The specifics of the application of the Failure Mode and Effects Analysis (FMEA) in the automotive industry

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Abstract: The Failure Mode and Effects Analysis method is one of the inductive failure analysis instruments, with a wide applicability in all industrial fields. The purpose of this paper is to evaluate the current stage of the FMEA research and application in the industrial field, with an emphasis on the elements that are specific to the automotive domain. The research will highlight the advantages and limitations specific to the FMEA, will describe the specific methodology of the automotive industry following an example, and also present the specific characteristics of the FMEA Project management software currently available. The future development opportunities will be identified, concerning the FMEA methodology and also the possible solutions for the enhancement of the FMEA project management applications.

Key-words: Failure Mode and Effects Analysis, Reliability, Risk Management, Automotive industry, FMEA Software, Knowledge bases

1 Introduction
Failure Mode and Effects Analysis is a risk management and quality improvement methodology, with the purpose of identifying the potential failure causes for products and processes, their quantification by the evaluation of the associated risks, the ranking of the identified problems in relation to their importance and the determination and application of corrective measures in order to address the greatest concerns. FMEA is one of the inductive methods for the evaluation of system reliability and security, with the specificity of the identification of causes of the previously defined top event using a bottom-up analysis approach [1]. Together with the deductive system analysis method of Fault Tree Analysis (FTA), FMEA is one of the most used quality instruments in the automotive industry. The first formal application of the FMEA in its current form was done during the years 1960, in the aerospace industry. Ford Motor Company introduced the first application of the FMEA in the automotive industry, during the years 1970, as a part of its quality program. In 1993, the Automotive Industry Action Group (AIAG) copyrighted industry-wide the FMEA standard (the technical equivalent of SAE J-1739 issued by the Society of Automotive Engineers), a reference manual that today (in it’s 4th issue, as of 2008) is used by the automotive suppliers or companies subscribing to the QS-9000 or equivalent standard as a guide for performing FMEAs in order to comply with the requirements of the “Big Three”: Chrysler LLC, Ford Motor Company, and General Motors Corporation. Nowadays, the FMEA is the subject of many standards and quality management strategies used in the automotive industry, such as the ISO-9001 series, ISO/TS 16949 and Six Sigma.

2 Basic concepts of FMEA
The main purpose for performing an FMEA is to prevent the possibility that a new design, process or system fails to achieve, totally or in part the proposed requirements, under certain conditions such as defined purpose and imposed limits [2]. Through the FMEA the client requirements are evaluated and products and processes are developed in a manner that minimizes the risks of the occurrence of potential failure modes, with an emphasis on insuring the safety and health of the personnel and the security of the systems. Another purpose of the FMEA is to develop, evaluate and enhance the design
development and testing methodologies to achieve the elimination of failures and thus obtain world-class competitive products. The FMEA methodology can be applied in the early selection phase of the concept or design, but should also be used when modifications of existing products or processes are performed or adaptations to new operating conditions are considered, when the existing legislation or current regulations suffer modifications and as a response to customer feedback, when issues are identified. In order to attain the maximal benefit from an FMEA, it has to be performed as early as possible during the development cycle of products or processes, in order to be able to apply the necessary modifications with minimal effort.

The main advantages of using the FMEA method are: the reduction of costs, with a critical impact on warranty returns, the reduction of the time needed from the project phase to the market launch and the improvement of the quality and reliability of the products, while increasing the safety of their operation [3]. The ultimate goal for attaining these benefits is the increase of customer satisfaction, which assures the growth of the organization’s competitiveness and the improvement of the image on the market.

The use of FMEA comes with a series of limitations, inherent to the nature of the method. First, taking into consideration that the analysis is based on a team effort, its quality depends on the experience and knowledge of the members about the analyzed elements and the previously identified failure modes. Consequently, certain essential failure modes can be omitted, an the evaluation of the risks suffers an important degree of subjectivity. The logical and methodical approach specific to the FMEA is often considered as a difficult and time-consuming process by the participants, an aspect that has to be balanced against the time economy obtained by avoiding the late appearance of failure modes, when important effort has to be made in order to eliminate them. Several researches concluded that most organizations fail to integrate completely the FMEA into their product and process optimization system and thus do not reach the full benefit from the implementation of the FMEA.

3 Characteristics, specific elements, types of FMEA

3.1 Characteristics and specific elements
The basic FMEA methodology specifies that the project manager forms a cross-functional team of specialists with an adequate level of knowledge in the field of the project objective and/or experience about key elements that define the analyzed product or process. The team should use the Brainstorming technique and cause-effect analysis in order to identify a set of information, which will be introduced in the FMEA sheet [4]. Although some of the steps of the FMEA can be executed individually, the essence of the analysis and the best results are obtained by the added value of ideas and know-how of the group and their interaction, in order to accomplish a methodical and complete evaluation of the failure modes, effects of failures and corresponding risks, as well as to stimulate the exchange of ideas and experience to increase the reliability of products and processes. The project team should include, besides the project manager (generally the system, product or manufacturing engineer) product engineers, process engineers (manufacturing/assembly), reliability specialists, quality engineers. Additionally, relating to the nature of the analysis and the level at which it is performed, team members can consist of supplier representatives, safety specialists, testing and service engineers and members of the purchasing department and other specialists.

As far as timing is concerned, the FMEA method is most effective as a preventive action, executed as early as possible in the development cycle and not as a post-factum method to determine corrective set of measures to eliminate or mitigate the effects of failure modes after their impact is observed by the client.

In order to assure the project success, it is necessary prior to the start of the FMEA to perform a pre-analysis that consists of gathering the essential resources for the project (e.g. archive documents, drawings, previous FMEA’s, specifications, regulations, quality, reliability, warranty reports, etc.), the general requirements of the analyzed product/process (client specifications, operating conditions, safety requirements, etc.), as well as to determine the structure and function of the objective.
A variant of the description of the FMEA process steps is the following (fig. 1):

1. Establish the FMEA team.
2. Develop a set of basic rules for the FMEA project.
3. The documentation and analysis of the information necessary for the development of the project.
4. Identification of the analyzed elements (components, assemblies, systems).
5. The identification for each analyzed element of the following information: functions, potential failure modes, effects, causes of failures and current control actions.
6. The evaluation of the corresponding risks.
7. The ranking of the failure modes considering the associated risks and the determination of corrective measures.
8. The application of the proposed corrective measures and the determination of their efficiency by re-evaluating the risks.
9. The documentation of the entire process (distribution, review and update).

![FMEA process steps diagram]

**3.2 Types of FMEA**

Several types of FMEA are used in the automotive industry, the most important of which are:

I. Design FMEA (DFMEA). This type of FMEA has the purpose of identification and prevention of failure modes of products, which are related to their design, in order to validate the established design parameters for a specific functional performance level, at system, subsystem or component level. The most important function of this type of FMEA is the identification in the early stages of design development of the potential failure modes in order to eliminate or mitigate their effects, select the optimal design variant and develop a documentary base to support future designs in order to minimize the risks that faulty products reach the customers.

II. Process FMEA (PFMEA). The purpose of this variant of FMEA is to determine the potential failure modes of manufacturing/assembly processes at operation, subsystem or system level and to eliminate as early as possible the process deficiencies that could lead to the apparition of defective products as well as to avoid using inadequate methods as part of the processes. Besides offering solutions for the improvement of the process design, PFMEA also provides solutions for the development of future processes and process validation programs.

III. System FMEA. This represents the highest level of FMEA and it is channeled towards the failure modes that can influence the systems and subsystems.
in the incipient stages of their conception with the purpose to minimize the risks of failures considering certain established specifications of the system project. Others types of FMEA that can be used in the automotive industry: Concept FMEA (CFMEA) – specific to Ford only, performed on designs and processes - , Machinery FMEA (MFMEA), Software FMEA, Logistic, Flux FMEA.

4 Automotive FMEA example. FMEA management Software.
For any type of FMEA, there is a common set of characteristics specific to this methodology. The result of the FMEA is a table which can take different forms, depending on the specifics of the analysis, the model that is adopted and the company where it is done. For exemplification, a part of Automotive Design FMEA (DFMEA) [4] has been presented in fig. 2, with a format specific to the automotive industry [5].

The first part of the FMEA sheet consists of a basic set of information that specifies the purpose of the analysis and also serves for identification and traceability reasons: 1 – FMEA number; 2 – FMEA type; 3 – Design responsibility; 4 – Prepared by; 5 – Model/year; 6 – Key date (initial estimation of the FMEA completion date); 7 – FMEA date (first iteration/last revision); 8 – FMEA core team; 9 – Item name/number and function.

The potential failure mode section (10) contains the ways in which the analyzed item fails to accomplish the established functions, to attain the requested level of performance or to completely satisfy the client requirements. The failure modes can be identified using the information gathered during the pre-analysis stage or with the aid of the FTA. In order to insure a thorough identification of the failure modes, the team must consider the operating environment (dust, temperature, humidity, etc.), conditions of use (vibrations, wear patterns) and the possibility of incorrect use or assembly of the elements.

The potential effects of failures (11) are described as the influence of the failure modes on the functions of the item, as perceived by the customer (internal/external). The team must also determine the consequences of failures on the analyzed item, subsystems of superior level (the next or following assemblies), the top-level design (e.g. the autovehicle) or the environment, as well as the potential breaches of current regulations or any potential threat to human and equipment safety. The risk evaluation methodology of the FMEA specific to automotive industry consists of the determination of the value of the three parameters, Severity (S), Occurrence (O) and Detection (D), on a Likert-type 10 point scale, using models that are defined in FMEA standards, manuals and guidebooks, or organization or project-specific variants. The value of the Severity (12) is an evaluation of the gravity of the apparition of the failure mode, and concerns its effect. The Classification column (13) marks special characteristics that could require special control measures. In column 14 are inscribed the Potential Causes/Failure Mechanisms, weak points of the item that lead to the apparition of the previously identified failure modes, with an emphasis on the determination of the root causes. The evaluation of the probability of apparition of the failure modes O (15) should be based on statistical information resulted form testing and service activity. The Current Control Methods (16) consist of evaluation methods or control actions with the purpose of prevention (the reduction or elimination of the failure modes) or the detection of the failure cause or mechanism or of the failure mode itself. The value of the probability of detection (17) of the cause/failure mechanism is an evaluation of the control methods capabilities to detect the cause, the failure mechanism or the failure itself, before the impact of the effect is observed.

The risk evaluation (18) is performed by the determination of the Risk Priority Number (RPN), with a value in the range 1 to 1000:

\[ RPN = S \times O \times D \] (1)

After the ranking of the risks according to the value of the RPN, recommended corrective actions (19) will be determined for the highest values (taking into consideration a previously determined threshold) but also taking into consideration certain qualitative rules, such as addressing failure modes with a ranking for Severity of 9 or 10, an Occurrence of 7 to 10, or a high combined value of the Severity-Occurrence ratings, regardless of the value of the RPN. The actions aim at the reduction of the value of the 3 parameters S, O, D, in that order, as well as responsibilities and completion dates (20).
The responsibilities for the application of the recommended actions will be marked in column 21, “Actions taken”, mentioning the completion date, the modifications and obtained results. Based on the results of these actions, the Resulting RPN value will be calculated as the product of the modified values of the S, O, D, parameters, in order to assess if the risks have been reduced to an acceptable level, otherwise, the steps 19 to 22 should be redone. The FMEA sheet should be treated.

Most FMEAs are documented as spreadsheets, which are easy to manage and store, and require minimal training. However, automotive companies have a choice between several Software packages which are designed for or include FMEA project management modules, which offer certain advantages over conventional spreadsheets. Among the benefits of such applications is the enterprise-wide implementation, automatic interface for data management, support for existing models and updates and chart exporting capabilities.

Some examples of such software include APIS IQ FMEA, Reliasoft’s XFMEA, or PTC’s Relex FMEA. Besides the productivity increase and data management benefits of such programs, several issues limit their use at an industry-wide level, such as implementation costs and compatibility issues.

### 5 Conclusions

In spite of the important benefits reported by the application of the FMEA method in the automotive industry, the research on the subject reported several shortcomings that need to be addressed in order to maximize the benefits of FMEA.

One important concern is the degree of subjectivity of the risk evaluation, highly dependant on the level of knowledge and experience of the evaluation team. In order to optimize development of the information base during the pre-analysis stage of the FMEA and to increase the efficiency of the failure mode identification process, a solution is the creation of Knowledge Bases (KB), from which relevant data can be automatically retrieved.

A study on the application of the PFMEA by automotive suppliers in the UK [6] concluded that in the absence of concrete data on the performance and benefits of the FMEA, on a cost reduction, quality improvement and problem prevention basis, most component suppliers in the automotive industry use the FMEA for compliance with their clients and industrial standards. A possible solution is the use of a cost-based model [7] for the FMEA.

The same study [6] also reveals the difficulties the FMEA team members encounter in understanding the concepts of cause, effect, and failure mode as well as

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**Figure 2. Example of DFMEA in the automotive industry (www.reliasoft.com).**

<table>
<thead>
<tr>
<th>Item</th>
<th>Potential FMEA Mode</th>
<th>Potential Effect(s) of Failure</th>
<th>Severity</th>
<th>Occurrence</th>
<th>Detection</th>
<th>Recommended Action</th>
<th>Responsibility &amp; Target Completion Date</th>
<th>Action Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>5. Front door L.H.</td>
<td>- Front door panel from vehicle - Occupant protection from window noise and side impact - Support exchange for door hardware including mirror, mirror, switch and window regulator - Provide proper surface for preserving interior panel - Paint and soft trim</td>
<td>Bent and damage</td>
<td>7</td>
<td>Upper edge of protective panel</td>
<td>6</td>
<td>Vehicle general durability test</td>
<td>A. Take Body Eng. 2/20/2013</td>
<td>Based on test results (Test No. 141) upper edge specification changed to 175 mm</td>
</tr>
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the problems with FMEA data management and update.
Risk evaluation using the RPN using traditional reasoning is also criticized by several authors [8], as there is no precise algebraic rule of evaluation for the Occurrence and Detection, and identical values of the RPN can be obtained using different combinations of the parameters and the value of the RPN isn’t influenced by the manufactured quantity and is not an efficient measure of the proposed corrective measures.
Most FMEA research consider methodology improvements for risk evaluation, such as fuzzy models [9] and FMEA process automation models.
In order to get the maximal benefit from the FMEA, automotive companies have to integrate completely the FMEA in their management system, and apply it in the earliest phases of product and process development.

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