

FAILURE ANALYSIS IN DEVELOPMENT & MANUFACTURE FOR CUSTOMER

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1 INTRODUCTION

Quality assurance of products and services is now an integral part of the automotive industry as well as of a wide range of other industries. An important part of quality management is a customer whose requirements for products and services influences and directs the running of the company.

An important part of the quality management system of the company is to establish procedures for quality planning. The sense of quality planning is in the prevention of either construction or manufacture failures, respectively their causes. Nevertheless it is a tool to increase the likelihood of early detection. FMEA method – analysis of possible failures and consequences (Failure Mode and Effects Analysis) is a most commonly used and customer required quality planning tool (Zgodavova, 1999). The complexity in the area of automotive industry is based in the manufacturing process as well as in the chain of suppliers the car producer must fully rely on (Zgodavova, 2009).

For car producer is important to have suppliers who can quickly and accurately respond to requests, quickly adapt to the rapid development and are reliable. Car producers require suppliers who have their processes under control, understand the specific requirements of their customers and focus on continuous improvement. This document focuses on the analysis of failures in the process of design, i.e. new product development which aim is to present such measures that are effective and implemented as a component of continuous quality improvement (Lengyel, et al., 2012). Risk FMEA analysis is used and deployed in the process of product design and enables to eliminate possible failures and reveal their possible causes in two basic stages: design and process. (Segismundo, et al., 2008; Carbone & Tippett, 2004)

This article represents the methodology of FMEA application in the analysis of a new product design failures. In the case study is shown the use of few quality tools: Block Diagram or Matrix Analysis as tools for planning of implementation of FMEA. Furthermore the method of implementation of FMEA is proposed.

2 LITERARY SURVEY

“Managing risk is not optional for organizations” (Reid, 2005). ISO 9004:2009 mentions risk only in general at the chapter 4.2 Sustained Success as meaning that *“an organisation’s environment is ever-changing and uncertain, and to achieve sustained success its top management should identify associated short-term risks and deploy and overall strategy for the organisation to mitigate them”* and it further refers to the standard ISO 31000:2009.

According to this standard risk is *“the effect of uncertainty on objectives and effect is a positive or negative deviation from what is expected.”* Risk management refers to a coordinated set of activities and methods that is used to direct an organization and to control the many risks that can affect its ability to achieve objectives (ISO 31000:2009).

General Motors (GM) (Ford Motor Company, 2004:2) has defined FMEA as *“a systemized group of activities intended to:*

- *recognize and evaluate the potential failure of a product/process and its effects,*
- *identify actions which could eliminate or reduce the chance of the potential failure occurring, and*
- *document the process. It is complementary to the process of defining what a design or process must do to satisfy the customer”.*

Design Failure Mode and Effects Analysis (DFMEA) is used to uncover design risk, which includes possible failure, degradation of performance and potential hazards. The Design FMEA is typically the first FMEA tool used in product development. (Quality-One International, 2011)

Narayanagounder and Gurusami (2009, pp. 524) state that Failure mode and effects analysis (FMEA) is generally defined as a systematic process to identify potential design and process failures before they occur, with the intent of eliminating or minimizing the risks associated with them. It is known that the FMEA method was first reported in 1920, but its use is only strongly documented since the early 1960’s. It was developed in the USA by National Aeronautics Space Agency (NASA). Since the beginning of 1970’s the FMEA method has been used in the automotive industry to address serious quality problems caused by automobile manufacturers. When analysing by using FMEA, the system behaviour is evaluated for each potential failure mode of each system component. Where there are unacceptable effects of failure, design changes need to be applied to mitigate these effects. The failures for corrective actions are prioritized according to the criticality of the part. The corrective actions are based on the probability of the item’s failure mode and on the severity of its effects. The parameters used in the RPN (Risk Priority Number) methodology to determine the criticality of an item failure mode are the severity, occurrence and

detection. Severity is assessed according to the weightiness of the failure mode effect on the next level assembly, the system or the user. Occurrence is assessed according to the likelihood of failure, which represents the relative number of errors expected during the design life of the item. Detection ability is assessing the ability of the proposed verification program to identify potential design weaknesses before the part or assembly is released for production. The RPN is a mathematical calculation of the severity, the occurrence and the detection (in equation form: $RPN = S * O * D$). The RPN number is used to identify the most critical failure mode which leads to corrective action. The FMEA approach uses RPN to evaluate the risk. The most crucial disadvantage of the traditional FMEA approach is that different sets of Severity, Occurrence and Detection can produce identical value of RPN, but the risk of the consequences can be quite different. This could result in a waste of resources and time, or in some cases high risk events go unnoticed.

The following summary (Table 1) is prepared according to the literary research work of Narayanagounder and Gurusami (2009, pp. 525-526) and a number of approaches for prioritization of failure modes to overcome the shortcomings of the traditional RPN approach.

Table 1 – Literary research

Author (year)	Title method for FMEA	Method description
John B. Bowles and C. Enrique Peláez (1995, cited in Narayanagounder and Gurusami, 2009)	FMECA	Method based on fuzzy logic for prioritization of failures for corrective actions in a failure mode, effects and criticality analysis
Rudiger Wirth et al. (1996)	WIFA	Knowledge-based FMEA to improve the process and design FMEAs by knowledge-based support of the user
Fiorenzo Franceschini and Maurizio Galetto (2001, cited in Narayanagounder and Gurusami, 2009)	FMEA	Method able to deal with situations having different importance levels for the three failure mode component indexes: (Occurrence, Severity and Detection)
Ravishankar and Prabhu (2001, cited in Narayanagounder and Gurusami, 2009)	FMEA	Modified approach for prioritizing failures in a system FMEA to perform corrective actions using ranks 1 through 1000 called risk priority ranks to represent the increasing risk of the 1,000 possible severity-occurrence-detection combinations
Anand Pillay and Jin Wang (2003, cited in Narayanagounder and Gurusami, 2009)	FMEA	New approach using ‘fuzzy rule base’ and ‘grey relation theory’ to overcome some of the drawbacks of traditional FMEA approach

Seung J. Rhee and Kosuke Ishii (2003, cited in Narayanagounder and Gurusami, 2009)	Life Cost-Based FMEA	Methodology, which measures the failure or risk in terms of cost. A Monte Carlo simulation is applied to perform a sensitivity analysis on the variables associated to failure cost: occurrence, detection time, fixing time, and delay time
Seyed-Hosseini et al. (2006, cited in Narayanagounder and Gurusami, 2009)	DEMATEL	Method called Decision Making Trial and Evaluation Laboratory approach for reprioritization of failure modes in a system FMEA for actions, which prioritizes alternatives based on severity of effect or influence and direct and indirect relationships between them
Arunachalam and Jegadheesan (2006, cited in Narayanagounder and Gurusami, 2009)	FMEA	Modified FMEA with a reliability and cost-based approach to overcome the current drawbacks of the conventional FMEA
Chensong Dong (2007, cited in Narayanagounder and Gurusami, 2009)	FMEA	Cost effective failure mode and effects analysis tool to overcome the disadvantages of the traditional FMEA wherein the cost due to failure is not defined
Jih Kuang Chen (2007, cited in Narayanagounder and Gurusami, 2009)	ISM	Interpretive structural model to evaluate the structure of hierarchy and interdependence of corrective action and the analytic network process to calculate the weight of a corrective action and a utility priority number (UPN) to combine the utility of corrective actions and make a decision on improvement priority order of FMEA
Carbone and Tipett (2004)	RFMEA	Modification of the process, product, and service FMEA technique. The detection value of the standard FMEA is modified for use in the project environment
Lian Yu Zheng et al. (2002)	FMEA	Knowledge-enriched model for process FMEA represents the process FMEA knowledge by algorithm to calculate the similarity among process failure problems based on “concept distance”
Estorilio and Posso (2010)	Process FMEA	Application strategy for automotive companies to correct problems associated with the use of FMEAs
Shirouyehzad et al. (2011)	FMEA	FMEA approach to identify critical failure factors in ERP (Enterprise Resource Planning) implementation

It is important to mention, that the new techniques in the prioritization of failures in the literature does not remove some of the disadvantages in the traditional FMEA approaches.

3 METHODOLOGY

Recent research in the literature (Pira, 2002; Zgodavová, et al., 2002; Tosenovsky & Tosenovsky, 2012) shows that a distinction is made in the system FMEA, FMEA of a product (construction) and FMEA of a process (process). The FMEA is a team analysis of possibilities of failures in the considered design, the risk assessment and the design and the implementation of measures leading to an improvement of the quality (Česká společnost pro jakost, 1997). This article describes a method that takes into account the presented aspects and also a procedure in which the quality tools are used. The first used tool is Block Diagram. It is a graphic description of relations between the product, its environment and its components. The role of the Block Diagram is to depict the analysed structure. The drawn line indicates where the analysis of the product ends. During a brainstorming session (creative problem solving method based on group solution) relevant data and facts are collected from all technical departments and persons respectively, who are part of a specific project (new product design) and are recorded to the Block Diagram. This ensures a unified understanding of the product within the team and allows a clear view of the product and its relation to its environment. The Block Diagram (Figure 1) contains following components:

- Analysed product name;
- Product environment (surrounding);
- Description of the physical relation to adjacent parts;
- Inputs and outputs;
- Boundaries of responsibility for the product system;
- Product components (1st level);
- Specific requirements / functions / features.

It is important to notice that the Block Diagram does not have a prescribed form. It can be drawn freehand or converted into a graphic form. It is a living document that throughout the design phase of the product may change. The relations to its environment or individual components can vary, can be added or deleted in various stages of development according to customer specific requirements or changing design solutions.

The Block Diagram is the basis for creating a Matrix Analysis. Product components listed in the Block Diagram and specific requirements or functions create its core. The sense of Matrix Analysis is to specify priorities and link functions of the analysed product with its components.

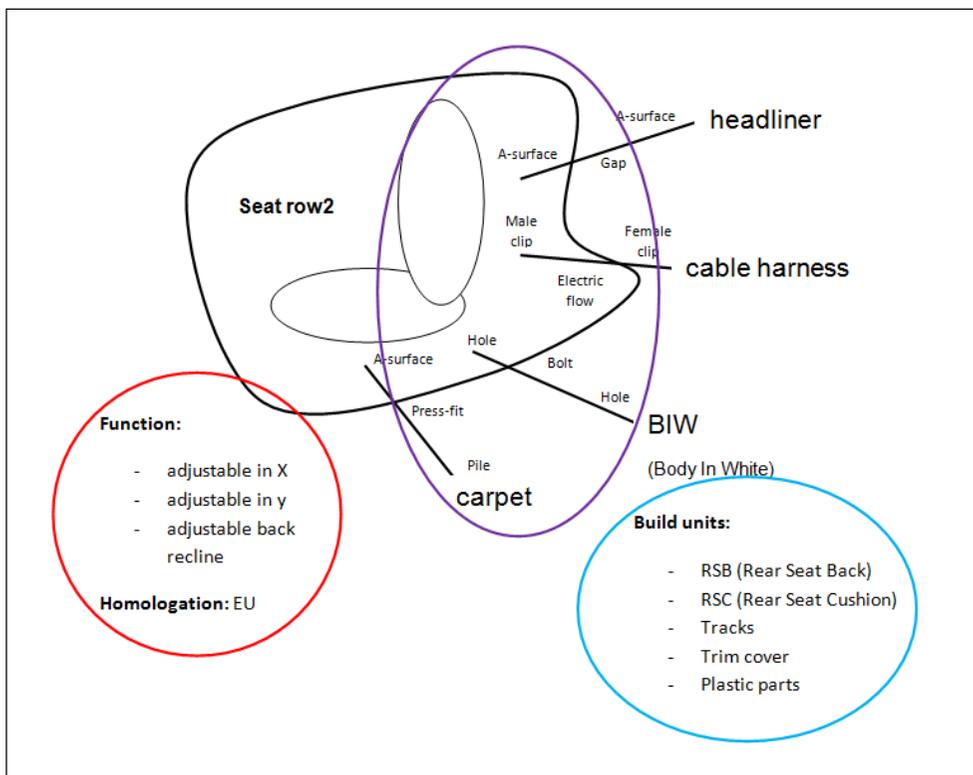


Figure 1 - Block diagram and information crossing to the Matrix analysis
(author's own handling)

Components of the product are listed from the left in the first column of the Matrix Analysis and product functions are presented within the first top line. In the upper left corner is always presented the name of the analysed product. (Figure 4). All functions must be assigned to one of the six basic functions of Matrix Analysis:

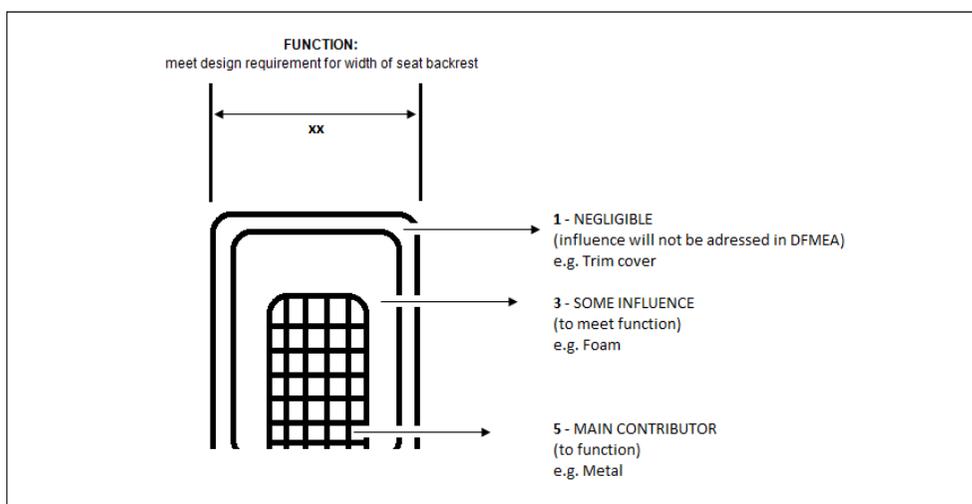
- Safety & Legal (9),
- Main functions (9) ,
- Packaging (3),
- Craftsmanship & Comfort (3) ,
- Manufacturability (3),
- Serviceability (1).

Numbers in brackets represent the weight of each function.

When the individual product functions were assigned to the functions of Matrix Analysis it is possible to start with risk assessment. This includes the assessment, the analysis and assigning weights to show the effect of each component on the

ability to provide product function. In this case weight values are 1, 3, and 5. The value 5 means a significant effect on the product function. If a component fails the product function fully fails. If the component has a modest but still significant effect on the product function the assigned value is 3. If the component has a negligible or minor effect on product function the assigned value is 1. In case of no impact the field remains empty. The fields with assigned value 1 or 0 are not considered in the FMEA.

Example for assigning weights to the components of the functionality of the product is shown in Figure 2. Presented is the back of the car seat consisting of a metal structure, foam and fabric cover. It expresses the effect of the individual components of the seat (metal structure, foam, trim cover) on the function "Aesthetic fulfilment of requirements for the width of the back".



*Figure 2 - Assign weights of product components to the functions
(author's own handling)*

The solved Matrix Analysis (see Figure 4) forms the basis for further analysis, which is D-FMEA. D-FMEA risk analysis is a systematic process for identifying potential design and process failures before they occur to eliminate or minimize the risk associated with them. An important part of the analysis is to set priorities of potential failures and set corrective actions to reduce the final risk number (RPN - Risk Priority Number). The value of Severity is in the range of 1-10. Severity, probability of Occurrence and probability of Detection form the RPN value which is decisive in the analysis.

Through D-FMEA we are able:

- to identify potential failures, causes and effects,
- to determine the risk (Severity, Occurrence, Detection),
- to define and prioritize actions, name those responsible for the actions, and create deadlines,
- identify special characteristics as a result of the analysis,
- to initiate action,
- to achieve continuous documentation,
- to document expert knowledge,

in order to reduce potential product weaknesses to a minimum.

3.1 Case study

The aim of this case study is to show at a particular example the possibilities of using the Block Diagram and Matrix Analysis during the implementation planning of FMEA Johnson Controls Inc., s.r.o. – OZ Trencin.

Step 1: The Block Diagram begins by defining the product, the environment and the relations of which are further analysed. It is important that on the brainstorming session attend all responsible persons in the field of Product Design, Manufacturing and Quality to ensure a flow of needed information and include all relevant relations of product.

1.1 Product selection for the analysis: fabric cover for front seat is analysed. Customer is a multi-purpose and off-road vehicles manufacturer Land Rover. Seat covers are in following variants: leather, fabric and their combination. A total sum of 8 variants.

1.2 Product environment overview: during the brainstorming session team members nominate the environment of the product. The environment includes all the elements which can come into contact with the cover. These elements are entered in the Block Diagram (blue cells, Figure 3).

1.3 Mapping inputs, outputs and relations: inputs, outputs and product relations with its environment are assigned. An example is the relation of the cover to the metal structure of the seat (backrest and seat). There are present handles on the cover (retainers) and small hooks on the metal seat structure. The relation between them is *hooking* (hold). The handles on the cover are considered as the inputs and hooks on the structure as the outputs (white cells, Figure 3).

1.4 Definition of responsibility boundaries: the boundary line determines where the product analysis ends. It's important to clearly determine where the responsibility for the product on the supplier side extends and for what exactly the customer is responsible.

2.2 Assigning of functions to the basic categories of D-FMEA and assigning of their weights: each function of the cover is assigned to the basic categories of the D-FMEA: Safety & Legal requirements; Main functions; Packaging; Craftmanship & Comfort; Manufacturability; Serviceability. In the same time the functions are assigned to their weights: ranking of 9 for Safety & Legal and Main functions; ranking of 3 for Packaging, Craftmanship & Comfort and Manufacturability; ranking of 1 for Serviceability.

2.3 Assigning of weights to the relation between product component and its function: they are assigned by mutual agreement in a team within range of 1, 3 and 5. Ranking of 5 is the maximum weight or the most significant effect of the component to the function. Weight 3 means moderate and weight 1 negligible effect. Fields that are left blank indicate that component has no effect to the function.

2.4 Prioritization: based on a prepared Matrix Analysis is possible to decide which component or which function of the cover should be analyzed in the D-FMEA as a priority. As long as we select a component the highest weight has the Trim back cover row1 (289). If we decide to analyze as a priority a function the highest weight (90) is in the category Safety & Legal.

Trim row1, Landrover L550 MY15	SE weighting	1.0 Safety & Legal [Trim row1, Landrover L550 MY15]				3.0 Manufacturability [Trim row1, Landrover L550 MY15]		2.0 Main Functions [Trim row1, Landrover L550 MY15]				4.0 Craftmanship & Comfort [Trim row1, Landrover L550 MY15]			5.0 Packaging [Trim row1, Landrover L550 MY15]	6.0 Serviceability [Trim row1, Landrover L550 MY15]		
		Safety during crash ensured	Low flammability ensured	Materials meet legal recyclability requirements	No leaching of hazardous gases/materials	Manufacture of single parts is feasible	Part identification/traceability meets requirements	Lumbar support adjustable	Seat heated	Seat ventilated (heat and cool)	Storage areas provided	Seat back recliner adjustable	Appearance design requirements met	Tactile design requirements met	Acoustical design requirements met	Design requirements for sun behavior met	Package interface requirements met	Parts are serviceable
Function weighting:		90	90	90	18	30	24	9	18	30	15	15	30	30	6	18	18	2
Function priority:		9	9	9	9	3	3	3	3	3	3	3	3	3	3	3	3	1
Trim cover cushion 5dr row1,	244	5	5	5	1	5	3		3	5			5	5	1	3	3	1
Trim cover back 5dr row1,	289	5	5	5	1	5	5	3	3	5	5	5	5	5	1	3	3	1

Figure 4 - Matrix analysis (author's own handling in SCIO software, Plato, 2013)

Step 3: D-FMEA Realization. This particular D-FMEA is treated as FMEA with the proposed actions and responsibilities which has the appearance of the classical form used in the implementation of FMEA. In the analysis the severity, occurrence and detection of specific potential failure is evaluated. If there is an unacceptable risk it is necessary to implement a change or corrective action. Corrective action can be preventive (e.g. numerical calculations) or detective (e.g. tests performed during the development phase). Based on the positive

results it is possible to lower the risk number (RPN) while the value of severity never changes. The conditions for implementing corrective actions are following:

- RPN > 100
- Severity > 7
- Occurrence > 5
- Detection > 5

4 CONCLUSION

FMEA is an advanced tool that can be defined as simple and intuitive providing added value to the risk management process. It presents the concept of a simple risk assessment based on probabilities and consequences by adding occurrence and detection attributes of risk event. D-FMEA is based on an risk assessment and also RPN which requires an immediate response plan. When the D-FMEA is properly used it can reduce the project risk and serve as a source of information for future projects so-called *lessons learned*.

The use of the Block Diagram and Matrix Analysis is useful during the implementation of FMEA, in the process of developing a new product:

- Using the Block Diagram can be determined the environment of the product, its relations with the environment, inputs and outputs, the boundaries of responsibilities, special functions and components. It provides a common understanding within the product team.
- The Matrix Analysis allows expressing the effect of analysed product component to provided functions. It also provides the ability to determine which components or product functions is in D-FMEA addressed as a priority.

Both tools are useful for product development. From the point of view and aspects that become apparent from the shown examples Block Diagram and Matrix Analysis can be used as a key factors to handle and develop the proposed FMEA methodology which are contribute to the improvement of product development process in the automotive industry. It is also the cornerstone for the implementation of the proposed FMEA methodology and also of D-FMEA and P-FMEA.

FMEA methodology eliminates the possibility of failures that could lead to the need of technical changes on the product and thereby endanger the smooth start-up of new production. Case study on a particular example shows the use, implementation and benefits of the proposed FMEA methodology.

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