CHAPTER 170

The FMEA methodology applied in the design of the Powertrain assembly of a Baja SAE vehicle

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ABSTRACT
The Baja SAE Project is a university engineering challenge, which proposes the construction of an off-road vehicle and its application in competitions with challenging dynamic tests. Each year these competitions become increasingly difficult and, with this, issues such as the breakage and maintenance of components of these vehicles appear. These problems affect the Powertrain sector of the TEC-Ilha Baja SAE Team that sought to use methods and tools to solve these issues, such as FMEA. This methodology is defined by the NBR 5462 standard of ABNT and consists of recording the useful life of the components used and analyzing the failures that occurred in these components in a period, seeking to evaluate three basic points, which are the severity, occurrence and detection. That said, after prospecting all the episodes of breakage of vehicle components in the last 10 years of competitions, the Team elaborated, according to this method, the decision matrices linked to the three basic pillars, in order to establish relationships and scores for each case and so that it was possible to calculate the Risk Priority Number, the NPR, directing attention during vehicle maintenance and repairs. In all, 12 failures were detected in components connected to the transmission, which were classified according to their NPR. Although there is an ideal condition that establishes that the correction of all failure modes provides better operation of the vehicle, only the most critical failure modes are selected, due to the cost associated with maintenance. By observing the NPR of each failure it is possible to conclude that the engine components are the ones that suffer most from the challenges imposed on the vehicle, having the displacement of the ignition coil, the fracture of the crankshaft and the compromise of the carburetor as the most critical points, which have NPR's of 360, 280 and 252, respectively, and the less critical CVT and reduction box components with NPR's ranging from 10 to 90. Thus, the application of the FMEA methodology in the project of the TEC-Ilha Baja SAE Team provides an effective and systematized analysis of the failure modes that are inherent to the components of the vehicle's power transmission subsystem, serving as a basis for decision-making in the scope of programming and carrying out preventive maintenance of the most critical components.

Keywords: FMEA, Maintenance, Failures, Powertrain, Risk Detection, Baja SAE.

1 INTRODUCTION

1.1 THE BAJA SAE BRAZIL PROGRAM

The Baja SAE project was born at the University of South Carolina in the United States in 1976. In Brazil, the activities of the modality began in 1991, driven by SAE Brasil, which later, in 1994, would start the Baja SAE Brasil Project, whose first national competition took place in the city of São Paulo, in 1995. (SAE BRAZIL).

Baja SAE Brasil is a project proposed to engineering students from higher education institutions throughout the country, which aims at the practical application of knowledge acquired in the classroom, and which contributes to the training of these young people for the job market. In this challenge, students form teams and seek to develop a real off-road single-seater sports *vehicle, whose* main objective is to overcome obstacles, participating in several stages ranging from its conception, design, construction, to the validation tests of the vehicle, which must have excellent performance in relation to speed, maneuverability, comfort and robustness in rough terrain, whose performance is put to the test in the competitions which these Teams are encouraged to participate. (SAE BRAZIL, 2021).

During the competitions, the race that most challenges the baja vehicles is the Enduro, which consists of a 4-hour race in a rugged terrain with obstacles ranging from mud puddles to large ramps, its end being marked by the end of time or by a very serious and irreparable breakdown of some part of the car. In this way, the car that completes the largest number of laps over the period of realization of the race wins the race.

Currently there are three annual stages: the National, the Regional, which are not complementary, and the World, which takes place in the United States, whose participation is claimed by the winning team of the National stage of Brazil. (SAE BRAZIL).

1.2 THE TEC-BAJA ISLAND SAE TEAM AND THE *POWERTRAIN SECTOR*

Technology, Engineering and Competence are the three mottos that are in the blood of the bajeiro and that give name to the TEC-Ilha Baja SAE Team. Representing the Faculty of Engineering of Ilha Solteira of the Universidade Estadual Paulista "Júlio de Mesquita Filho" – UNESP/FEIS, it was founded on November 20, 2006, in Ilha Solteira – SP, by a group of Mechanical Engineering students, who were looking for something more to complement their training and apply their knowledge. (TEC ISLAND).

With more than 17 years of history, it has several awards, such as 1st place in Acceleration in the National Stage of 2015, 3rd place in APD / Comfort in the Southeast Regional Stage of 2022 and 4th place in APD / Comfort in the National Stage of 2023, being the most ergonomic car in the Southeast. It had the launch of its first *off-road vehicle* in 2008 and since then has been seeking its space within the world baja SAE and continuously improving its designs. (SAE BRAZIL, 2023).

Currently TEC-Ilha Baja SAE is composed of administrative sectors such as Human Resources, Finance and Marketing and technical sectors such as Structural Calculation, Drives, Electronics, Suspension and Steering and, finally, the *Powertrain*. The latter being responsible for taking care of the longitudinal performance of the car, as well as its transmission components such as engine, continuously variable transmission (CVT), reduction box and homokinetic semi-axles.

Figure 1 shows the Baja vehicle of the TEC-Baja Island SAE Team for the 2022/2023 season.

Figure 1 – Baja Vehicle of the TEC-Baja Island SAE Team of the 2022/2023 season

Source: Prepared by the authors, 2022.

2 CONCEPTUALIZATION OF FMEA

The method of Analysis of Failure Modes and their Effects, better known by the English acronym FMEA, is defined by the NBR 5462 standard of ABNT (Brazilian Association of Technical Standards) as a qualitative method of reliability analysis that addresses the study of the failure modes that may exist for each item and the determination of the effects of each failure mode on other items and on the specific function of the set. (ABNT, 1994).

In other words, according to Toledo and Amaral, the methodology aims to evaluate and mitigate risks through failure analysis, by determining the cause, effect and risk of each type of failure, and implement measures to increase reliability. Also according to the authors, the analyses by the method can be classified into product (or project) FMEA and process FMEA. The first classification refers to the analysis of failures that may occur in the product in view of the project specifications, while the second considers the failures in the planning and execution of the process.

3 GOAL

Increase the reliability of the components of the *Powertrain* assembly of a baja SAE vehicle by analyzing the detected faults.

4 METHOD

According to the classification of the existing types of FMEA, it is necessary to highlight that the present work consists of the application of a product FMEA, since all the analyses of the failure modes are focused on the determination of the defects occurred in components (or products) of the design of the power transmission system of a baja SAE vehicle. Having recorded this observation regarding the application of the method, it is necessary to present the decisions taken by the group for the effective use of the methodology.

4.1 TEAM DATABASE ANALYSIS

Before applying the FMEA methodology in the case presented, it was first necessary to perform an analysis of the team's database to acquire data, as shown in Chart 1. Thus, a survey was made of the last 10 years of activity of the Team, taking into account all the participations in periods of pre-competitions and competitions, in which the vehicle was more used and its parts were more requested, resulting in a total of 14 competitions.

Table 1 – Participation of the TEC-Baja Island SAE Team in competitions in the last 10 years

Baja SAE Brazil National Stage	Participation	Baja SAE Brazil Southeast Stage	Participation
2013	X	2013	
2014	X	2014	X
2015	X	2015	
2016	X	2016	
2017	X	2017	
2018	X	2018	X
2019	X	2019	X
2020	X	2020	
2021		2021	
2022	X	2022	X
2023	X	2023	

Source: Prepared by the authors, 2023.

In addition to the participation data, it was possible to identify all the failure modes that existed and to make an estimate of the total hours of employment of the vehicle in *off-road activities* in this period. Thus, it was possible to determine the main points of the FMEA methodology, create relationships for each existing failure and apply the methodology within the transmission design to the team vehicle.

4.2 APPLICATION OF THE FMEA METHOD

The FMEA method is based on the analysis of the failure modes that occurred in a given device, part or assembly, seeking to evaluate three basic pillars, which are: severity, occurrence and detection. Therefore, it is important to highlight the meaning of each of these terms. According to Capeleto

(2018), the severity index evaluates the effects of the occurrence of the failure, its impacts and severity. The occurrence rate is based on the probability of the failure occurring. And finally, detection relates to the efficiency of the ability to detect these possible failures.

In this way, the decision matrices referring to each of the pillars of the method are constructed, in order to establish relationships and indices for each case, thus being able to finally arrive at the parameter called the Risk Priority Number.

In the severity decision matrix, levels were defined, with indices from 1 to 10, ranging from mild to very serious and criteria ranging from a simple performance failure to compromise the safety of the pilot and the locomotion of the vehicle. Thus, the severity decision matrix is presented in Chart 2.

Table 2 – Severity decision matrix

Severity (S)	**Criterion**	**Index**
Very serious	Safety risks and non-locomotion of the vehicle	10
Serious	Security risks and risks of spreading the problem	9
Very high	Security risks and yield failure	8
Discharge	Security risks	7
Moderately high	Total component loss	6
Moderate	Non-locomotion and risks of spreading the problem	5
Moderately low	Non-locomotion of the vehicle	4
Low	Risks of problem spread and yield failure	3
Very low	Risks of spreading the problem	2
Bland	Yield failure	1

Source: Prepared by the authors, 2023.

In the occurrence decision matrix, taking into account the number of episodes in which the problems were presented, levels were also defined, with indices from 1 to 10, ranging from a very low to a very high occurrence rate, and time intervals were assigned to each type of occurrence ranging from 37 to 370 hours. Thus, the occurrence decision matrix is presented in Chart 3.

Table 3 – Occurrence decision matrix

Occurrence (O)	**Occurrence in operating hours**	**Index**
Very high	1 in up to 37 hours	10
	1 in 74 hours	9
Discharge	1 in 111 hours	8
	1 in 148 hours	7
Moderate	1 in 185 hours	6
	1 in 222 hours	5
Low	1 in 259 hours	4
	1 in 296 hours	3
Very low	1 in 333 hours	2
	1 in 370 hours	1

Source: Prepared by the authors, 2023.

Finally, for the detection decision matrix, levels were defined, with indices from 1 to 10, ranging from immediate to very remote, and the modes that each type of detection can assume were assigned, ranging from a simple visual inspection to the disassembly and laboratory analysis of the component in question. Thus, the detection decision matrix is shown in Chart 4.

Table 4 – Detection decision matrix

Detection (D)	Detection modes	Index
Very remote	Disassembly and analysis	10
Remote	Analysis	9
Very difficult	Auditory perception and analysis	8
Difficult	Disassembly	7
Moderate	Auditory perception and disassembly	6
Easy	Auditory perception	5
White	Visual inspection and disassembly	4
Very clear	Visual, auditory inspection and disassembly	3
Clear	Visual inspection and auditory perception	2
Immediate	Visual inspection	1

Source: Prepared by the authors, 2023.

After defining the three decision matrices mentioned above, the risk assessment was performed through the product between the indexes of each matrix, thus generating the Risk Priority Number – NPR.

5 FINDINGS

According to the definition of the matrices of the severity, occurrence and fault detection indices, it is possible to arrange the failure modes recorded in the periods of activity of the vehicle in a table, classifying them in relation to the indices according to the matrices and calculating the number of priority of risk of each of the types of failure observed, as shown in Table 1.

Table 1 – Failure modes recorded with their respective indexes and risk priority numbers

Failure modes	S	Or	D	NPR
Displaced ignition coil	4	9	10	360
Crankshaft fracture	4	10	7	280
Carburetor clogging	4	9	7	252
Excessive wear of gear teeth	2	9	10	180
Breakage of the shaft tip ball bearing frame	6	7	4	168
Engine gasket rupture	3	9	4	108
Carburetor fuel spill	10	9	1	90
Breaking of the CVT gear cover fastening clip	9	10	1	90
Fuel hose crack	10	7	1	70
CVT exchange cover cracking	2	10	2	40
Crack of a face of the motor pulley	6	3	1	18
Secondary shaft seal seal compromise	2	5	1	10

Source: Prepared by the authors.

6 DISCUSSIONS

Table 1 presents the failure modes recorded in the periods of activity of the vehicle in descending order of the number of risk priority, which directs the focus that the team must establish in the scope of performing maintenance of the components. Although the ideal condition establishes that the correction of all failure modes provides for better operation and, consequently, a better performance of the vehicle in the competitions contested, it is necessary to select only the most pronounced failure modes, due to the prohibitive characteristic of the cost inherent in maintenance, and apply actions for their corrections. Thus, the classification by means of the risk priority number identifies which failure modes require greater attention and guides decision-making towards maintenance.

In addition to the guidance in the scope of the performance of the necessary maintenance to the vehicle, the application of the method promotes an efficient way of recording the useful life of the components used. In the long run it is possible to have an extensive spreadsheet of fault data. This temporal record of failures may present a certain repeatability of occurrence in some specific way, which may indicate some design inconsistency, whether due to an incorrect sizing of components, mistaken selection of materials, adoption of incoherent hypotheses, for example. In this way, the application of the FMEA can also evidence possible discontinuities allocated in the development of the project, becoming a useful tool for the team regarding the reliability of the vehicle developed.

7 CONCLUSION

The study and application of the FMEA methodology in the design of the Baja vehicle of the TEC-Ilha Baja SAE team provides an effective and systematized analysis of the failure modes that subject the components of the vehicle's power transmission subsystem. With this analysis it is possible to identify the most accentuated failure modes by assigning a risk priority number based on the matrices of the severity, occurrence and detection indices defined by the team. The criticality of each mode and effect of failure serves as the basis for decision making in the context of programming and performing preventive maintenance on the most critical components, given that it is not possible to correct all defects. Observing the data in Table 1 regarding the failure modes treated by the FMEA method, it is noted that the main attention of the team should be directed to the failures that occurred in components connected to the vehicle's engine, with the defects of the displaced ignition coil, fractured crankshaft and clogged carburetor being the most strident. Thus, preventive maintenance should be designed with the objective of mitigating the occurrence of these most critical failure modes, so that the vehicle's performance in competition can be improved based on the systematized analysis of failures with the FMEA methodology. In addition, the application of the method provides a good database of the useful life of the components, also serving as an indirect indicator of a possible inconsistency in the definition of the project through the recurrent observation of a specific failure mode.

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