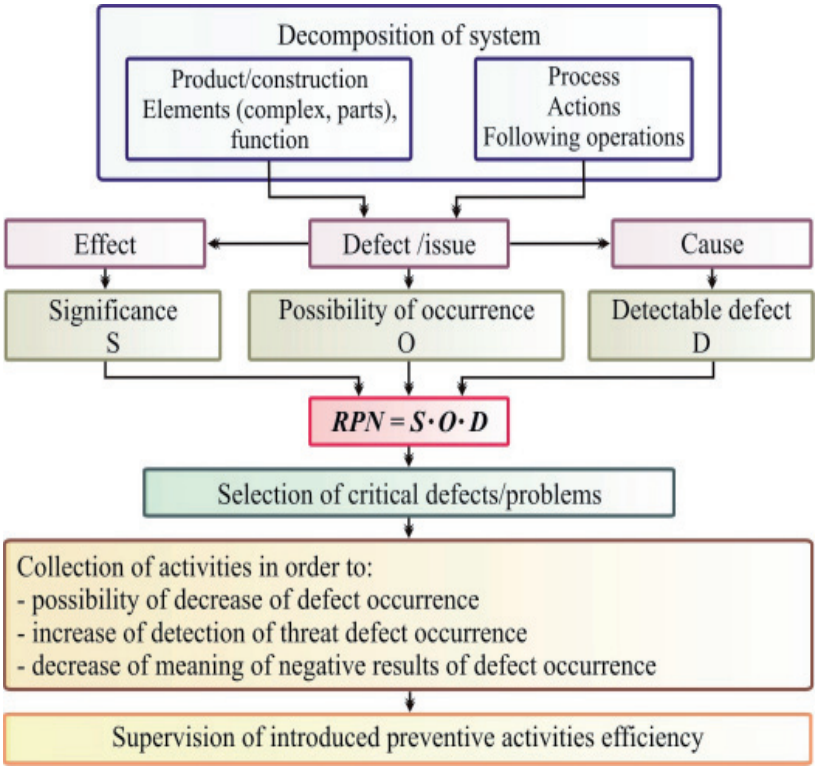


Fig. 1. FMEA diagram [5]

FMEA analysis is advisable to use when [2]:

- fulfil the customer expectations,
- adapt to regulations such as relating to production safety, responsible for the product, etc.,
- reduce the quality cost,
- reduce the time associated with the implementation of the new technologies and introduction of the new products on the market, etc.,
- avoid of more defects formation during production and reduce the number of complaints,
- make accurately decisions related to investments.

## 3. Environmental FMEA

The E-FMEA method is a tool used in the ecodesign of the product and process. The ecodesign is a new approach to designing depending on identification of the environmental aspects connected with a product and consideration them to the designing process already on the early stage of the product development [6,12,13].

E-FMEA takes the environmental impacts of the product (or process) into account and makes possible theirs improvement.

The E-FMEA method allows for a systematic summary of potential environmental problems associated with a product or process, before their consequences occur. The aim of the E-FMEA is to identify and evaluate the potential environmental impacts in all phases of lifecycle of a product in a strictly defined way (Environmental Life Cycle Assessment – LCA – is a quantity technique which treats to a whole life cycle from extraction of raw materials to recycling and disposal).

The purposes of E-FMEA in the environmental management are:

- preventive risk assessment of the environmental impacts and elaboration of the counteraction operations,
- identification of the critical components and potential weak areas,
- early diagnosis and location of possible errors and the environmental impacts,
- avoidance of a trouble important for the environment,
- improvement of the systems, products and processes in the environmental aspect.

The notions in E-FMEA from the quality FMEA are substituted by the environmental notions: defect – environmental influence, defect cause – impact cause, defect sequence – environmental load, importance of defects – importance of impact, probability of defect appearance – probability of cause, probability of detection – impact factor [11].

The 'environmental impact' is not valued and 'environmental load' means negative consequence of the impacts. This is the criterion which estimates importance of the environmental impacts (S).

The potential technical causes make possible estimation of probability of impact risk occurrence (O). One can estimate the possibility of influence of the causes. If the impact is small, the problem and the related risk can be quickly reduced. The criteria: evaluation of importance of environmental impact (S), probability of cause occurrence (O) and causes of influence (D) in the range of 1 (small risk) to 10 (high risk) are assigned. Finally, the product of these three values RPN (Risk Priority Number) is obtained. These three factors are estimated by experts in accordance with a scale based on commonly agreed evaluation criteria. The target of the E-FMEA analysis is to settlement of preventive actions, responsibility, time-limits and realization budgets [11].

After the end of actions recalculation of RPN is undertaken. On this basis, we can conclude how effective were the action and whether further improvements are needed.

Below showed the procedure for RPN calculating [11]:

1. Development and approval of a timetable;
2. Evaluation of the environmental load by the impact. Preparation of proposals importance points (S) and assignment of appropriate values for an analyzed load;
3. Evaluation of the impact causes. Preparation of proposals points (O) and assignment of appropriate values for an analyzed cause;
4. Evaluation of the actions concerning an environmental protection. Preparation of proposals points (D) and assignment of appropriate values for an analyzed action;
5. Calculation of RPN as the product of SOD;
6. Determination (by a working team) of acceptable RPN values below which obtained result is regarded as a satisfactory and ending the E-FMEA analysis. While calculated RPN will be bigger than acceptable RPN value, it is necessary to propose further actions to reduce the environmental load;
7. Determination of acceptable RPN. That is a specific difficulty and it is connected with a subjective approach to the problem by the working team taking external conditions and a current state of the company into account.

### 3.1. EEA methodology

The environmental FMEA is known as Environmental Effect Analysis (EEA), also [7].

The proposed in [7] the EEA methodology is always elaborated as a simple, linear tool which consists of 5 steps (Fig. 2) [7]:

- preparations,
- inventory,
- analysis,
- implementation,
- and follow-up.

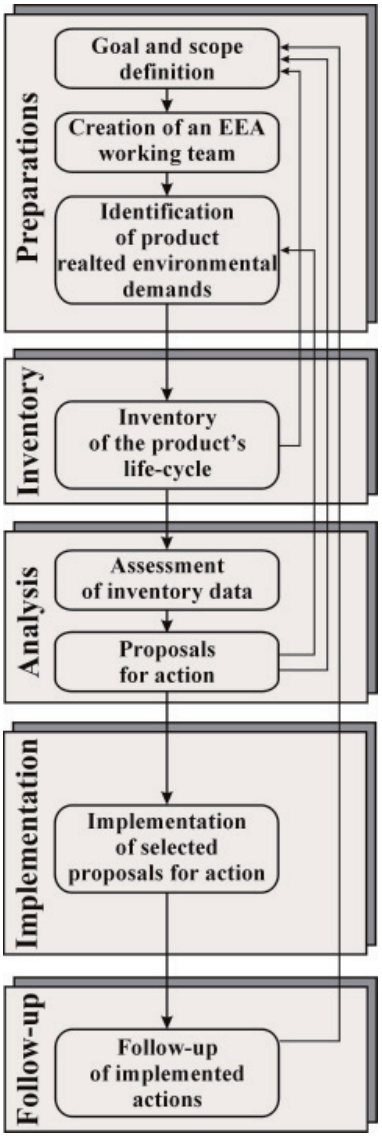


Fig. 2. Schema of the EEA procedure [7]

In the preparations phase there are determination of goal and scope analysis and creation of working team. The essential part in this stage plays identification of the kinds of the environmental demands and regulations included in the assessment.

The EEA working team should consists of: designers, production staff, purchasers and service personnel, and experts from various areas especially from the environmental protection, etc. The experts team from so many fields is necessary because of the interdisciplinary character of the work. An EEA leader manages the team. His/her main task is to be an expert on the method, a guide for the group. The effective communication is the key, or the most important factor of success. It influences on every aspect of EEA workings and theirs efficiency [7].

The inventory is a time-consuming stage. It depends on defining of the environmental considerations. The expert knowledge is very important in this phase. Often, additional information depending on the size of studied system and the need for detailed information are needed.

The assessment of the inventory data is the next stage of the EEA methodology. It depends on estimation of each data effect by many valuation methods. The selected data have a quantitative character, exactly specified or valued character for input and output of every process.

The proposals for actions is the final step of the analysis. The concluding step for this phase is to select many modernizations in the product design [7].

The last step is a follow-up of the implemented changes, among other things to check if it is probable that there will be unprecedented rebound effects on other product characteristics [7].

This is only a short presentation of the proposed in [7] EEA methodology. It can be used for example: before LCA, behind LCA and parallel to LCA, etc.

### 3.2. Proposed methodology of E-FMEA

The environmental management is an area of a special attention because it has multiple effects on such aspects of activities in companies as:

- financial condition,
- prestige and image,
- working conditions.

It is impossible to reject the concept of the environmental management associated with the lack of its implementation in the enterprises.

If the quality management is implemented in companies which are able to understand its value and meaning in the

context of a wider improvement, the environmental management is implemented in every company in the field of fundamental meeting the requirements of the law in this respect. However, it does not have the constituent elements of improvement, but it is only a fulfillment of certain requirements. The next level of development of the environmental management is associated with the search for relevant principles, tools and methods for the environmental management, their implementation and maintenance in order to improve the widely understood eco-effectiveness of realized processes.

A priority for many companies is to demonstrate the activities undertaken in the field of eco-management, which is the foundation of the positive creating of the company's image, but also it is a pass in applying for grants to further eco-development.

Design for Environment (DfE) is becoming more and more important in the aspect of business management (Fig. 3). DfE involves:

- design of pro-environmental materials,
- design of pro-environmental products,
- design of pro-environmental technologies,
- design of pro-environmental machinery and equipment.

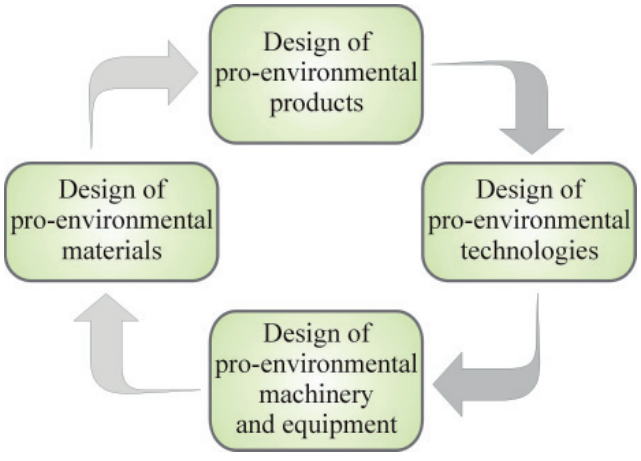


Fig. 3. Eco-design as a series of manufacturing process improvement

This is a contemporary quartet for pro-environmental management in the context of minimizing the impact on the environment, acting in a closed loop forcing at each developmental aspects.

In the aspect of undertaken actions in the pro-environmental design of materials, the impact of the enterprises is limited by the ability to the research which are aimed at finding the new pro-organic materials. The engineers and designers should search for solutions to fit the appropriate materials from a broad base of available materials.

A particular type of the actions having the ability to effective eco-design is in the range of the product, technology, machinery and equipment in the productive processes [14].

The authors a new methodology of E-FMEA proposed. The basis for the development is FMEA – the classic method used in the quality management. This method makes possible reduction of the risk level of an impact of the process on the environment. So, the factors and numerical values of evaluation of importance of environmental impact (S), probability of cause occurrence (O) and causes of influence (D) were defined according to [15]. In the proposed methodology the authors also assume that the defects occurring in the process are a threat for the environment. They have an essential meaning for the assessment of the process eco-efficiency.

## 4. Conclusions

The environmental FMEA is used for minimization of excessive environmental impact of production processes (using energy, water, raw materials, auxiliary materials and emissions) or with product use and waste elimination. The analysis helps to improve the normal functioning of processes and products manufacturing with regard to the environmental aspects.

The comparative assessments of various environmental impacts require social consensus and that is why necessary development of the intrafactory regulations (standards, regulations, systems) are needed. The measure can not be just keeping regulations set limits but the idea of continuously improving of the environmental impacts.

The principles, methods and tools should be sought in terms of eco-management to support it.

Considering this problem on the basis of similarity to the quality management one should introduce some systematics:

- principles of eco-management,
- methods of eco-management,
- tools of eco-management.

The methodology of E-FMEA suggested in the paper is a part of the scope of the eco-management methods dedicated to the manufacturing processes.

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