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RELIABILITY IMPROVEMENT OF CAR SLIDING DOOR USING AXIOMATIC APPROACH

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ABSTRACT

In this paper, we discuss the potential utilization of the Axiomatic Design methods in order to enhance the development of Failure Modes and Effects Analysis.
At first the Axiomatic Design allows to describe the optimisation of decomposition physical-functional of the project. Due to this operation and to the esteemed RPN (RPN_e) it is possible to enlighten the most critical components, so to establish a priority order for intervening on components. To use the FMEA it is important to have a very good knowledge of these components to make a new decomposition until reaching the functional requirements (FRs) and design parameters (DPs) leaves. At this state we must apply FMEA, calculating the true RPN.
This approach has been validated by its application to the sliding door of Fiat Auto vehicle.

Keywords: Axiomatic Design, Failure Modes and Effects Analysis, Esteemed Risk Priority Number (RPNe)

1 INTRODUCTION

The objective purpose of this paper is to explain how Axiomatic Design (AD) can be applied to study the reliability.
Traditionally, engineering design has been carried out by the experience or intuition of expert engineers; however, the empiricism of a designer is limited and can lead to poor design practice.
It is self-evidence that decisions made during the design phase of product development will greatly affect the product quality.
The AD provides a general theoretical framework that helps designers to understand design problems. The approach is based on the AD as framework methodology that optimizes the functional analysis which is at the beginning of Failure Mode and Effect Analysis (FMEA).
The FMEA is a "logical, structured analysis of a system, subsystem, device, or process."
It is one of the most commonly used reliability techniques for system risk assessment.
The FMEA is used to identify possible failure modes, their causes, and the effects of these failures. The proper identification of failures may lead to solutions that increase the overall reliability and safety of a product.
It is very important to define how the companies execute this technique. In particular in this paper we have analyzed the Fiat Auto FMEA. It is based on the drawing up of two technical reports:

- Correlation Matrix (CM)
- Risk Matrix (RM)

The first one (CM) is a document in which we can find all the leaves functions, all the components and the intensity of their correlations; the second (RM) is a sort of FMEA form.
It is self-evidence how the AD can help the designer to draw and to optimize the CM. It leads the designer in this operation, providing rules to make the decomposition. By using Mapping and Zigzagging, the design can be summarized in two structures which are hierarchically arranged in levels of increasing detail and correlated by the Design Matrices (DM).
Besides it has carried out an efficacious procedure to identify the components which are more critical about the reliability of total system. This leads to a reduction of elements to be analyzed, with obvious benefits in terms of cost and time.

2 FMEA AND AD

The FMEA allows to develop a qualitative and quantitative analysis of the reliability. In connection with a great simplicity of this method, a careful evaluation of the system decomposition is needed by identifying a list of the functions of the sub-systems.

The *modus operandi* is:

- application of AD to the System or to the Component which is studied;
- compilation of the Correlation Matrix;

- evaluation of the results obtained through the comparison with the standard of the enterprise;
- identification of the critical elements;
- execution of the FMEA on these elements;
- storage of the results and an eventual updating of the enterprise standard;

All these operation are studied in detail in the following steps (figure 1):

Step1: physical and functional decomposition and a drawing up for the correlation matrix.

Step2: Identification of the succession of elements on the basis of their criticality and then their correction.

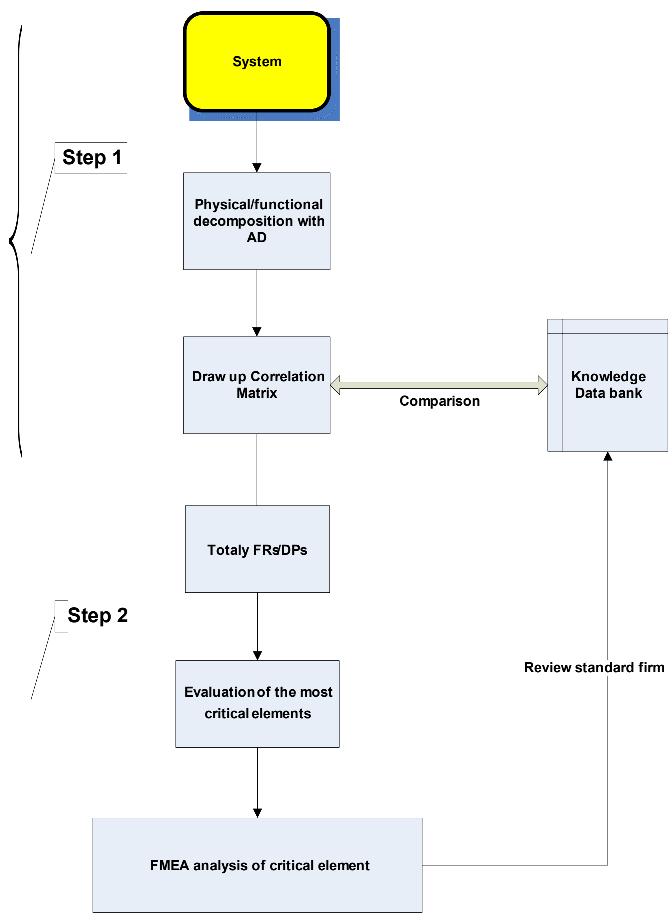

Figure 1 – Scheme of the approach

2.1 STEP 1

A correct and complete individualization of the functions and the parts forming the object of the study is essential for the next FMEA.

Choosing the most important functional requirement, this step starts with the design parameter selection. The functional requirement of the next level can be determined only when the design parameter is properly selected. Zigzagging among function requirements and design parameters is also necessary because two sets of each level are not only connected but also dependent on each other. With axiomatic approach, the ideas in the initial stages of design can be materialized in a scientific way. Firstly because the functional requirement has to be defined and secondarily for the selection of design parameters that satisfy the functional requirement.

The Process Mapping between the Functional Domain and the Physical Domain can be expressed mathematically in terms of the characteristic vectors that define design goals and design solution using the Design Matrix.

$$\begin{Bmatrix} FR_1 \\ FR_2 \\ \vdots \\ FR_n \end{Bmatrix} = \begin{bmatrix} A_{11} & A_{12} & \cdots & A_{1m} \\ A_{21} & A_{22} & \cdots & A_{2m} \\ \vdots & \vdots & \vdots & \vdots \\ A_{n1} & A_{n2} & \cdots & A_{nm} \end{bmatrix} \begin{Bmatrix} DP_1 \\ DP_2 \\ \vdots \\ DP_m \end{Bmatrix} \qquad (1)$$

In order to quantify the intensity of the links is necessary to know the relationship between Functional Requirements (FRs) and Design Parameters (DPs):

$$A_{ij} = \frac{\partial FR_i}{\partial DP_j} \qquad (2)$$

In general it is difficult to calculate this relation, so that it could be better to fix three numbers (1, 3, 9) corresponding to three different kind of links (weak, middle, strong), where:

1= weak link: the function is lightly degraded failing contribution of the component;

3= middle link: the function is only reduced failing contribution of the component;

9= strong link: the function is completely annulled failing contribution of the component;

The result of AD application is a tree structure which gives an accurate picture of the physical and functional decomposition, showing the links between FRs and DPs (figure 2) .

2.2 STEP 2

In order to reduce the number of couples function/element to analyze, it has been defined an evaluation method of the most critical elements. In particular an index has been calculated by considering both functional and reliability aspects.

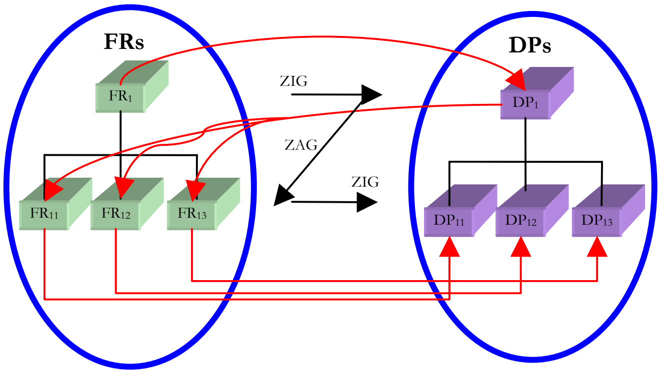

Figure 2 – FRs and DPs process mapping

This index, called by authors RF (Reliability-Functionality), is expressed with the following notation:

$$RF = \frac{RPNe}{RPN_{Critical}} \cdot \prod_{l} \left\{ 1 + \frac{\left[\left[\left(\sum_j A_{ij}\right) - a\right]\right]}{N_{Tot}} \right\}_{l} == \frac{ISPR}{IPR_{Critico}} \cdot K \qquad (3)$$

where:

- l: Decomposition level of the system.
- A_{ij}: element of the Correlation Matrix at the considered level
- N_{Tot}: Total number of functions defined at the decomposition level considered.
- RPNe: Risk Priority Number Estimate
- $RPN_{Critical}$: Risk Priority Number Critical (threshold value fixed by company)
- a: Maximum value A_{ij} referring to the line considered

In the case, for example, of a system characterized by a decomposition into two levels (sub-system, component) the formula is:

$$RF = \frac{RPNe}{RPN_{Critical}} \cdot \left\{ 1 + \frac{\left[\left[\left(\sum_j A_{ij}\right) - a\right]\right]}{N_{Tot}} \right\}_{sub-system} \cdot \left\{ 1 + \frac{\left[\left[\left(\sum_j A_{ij}\right) - a\right]\right]}{N_{Tot}} \right\}_{componenet} \qquad (4)$$

To calculate this index is necessary to fill the document shown in figure 3. it can be observed, that there are some common fields in the FMEA sheet, such as:

- Potential failure mode
- Potential effect(s) of failure
- Potential causes of failure
- Severity

The Occurrence (O*) and the Detection (D*) are only estimated.

FRs	DPs	Potential failure mode	Potential effect(s) of failure	Potential causes of failure	G	O*	D*	RPNe

Figure 3 – Document necessary to calculate RPNe

So it is essential not to make confusion between the esteemed Risk Priority Number (RPNe) and the true RPN.

This index allows to give importance as much highest RPN as those whose malfunctioning influences an high number of Functional Requirements (FRs).

3 CASE STUDY

The approach above has been validated optimizing the functional analysis of the sliding door used by Fiat Auto (figure 4).

Figure 4 – Sliding door

From the analysis of some internal data bank of Fiat Auto emerges how the sliding door has an higher number of failures than a "classic" door hinged at a side and rolling around a fixed axis.
The reasons are due to the major complexity of the opening and lock system.
At present time the two steps introduced before (Step1, Step2) can be applied. The decomposition (figure 5, figure 6) has been realized through the identification of the functions tree and elements tree.

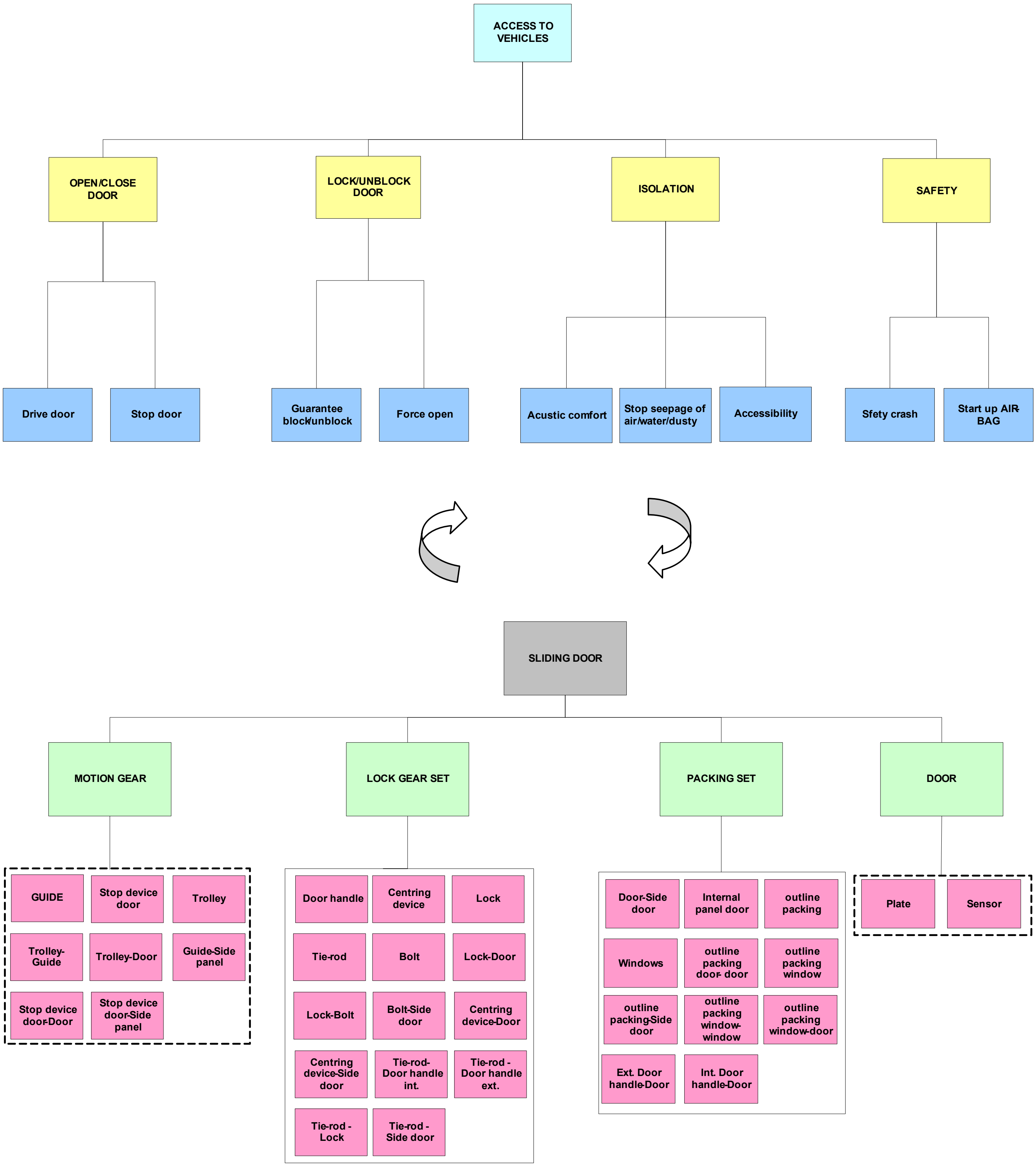

Figure 5 – Functional and physical tree of the sliding door

		FR1: Open/Close door		FR2: Block/Unblock door		FR3: Isolation			FR4: Safety	
		Drive door	Stop door	Guarantee block/unblock	Force open	Acustic comfort	Stop seepage of air/water/dusty	Accessibility	Sfety crash	Start up Air-Bag
DP1: Motion gear	Guide	9								
	Stop device door		9							
	Trolley-Guide	9				3				
	Trolley	9				3				
	Trolley-Door	3				3				
	Guide-Side panel					3				
	Stop device door-Door		9							
	Stop device door-Side panel		9							
DP2: Lock gear set	Door handle			9	9	3				
	Centring device		1	9						
	Lock			9	9	3				
	Tie-rod			9	1					
	Bolt		3	9						
	Lock-Door		3	9	3					
	Lock-Bolt		3	3		3				
	Bolt-Side door		3							
	Centring device-Door		1	3		3				
	Centring device-Side door		1	3		3				
	Tie-rod- Door handle int.			3		3				
	Tie-rod - Door handle ext.			3		3				
	Tie-rod - Lock			3		3				
	Tie-rod - Side door					3				
DP3: Paking set	Door-Side door	3				9			3	
	Internal panel door					9				
	outline packing						9			
	Windows							9		
	outline packing door- door						9			
	outline packing window						9			
	outline packing-Side door						9			
	outline packing window-window						9	1		
	outline packing window-door						9			
	Ext. Door handle-Door					3	9			
	Int. Door handle-Door					9				
DP4: Door	Plate					3			9	
	Sensor									9

Figure 6 – Correlation Matrix of the sliding door

This tree has three levels of the decomposition:

- System
- Sub-system
- Component

In the first level, the function and the element have been obtained; respectively:

- FR: access to vehicles
- DP: sliding door

The Zigzagging allows to get down into the second level:

- FR_1 = Open/close door
- FR_2 = Block/unblock the door
- FR_3 = Isolation
- FR_4 = Safety

The design parameters for satisfying the functional requirements are:

- DP_1 = Motion gear
- DP_2 = Lock gear set
- DP_3 = Packing set
- DP_4 = Door

By repeating this procedure the desired level is reached.
Consequently the Correlation Matrix is to be filled and the more critical elements need to be defined.
In accordance with Fiat Auto, it has been paid attention to the following functions:

- Drive door
- Guarantee hooking

The elements involved in these function leaves are:

- Guide
- Trolley
- Lock
- Handle
- etc.

On the basis of the index RF, calculated with (3), it is possible to obtain the sequence for the actions taken (table 1) and e.g. the components with RF ≥ 1 must be analyzed with FMEA.

Briefly, the advantages of introducing the aforesaid methodology in the product reliability design is the reduction of elements to analyze, with obvious benefits in term of cost and time.
In particular, as shown in the case study, the Step 1 helped the designer to deduce the FRs and DPs, while the Step 2 allowed him to cut about 30% of couples of FR/DP to analyze by FMEA analysis.

DPs	Potential causes of failure	RF
Door Handle	High force of inertia	2.50
Trolley	Deterioration of roller	2.38
Trolley	Deformation of trolley	2.38
Lock	Oxidation of the leverage	2.08
Door Handle	Ice on the leverage	1.66
Lock	Ice on the leverage	1.66
Bolt	Dimension error	1.52
Bolt	Corrosion	1.52
Bolt	Deterioration of form	1.52
Centring Device	Release door clamp	1.38
Tie-Rod	Errors of the size	1.27
Tie-Rod	Corrosion	1.27
Tie-Rod	Deformation of form	1.27
Trolley-Guide	Error of section size	1.20
Door-Side Door	Interference between door and side door	1.18
Door Handle	Breaking elastic element	1.12
Door Handle	Oxidation of the metal objects	1.12
Guide	Oxidation of the way	1.08
Lock	Surface oxidation	1.07
Trolley-Guide	Interference between door and side door	1.01
Lock-Bolt	Release door clamp	0.96
Door Handle	Inadequate elastic force recovery	0.83
Lock	Climbing of the leverage	0.83
Tie-Rod	Surface oxidation	0.64
Lock	Surface oxidation	0.64
Door-Side Door	Interference between door and side door	0.59
Centring Device	Error of balancing	0.55
Tie-Rod	Climbing of the tie-rod	0.53
Trolley-Door	Interference between door and side door	0.50
Tie-Rod	Surface oxidation	0.38

Tab. 1 – List of less reliable components

4 CONCLUSIONS

In this paper, it has been discussed how the Axiomatic Design can be integrated with the Failure Modes and Effects Analysis.

This procedure is very useful for complex systems, as well as those with a very high number of FRs and DPs.
In particular, the use of Zigzagging allows to improve the physical-functional decomposition and establish an order of priority for intervening on system components (before to execute the FMEA completely).
All this brings to the reduction of time and cost needed without affecting the effectiveness of the reliability analysis.
The approach has been validated by its application to the sliding door installed by Fiat Auto on some vehicles.

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