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## APPLICATION OF THE FMEA METHODOLOGY TO IDENTIFY CRITICAL COMPONENTS IN A FORMULA SAE VEHICLE

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**Abstract.** *The present work presents an application of the FMEA methodology for the detection of critical components of a Formula SAE vehicle. For this, all vehicle components were listed as well as their functions and also their failure modes and effects were analyzed. Quantitatively evaluating the severity, the possibility of occurrence and the possibility of detecting the most serious fault in each of the components, it was possible to generate a risk priority number. Based on this value, it is possible to develop monitoring management methods for the critical items of the vehicle.*

**Keywords:** *FMEA, monitoring management, modes and effects of failure, critical components*

### 1. INTRODUCTION

#### 1.1 FMEA (Failure Mode and Effect Analysis)

The FMEA (Failure Mode and Effect Analysis) had its origins in the late 1940s in the United States. It derives from a standard developed as a reliability assessment technique to determine the effects on systems and equipment failures. FMEA arise from the need to predict failure modes in critical sectors such as the aircraft industry. In this branch, total reliability must be guaranteed, since any deviation can lead to several deaths. However, FMEA today is a consolidated methodology and applied in several fields and is the initial step to define the key components to be analyzed of any mechanism, being a fundamental pillar of any maintenance system.

The initial motivator of designing an FMEA for a FORMULA SAE vehicle is to develop a maintenance catalog, one of the key points to which they constitute the proof of manufacturing. Moreover, with the correct application of this methodology it is possible to monitor the health of the assets, since it is known the components that usually have more recurrent and serious failures. This allows you to define the parts that deserve more attention in testing and which components need to be scaled in future designs to increase vehicle reliability.

The failures were classified according to their impact on the success of missions and with the safety of both personnel and equipment (Silva et al, 2018). According to NBR 5462, FMEA is a qualitative method of reliability analysis that involves studying the failure modes that may exist for each item, and determining the effects of each failure mode on the other items besides their specific function within the set.

The sooner the FMEA is done, the easier and cheaper the changes will be, if necessary, in the product development phase. However, in the project initial phases the information is reduced, so the functional approach predominates.

Failure mode is the defect shape, the way in which it presents itself. It occurs when the component under study fails to fulfill its function or does not conform to specifications. Effect is the result produced by an action or agent. It is the form or manner of how the failure mode manifests itself or how it is perceived at the system level (PMBOK, 2000).

A certain failure mode or effect become more or less evident depending on the function that the item is performing in that particular case. The relationship between the failure mode and the effect, if well controlled, can be a great help for reliability analysis and for maintenance processes to be adopted. The material generated by the FMEA is intended to serving as a tool for forecasting failures and to assist both the development and analysis of products, processes or services.

The FMEA systems analyzes systems and their subdivisions in the early design and design phases focusing on potential failure modes including interaction between elements and systems themselves. This increases the detection likelihood of potential problems in addition to helping to set the basis for diagnostic procedures (Stamatis, 2003).

FMEA can be an important tool in project management. Another benefit is the monitoring of major vehicle failures, which tend to diminish with the more severe monitoring they will have. Combined with other maintenance techniques such as penetrating liquid testing, ultrasound testing and lubrication, the components life can be extended. And finally, opportunities for future improvements in project robustness and reliability can be seen.

## 1.2 FORMULA SAE

The SAE BRASIL Formula competition, as well as the other competitions promoted by the Society of Automotive Engineers (SAE), provides Engineering students with an opportunity to apply their undergraduate knowledge in the design and manufacture of a formula single-seat competition vehicle. The main objectives are the application of the knowledge developed in the classroom in a concrete challenge as well as the encouragement of teamwork. To fulfill this purpose a number of skills are developed by the students such as the sense of responsibility, the development of new projects in the areas of mechanics and electronics as well as the evolution of new production methodologies aimed at improving the design process of the project. car. Another positive point to be highlighted is the visibility of large companies, the opportunity for recognition and the experiences, as students already live in a preliminary phase with the day-to-day challenges of an engineer, being an experience because of the unique professional and personal training (SAE BRASIL, 2019).

To assess the competitiveness of both the team as well as their cars, they are evaluated in a series of tests in the competition held annually. Project, cost, structure, and impact attenuator reports are required. In addition, there are Design, Business and Manufacturing presentations. Vehicle performance is verified in static and dynamic tests. Thus, SAE lists a series of goals to be met by the teams. The team should be viewed as an engineering company that designs, manufactures, tests and presents a vehicle prototype; it must be durable enough to successfully complete all competition events. Factors such as esthetics, cost, ergonomics, maintenance and manufacture are marked differentials. Finally, each project is reassessed against competitors to determine which vehicle best meets the objectives, to be competitive with the simplest manufacturing and lowest possible cost (FORMULA SAE, 2019).

## 2. MATERIALS AND METHODS

In the case under study, the components were specific as to the function; the mode, effect and cause with which there may be a failure; current controls for the prevention of the failure; besides the numerical quantification of the pillar questions of an FMEA (Silva et al, 2018). The layout of the spreadsheet used in the analysis contains, in addition to a header that allows satisfying information such as: responsible for the project, classification of the FMEA (design, process, service and system) and the set to which it refers, also presents the organization of the criteria analyzed in the components and mentioned above. The components were grouped into items and the items were organized into sets. Each set refers to a vehicle system used as the object of study. RPN is calculated based on the product between gravity (G), occurrence (O) and detection (D). The first index is how harmful the failure is to the vehicle, being considered the maximum degree when it causes the vehicle to stop. Occurrence refers to the frequency which this failure occurs. Finally, detection is how noticeable the anomaly is. The systems are: aerodynamics, drives, electronics, powertrain, steering, structure, suspension, and transmission.

The process for project development was organized in seven main steps:

Step 1 - Identification of all vehicle components and description of its functions;

Step 2 - Listing of the failure modes that could occur with the component. And ordering these, according to severity when considered the complete vehicle and moving;

Step 3 - Identification of the effects of these possible failures (loss of handling, non-locking of the brake disc, shutdown of the car and others);

Step 4 - Identification of possible causes for the failure modes encountered;

Step 5 - Description of current controls so that these failures do not occur;

Step 6 - Evaluation of the severity of the failure, considering the vehicle during a test or competition, evaluation of the occurrence and detection possibility of this failure;

Step 7 – Based on severity, occurrence and detection values, the calculation was made to obtain the risk priority number.

## 3. RESULTS AND DISCUSSIONS

The case study performed has as object of analyzing the vehicle constructed and used by the Fênix Racing Formula SAE team in the year 2018, from São Paulo State University – campus of Ilha Solteira. The vehicle is composed of 224 components. Within the 8 areas, in which they were organized, components were grouped into 49 items. Both the grouping in areas and in items were made considering the mechanical issues involving the vehicle. The results obtained for the Risk Priority Number (RPN) have showed that 39, of 224 components, were considered at risk; therefore, more prone to failure. Those who presented RPN equal to or greater than 100 were considered as risk components.

The FMEA can be considered an iterative project, which is in constant modification and development. This happens because as the components with the most probable pretense to failures are detected; maintenance, preventive and predictive analysis managements are developed.

Through these other projects, critical components can have their analysis modified and, that way, other type of the failure modes would be considered more severe and new topics added to the base spreadsheet of the FMEA.

Figure 1 is the representation of an item of the spreadsheet developed in the project and Figure 2 the continuation of the same. Figures 3, 4, 5 and 6 are representing the same.

The highest observed RPN components from each vehicle subsystem considered are showed in Table 1.

Nº	ITEM	COMPONENT	FUNCTION	POSSIBLE FAILURES		
				MODE	EFFECTS	CAUSES
1	Brake (Drive)	Pedal	System drive	Break	Turning off the car	System overhead
2		Balance Bar	Power distribution	Break	Loss of brake system	System overhead
3		Aeroquip	Fluid transport	Rip	Loss of brake system	Lack of protection
4		Rigid Pipe	Fluid transport	Crack	Loss of brake system	Compression
5		Mute button	Turning off the car	Non-trigger	No engine shutdown	Open circuit
6		Master Cylinder	Hydraulic Lever	Crack	Fluid leak	Lack of maintenance
7		Brake fluid	Transfer the hydraulic pressure	Bubbling	Loss of pressure in the brake system	Improper sealing
8		Fluid reservoir	Confine the brake fluid	Break	Fluid leak	Compression

Figure 1. Name, function and failure analysis of drive subsystem (item) components

CURRENT CONTROLS	INDEXES			
	G	O	D	RPN
Super sizing (safety coefficient 2.5)	8	2	1	16
Super sizing (safety coefficient 2.5)	8	1	2	16
Appropriate allocation (wiring project development to keep the aeroquips away from hot parts or sharp)	9	7	7	441
Appropriate allocation (wiring on CAD design to prevent compression by the pilot or other components)	7	7	7	343
Continuous inspection (conducted by electronic area before and after each test)	8	2	5	80
Continuous inspection (held during the exchange of brake fluid)	9	3	7	189
Exchange held every 3 months according to the manufacturer	7	2	6	84
Allocation defined in the project phase	3	4	1	12

Figure 2. Current controls and values for the RPN calculation of components show in Figure 1

Nº	ITEM	COMPONENT	FUNCTION	POSSIBLE FAILURES		
				MODE	EFFECT	CAUSES
1	Suspension bottom front arm	Tubes	Structural	Break	Loss of driveability of the car	System overload
2		Plate	Support	Break	No component support	System overload
3		Support of kneecap	Support	Break	System malfunction	System overload
4		Kneecap	Support	Break	System malfunction	Fatigue
5	Suspension top front arm	Tubes	Structural	Break	Loss of driveability of the car	System overload
6		Plate	Support	Break	No component support	System overload
7		Support of kneecap	Support	Break	System malfunction	System overload
8		Kneecap	Support	Break	System malfunction	Fatigue
9		Push rod plate	Support	Break	System malfunction	System overload

Figure 3. Name, function and failure analysis of suspension subsystem (item) components

CURRENT CONTROLS	INDEXES			
	G	O	D	RPN
Realization of test to attainment of the forces which the component is requested, and comparison of these values	9	3	1	27
Proper positioning (considering the direction force exerted) and minimum dimensions.	5	3	3	45
Component verification	7	2	2	28
Component verification	6	6	7	252
Control of test site	9	3	1	27
Control of test site	5	3	3	45
Component verification	7	2	2	28
Component verification	6	6	7	252
Component verification	8	3	3	72

Figure 4. Current controls and values for the RPN calculation of components show in Figure 3

Nº	ITEM	COMPONENT	FUNCTION	POSSIBLE FAILURES		
				MODE	EFFECT	CAUSES
1	Differential	Internal gears	Allow different angular velocities between the wheels or transfer torque	Locking of internal gears	System/car stop	Lubrication problems
2		Carcase	Fix internal gears	Fragile fracture	System/car stop	Efforts above those predicted or project error
3		Carcase	Fix internal gears	Flow: the loss of geometric properties	Locking of internal gears	Problems with material or project error
4	Connection differential-crown	Flange	Connect the differential to the transmission kit	Striated teeth break	System/car stop	Operator error

Figure 5. Name, function and failure analysis of the transmission subsystem (item) components

CURRENT CONTROLS	INDEXES				CONTROLS NEEDED
	G	O	D	RPN	
Regular check lubricant level	10	2	4	80	Visual inspection
Use of safety factor; instrumentation	10	1	3	30	Visual inspection; non-destructive testing
Use of safety factor; instrumentation	10	2	4	80	Accuracy in the alignment/assembly
None	10	5	9	450	Electronic exchange of gear restriction

Figure 6. Current controls and values for the RPN calculation of components show in Figure 5

Table 1 contains the highest RPN components from each subsystem.

Subsystem	Item	Mode of failure	Current controls	RPN
Aerodynamics	Undertray	Impact	Fixing planning	120
Drive	Aeroquip	Lack of protection	Appropriate allocation	441
Electronic	Engine temperature sensor	Wear	Continuous inspection	210
Engine	Oil seal	Break	Noise control	81
Steering	Rack	Fatigue	Oversizing of component	500
Structure	Impact attenuator	Incorrect use	Proper use	250
Suspension	Kneecap	Break	Component verification	252
Transmission	Flange	Striated teeth break	None	450

Table 1. Most critical component of each subsystem

#### 4. CONCLUSIONS

The FMEA methodology, as well as other risk management tools are extremely important for project management. In a Formula SAE team this need is also true, and when the sectors of maintenance and control of parts ally their knowledge and needs to the project sector through tools such as the development of an FMEA, the failure rate reduces considerably.

Therefore, this work contributes to the approach of the engineer in participant formation of the formula SAE group with the FMEA tool that is strongly used by the industry. In addition, it allows the vehicle in question to provide analysis of its systems and processes that corroborate for increased reliability and greater safety for those involved in the project.

Only with the monitoring and development of basic controls of components considered critical, the reduction in the number of test failures when compared vehicles of 2017 and 2018, the year the methodology was started, was about 50%. However, when applied in the maintenance area, in order to have the expected result, it is necessary to combine the results obtained with the FMEA to other methodologies, mainly of management of monitoring and of predictive and preventive maintenance.

As part of the monitoring management, a maintenance catalog was made. Figure 7 exemplifies one of the items in this catalog. In it, the most critical FMEA items were cited with special observations to be analyzed at the beginning and end of each test.

In order to fulfill the information of the maintenance catalog, the control of vehicle test times was started, so that the parts maintenance hours can be followed more accurately. An example of this control is shown in Figure 8.

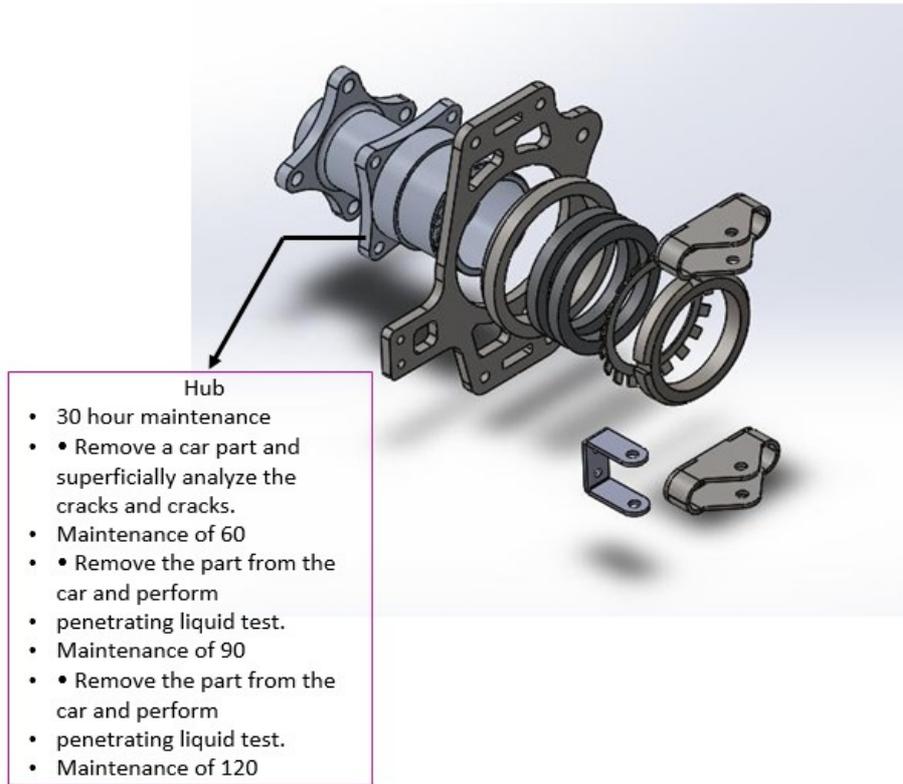


Figure 7. Hub catalog of the maintenance

Date	Test time (min)	Tested Areas	Initial Information	Final Observation
22/out	150	All	-	worn brake pads (caliper 3)
28/out	30	Engine and Eletronics	-	No components showed variation
29/out	70	All	changed brake pads 3 and 4	No components showed variation
04/nov	45	All	changed Master Cylinder (nº2 ---> nº3)	cracked aeroquip connector (caliper 1)
07/nov	40	Suspencion ( tilt)	-	-

Figure 8. Control of the vehicle test time

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## **7. RESPONSIBILITY NOTICE**

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