TRIZ METHODOLOGY APPLIED IN D-FMEA PREVENTION AND DETECTION ACTIONS

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ABSTRACT: One of the most actual problems faced by the automotive industry is that generally OEM's want to obtain high performance, high quality, safe product and low costs of components. In this sense, the OEM's impose very "drastic" requirements and suppliers apply different preventive and detective methodologies within the development process in order to obtain high quality of the developed product. The TRIZ methodology applied in Design Failure Mode and Effects Analysis is one of the new approaches which validate and control the prevention and detection actions and the obtained actions are closer to the technical reality of the product characteristics contradictions. Very often the D-FMEA actions are generated as a group of actions and are losing the technical veracity. TRIZ can show the optimal solutions to the potential causes, potential effects and potential failure modes.
KEY WORDS: TRIZ, D-FMEA, cause, actions, validation.

1 INTRODUCTION

One of the most often challenges of the development process in the automotive industry is the level of quality and reliability of the products. Most of the OEM's (Original Equipment Manufacturer) ask suppliers to ensure a negotiated level of quality, for the developed products which are delivered. The quality means to develop a product according to customer requirements.

In order to ensure the quality of the products, different quality methodologies were developed, which prevent the occurrence of defined and out-carried failures of preventions actions. For measuring the capability for detection of the problems, the detection actions were defined, in order to test the product and if occur defects are easily detected.

In the automotive industry the international organizations (e.g. AIAG – Automotive Industry Actions Group, VDA – Verband der Automobilindustrie) defined a set of methods and tools which are applied during product life cycle, like APQP (Advanced Product Quality Planning), FMEA (Failure Mode and Effect Analysis), SPC (Statistical Process Control), FTA (Fault Tree Analysis), etc.

Most of the methods and tools mentioned above are used during the development phase of the product. Each of these brings an added value to the product through the applied process during the development phase:

- APQP – describes the process of product development and following this methodology supplier can better understand the needs of customers (Smith, 2004);
- FMEA – is an inductive and preventive analytical method; with this method, risks are identified, therefore it shows what parts should be fixed before a failure during production or functioning occurs (Stamatis, 2003);
- SPC – it contains several statistical methods which monitor and control a process and according to Doty these are focused on variations of the process and correcting of these variations (Doty, 1996) ; the result is an improved process (Stapenhurst, 2013);
- FTA – is a deductive analysis method, which identifies possible errors and leads to the root cause of failures (Misra, 2008).

The above mentioned methods and tools are used on one hand to control the process variations and on the other hand like preventive methodologies, in order to detect potential issues, to eliminate the root cause and for products to be delivered according to customer requirements.

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In the development process, a strategy starts being changed from the preventive process to the predictive process and this means more accuracy in prediction of what can go wrong with the product after delivering it to the customer.

The objective of this research is to show how the TRIZ methodology can improve the Design-FMEA during the development phase.

2 FMEA METHODOLOGY

The history of FMEA has started in 1949 and was used by U.S. Armed Forces. After that, in 1963 NASA used the method in the Apollo space program (Carlson, 2012).

FMEA is an inductive method and allows a systematic study of causes and effects. In the automotive industry are two international standards which are followed by the suppliers, AIAG with manual Potential Failure Mode and Effects Analysis and also VDA with guideline VDA 4.2 Quality Management in the Automotive Industry Product – and Process-FMEA.

In sense there are two international directions, one direction given by the German OEM's (VDA (Original Equipment Manufacturer) and another direction given by the American OEM's (AIAG).

During the product development done by the supplier teams, in case that a team works with different OEM's from different continents, is very important that they follow their own standard.

AIAG defines the FMEA as "an analytical methodology used to ensure that potential problems have been considered and addressed throughout the product and process development process" (FMEA Fourth Edition, 2008). VDA defines the FMEA "as an important methodical instrument, the FMEA allows possible failures to be identified at an early stage, in order to prevent their occurrence beforehand" (VDA, 2012).

With other words, FMEA is a preventive method that identifies the potential failures and shows how the risks can be avoided or mitigated.

Furthermore, the research of this article shows an improvement of the detection and prevention actions definition and verification and the consistency of the defined actions. In this case, only the Design-FMEA is taken into consideration, but this method can be extended to other types of FMEA.

Actually, there are many types of FMEA and different classifications are given by standards and also by the different authors. Both standards VDA and AIAG show three main types of FMEA: System FMEA, Design FMEA and Process FMEA.

There are also many other types of FMEA as shown in (Carlson, 2012): "Concept FMEA, Reliability-Centered Maintenance (RCM – used to determine preventive maintenance), Software FMEA (applies to product with software), Hazard Analysis (identification of potential hazards associated with the use of product), Human Factors FMEA (focus on interaction between human and equipment), Service FMEA (service of equipment during operations), Business Process FMEA, etc."

The most common types used in the automotive industry are: system FMEA, Design FMEA and Process FMEA. Out of these types, only D-FMEA was chosen for analysis applying TRIZ methodology for improving of detective and preventive actions.

2.1 D-FMEA – specific approach

D-FMEA is focused on functions of the product design in the early stage of development. During the development of D-FMEA the product characteristics of potential failure modes and identification of risks are analyzed.

The objective of D-FMEA is to demonstrate that the product is developed according to the customer and to legal requirements.

This methodology ensures that all customer and legal requirements are implemented, interaction between functions, effect and cause are analyzed. Against potential malfunction, preventive and detective actions were considered. The aim is to show how "secure" the product is, in front of the possible failures (due to internal or external causes).

The Guidelines for FMEA says that one of the objectives of Design FMEA is to "maximize design quality, reliability and maintainability while optimizing expenses" (***, 2005). That means that a product with such a developed methodology, offers a high level of assurance that requirements are implemented and tested and the product meets the reliability requirements.

As inputs for D-FMEA presented in Fig. 1 are at least the legal requirements, customer requirements and International standards specific to OEM's.

The D-FMEA is carried out also for root cause analysis, implementing of corrective actions, identification of key characteristics and optimization of the product.

The D-FMEA starts in the early stage of the product development, before having the concept freeze and before design is validated.

2.2 Development steps of D-FMEA

The main organizations from automotive industry (AIAG and VDA 4.2) show the requirements of D-FEMA developments.

In the VDA 4.2 approach several requirements are asked to be followed in the D-FEAM development methodology, such as: "structure analysis, function analysis, failure analysis, actions analysis and optimizations" (VDA, 2012).

In the AIAG next steps are required to be followed: identify functions, requirements, and specifications, identify potential failure modes, identify potential effects, identify potential causes, identify controls, identifying and assessing risks recommended actions and results" (***, 2008).

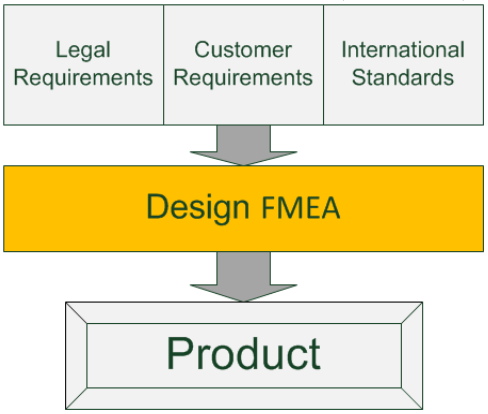

Figure 1. D-FMEA inputs

At the end no matter what guideline is followed (AIAG or VDA), there is only one scope of D-FMEA: obtaining a product which is: reliable, robust, safe and secure against failure occurrence as explained in Fig. 2.

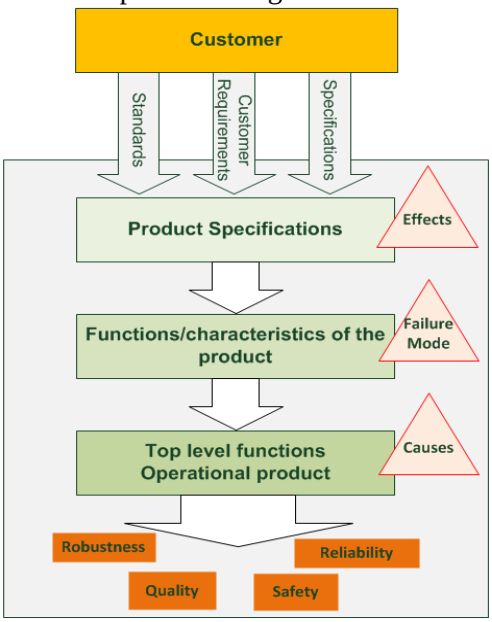

Figure 2. Development steps

From the construction point of view specialized software (E.g. APIS IQ-RM, Isograph, Reliasoft, etc.) or templates or guidelines given directly by the OEM's to organizations can be used and above steps are followed: Effects, Failure Modes and Causes.

Next step will be an analysis of how preventive and detective actions are defined and how the improvement of these, applying TRIZ methodology, can be done.

3 ACTIONS DEFINITION

The definition and implementation of the recommended actions is performed in order to eliminate the failure mode and to reduce the consequences of the effect. Another consideration of actions presence in D-FMEA is described by AIAG in the FMEA Manual that show risk mitigation and actions are reduced severity, detection and occurrence (***, 2008). For reduction of S (severity) O (occurrence) and D (Detection) a set of actions is prepared and defined for each possible failure mode.

The goal is to make a modeling of prevention and detection actions with TRIZ methodology. The expected result is having the possibility of adding an attribute, which will highlight that the existing actions are obtained after TRIZ is applied (and in behind are defined TRIZ solutions) during performing the risk analysis. In this sense at the beginning, the contradictions and improving and worsening parameters are predefined. When a customer claim occurs, one of the D-FMEA goals is to verify the impacted functions. In this case, the existing TRIZ parameters can be taken to be analyzed and solutions can be generated in the design of the impacted product.

In order to make a prioritization of the risks, for each set of prevention and detection occurrence (occurrence of failure cause) and detection (detection of failure cause or mode) are defined and for each potential failure mode at product level the severity (impact on customer side) is set.

For each preventive and detection actions, ratings for Occurrence (O) (from 1 to 10, when 10 is very high probability to occur the failure and 1 improbable failure to occur) and for Detection (D) (from 1 to 10, when 10 very probable that failure will not be detected during tests and 10 improbable rating failure can be detected with high rate) are assigned.

3.1 Prevention actions

The scope of prevention actions is to reduce and/ or eliminate the occurrence of potential failure causes. Anleitner describes in *The Power of Deduction Failure Modes and Effects Analysis for Design*, that for the prevention action definition, an analytical assessment is performed (Anleitner, 2010). On one hand, the prevention actions implemented into D-FMEA process are reducing the occurrence of potential failures; on the other hand, the preventive actions are not so expensive, considering the costs, to be implemented.

The definition of preventive actions makes firstly a classification of the actions.

Preventive actions classification:

- Simulations – 3D CAD simulations (thermal analysis, structural analysis, collision tests, etc.);
- Calculations – tolerance calculations;
- Reviews – concept reviews, specification reviews, etc.;
- Material selections – selection of materials according to the international and customer requirements;
- Specification (drawings, specifications) – defined on the drawing or in the system specification parameters, values, etc;

The preventive actions are carried out by the development team (a responsible is assigned for each action) before customer requirements are implemented and before having a complete status of D-FMEA.

3.2 Detection Actions

The scope of detection actions is to reveal if potential failure causes occur during testing. The detection actions are defined for each potential failure cause and as a measurement rating, the Detection (D) attribute described above is used.

In all cases, the detection actions are very difficult to be assigned, because the product has not been tested to detect the possible failures and a verification/validation of the quality of detection actions. These will be proved by end of product design validation.

A classification of detection types of actions is as follows: experiment, tests (design validation tests), design release, design review, drawing release, module design testing, etc. An important aspect of DA (Detection Actions) represent how well a potential defect in the product is detected and as mentioned by Mausch in *Quality Technician…*, the goal is to detect the defect in time in order not to be reached by customer (Mauch, 2009).

4 TRIZ METHODOLOGY – VALIDATION OF ACTIONS

Theory of Inventive Problem Solving (TRIZ) it is a method which solves the problems by generating technical and non-technical solutions (Altshuller, 1999). The reason is that TRIZ methodology was chosen to be applied for increasing the efficiency of the actions in D-FMEA. TRIZ methodology is also concentrated on solving problems (Tiuc and Draghici, 2015) which could appear in the development phase or later in production phase or much more lately at the final customer (end user) which is dangerous.

At the moment the TRIZ methodology has not been yet adapted in order to validate the actions through an automat system and in this case the chosen actions are validated from a top (Ex. Top 10, 20,… RPN - Risk Priority Number) generated from D-FMEA.

In order to determine and validate the prevention and detection actions, the chosen function of the impacted product is that product must “meet environmental requirements”. The potential failure mode finds that “environmental requirements are not met” and the potential effect of the failure is that “temperature requirements are not met” with the potential cause of failure “material not resistant to environment according to customer requirements”.

In that case the definition of the technical contradiction consists on the by client required temperature on which the materials should resist, this means 85^0C and the intern requirements demand that for this group of products the granted temperature should be customer requirements. The resulted technical contradiction is: temperature vs reliability. If the material will be chosen for an inferior temperature grade, the “reliability of the product” could be affected. In this case the contradiction defined is that “material selection must correspond to the temperature request and also must meet reliability requirements”.

In order to take the right and most suitable prevention and detection actions from technical point of view, the TRIZ methodology was applied.

First of all the improving parameter with impact on the product function was chosen, which is the “temperature”. The temperature is the parameter that can influence the testing of the product when during the design validation is tested the material. Then, after the improving parameter was set, a worsening parameter was identified. The worsening parameter is not a simple and easy to

find. For an accurate finding of this parameter next question was helpful: "what can go wrong if the temperature parameter will not be improved?".

At the junction of these two parameters "temperature" and "reliability", the improvement parameters were generated (Altshuller, 1999) as follows:

- 19 – Periodic actions: the product was tested at different temperatures in a cyclic way (switching from a high temperature to a lower temperature) in a predefined time and frequency.
- 35 – Parameters changes: changing of the testing temperatures
- 3 – Local quality: the materials for the different components each chosen depending on the applicability and product.
- 10 – Preliminary actions: a pre-testing of the critical components, etc.

TRIZ methodology says that the solving of problems is based on inventiveness, or better on creativity. The creativity consists on taking the above parameters and bringing them in their area of interest.

In the current case the takeover of these parameters, the validation of prevention and detection action and more than that even their definition drives to the validation of actions with their help.

The resulting actions by applying TRIZ methodology are:

- Prevention actions: selecting the material (according to customer and internal requirements) and performing a design review;
- Detection actions (at least two tests to be performed): thermal shock test and temperature cycle test.

Detection and prevention actions that are assigned to the most critical potential cause failures are validated by the TRIZ methodology on the basis of 39 contradiction parameters as presented in Fig. 3.

The advantage using TRIZ validation of the causes and actions with the highest RPN, first of all is assuring that the taken and defined actions are most suitable from technical point of view and the parameters generated are added in a special row in the D-FMEA (or as a mark or note in software D-FMEA) as presented in Fig. 4.

Worsening characteristic / Improving characteristic		Weight of moving object	Speed	Force (Intensity)	Stress or pressure	Shape	Temperature	Reliability
		1	9	10	11	12	17	27
1	Weight of moving object	-	2, 8, 15, 38	8, 10, 18, 37	10, 36, 37, 40	10, 14, 35, 40	6, 29, 4, 38	1, 3, 11, 27
9	Speed	2, 28, 13, 38	-	13, 28, 15, 19	6, 18, 38, 40	35, 15, 18, 34	28, 30, 36, 2	11, 35, 27, 28
10	Force (Intensity)	8, 1, 37, 18	13, 28, 15, 12	-	18, 21, 11	10, 35, 40, 34	35, 10, 21	3, 35, 13, 21
11	Stress or pressure	10, 36, 37, 40	6, 35, 36	36, 35, 21	-	35, 4, 15, 10	35, 39, 19, 2	10, 13, 19, 35
12	Shape	8, 10, 29, 40	35, 15, 34, 18	35, 10, 37, 40	34, 15, 10, 14	-	22, 14, 19, 32	10, 40, 16
17	Temperature	36,22, 6, 38	2, 28, 36, 30	35, 10, 3, 21	35, 39, 19, 2	14, 22, 19, 32	-	**19, 35, 3, 10**

Figure 3. Preventive and Detective actions validation

In case of claim existence, based on the parameters existence in D-FMEA, the occurrence of defects can be very easily verified and also if the defined actions were followed and what improvements can be done. Many times in reality the defined actions are subjective, especially for products without safety relevance, because many "group" general actions assigned to the potential failures (most for prevention actions) are generated and TRIZ methodology verifies if the defined actions are technical feasible and secure the product from the quality point of view.

Product Function	Potential Failure Mode	Potential Effects of Failure	SEVERITY	Potential Causes of Failure	OCCURRENCE	DETECTION	RPN	Prevention Actgion	Detection Action	TRIZ Parameters	Responsible / Due Date	Action Results
Meet Environmental req.	Environment req not met	Temperature req not met	8	Material not resistant to environment acc CR	3	3	72	1. Material selection (standard CR) 2. Design Review	1. Thermal Shock 2. Temperature Cycle	**19, 35, 3, 10**	TBD /01.01.3000	100%

Figure 4. TRIZ parameters added into D-FMEA

In the Fig. 4 TRIZ parameters are emphasized, which allow to the user to visualize and then to take the parameters and analyze the proposed solutions.

5 CONCLUSIONS

D-FMEA is a preventive methodology applied also in automotive industry and its actions increase the level of trust of the customer. The proposed method for validation of the prevention and detection actions is a new step introduced in the D-FMEA development taking into consideration the actual situation when most of the OEM's applied TRIZ methodology in the products development.

The advantages of using this step in D-FMEA:

- The focus in on top of the most exposed product characteristics and for defined actions is performed a technical verification with TRIZ method;
- TRIZ is a method with large applicability; trough it simple solutions to the complex problems during and after development can be found;
- Besides validation of the actions, also the veracity of the potential causes of failures, potential effects of failure and potential failure mode are verified;
- Adding of new technical actions (due to combination of parameters) which until now were not taken into consideration;
- After applying TRIZ a risk analysis can be started in order to reduce the RPN.

Disadvantages using TRIZ methodology in D-FMEA:

- TRIZ methodology is not very well known by the supplier in the development and by the involved stakeholder;
- Requires an additional column in the D-FMEA template (Fig.4) for adding TRIZ parameters.

TRIZ applied in D-FMEA is an actual and new methodology, by following the same methods as OEM's and with this methodology, solutions can be generated regarding the process, the technical issues ore regarding management.

Another usage of applying TRIZ methodology is the global application in FMEA (concept FMEA, Process FMEA, System FMEA); action validation is performed same as for D-FMEA. Moreover, a future application of TRIZ is to add this methodology in combination with FTA, FMEA and other methodologies and to extract the most robust solutions.

6 ACKNOWLEDGEMENTS

This work was partially supported by the strategic grant POSDRU/159/1.5/S/134378 of the Ministry of National Education, Romania, co-financed by the European Social Fund – Investing in People, within the Sectoral Operational Programme Human Resources Development 2007-2013.

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