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FMEA, CAD & CFD INTEGRATED IN THE FIGHT AGAINST THE SARS-Cov 2 PANDEMIC: DEVELOPMENT OF AEROSOL PROTECTIVE APPARATUS FOR PROFESSIONAL DRIVERS

FMEA, CAD & CFD INTEGRADOS NO COMBATE A PANDEMIA DE SARS-Cov 2: DESENVOLVIMENTO DE APARATO PROTETOR CONTRA AEROSSÓIS PARA MOTORISTAS PROFISSIONAIS

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RESUMO

A pandemia de SARS-CoV2 traz para a sociedade um grupo de novos desafios relacionados aos esforços para combater doenças e retorno global pós-pandemia. Este trabalho propõe uma metodologia de desenvolvimento de produto integrado (FMEA + CAD + CFD) para obter um protótipo de um escudo de aerossol para motoristas profissionais. Foi obtido um novo protótipo CAD do escudo aerossol do motorista. A metodologia FMEA + CAD + CFD foi proposta para reduzir o tempo e os custos de desenvolvimento. Das ferramentas básicas de desenvolvimento, um protótipo baseado em CAD foi obtido. Esse modelo inicial suporta um aplicativo FMEA - para corrigir os modos de falha, ele pode ser identificado e priorizado pelo número de prioridade do risco. A simulação de CFD foi usada para discutir a eficiência da barreira. O FMEA pode ser usado para corrigir o protótipo no ambiente CAD - evitar colocar protótipos na produção com inadequações - e reduzir o tempo e os custos totais de desenvolvimento. Para produtos que possuem funções baseadas em dinâmica de fluidos, as soluções dos modos de falha correlacionadas podem ser ajudadas pela simulação de CFD - uma técnica que substitui experimentos físicos reais não triviais. O FMEA reduz em mais de 90% todos os modos de falha RPN no protótipo baseado em CAD, após ações de correção. A simulação CFD mostra que as linhas de fluxo são fortemente desviadas pelo escudo do motorista, em comparação com a situação sem escudo.

ABSTRACT

The SARS-CoV2 pandemic brings to society a group of new challenges related to efforts to combat disease and post-pandemic global return. This work proposes an integrated product development methodology (FMEA+CAD+CFD) to obtain a prototype of an aerosol shield for professional drivers. A new driver aerosol shield CAD prototype was obtained. The FMEA+CAD+CFD methodology was proposed to reduce development time and costs. From the basic development tools, a CAD based prototype was obtained. This initial model supports a FMEA application - to correct failure modes it can be identified and prioritized by the risk priority number. CFD simulation was used to discuss the barrier efficiency. The FMEA can be used to correct prototype in CAD environment – avoid put prototypes in production with inadequacies - and reduces total development time and costs. For products that have fluid dynamics-based functions, the failure modes solutions correlated can be helped by CFD simulation - a technique that replaces non-trivial real physical experiments. The FMEA reduces plus to 90% all failure modes RPN in CAD based prototype, after correction actions. CFD simulation shows that the flow lines are strongly deflected by the driver's shield, compared to no shield situation.

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1 INTRODUCTION

Professional drivers have an exhaustive workload, where they can face irregular working hours and can stay awake for more than 18 hours / day, which reduces their performance and attention (Narciso et al., 2017). These professionals are exposed to an extensive list of occupational diseases, such as low back pain (Longen, 2016; Barros, et al., 2020; Fratti, et al., 2019), chemical dependency, (Barbosa et al., 2018) such as alcohol and amphetamines (Mayer, et al., 2018), sleep disorders (Silva, et al., 2016), eating disorders and obesity (Delbim, & Baciuk, 2016; Pinto,& Bueno, 2019), sexually transmitted diseases (Rocha, et al., 2017), smoking (Fernandes et al., 2017), and in this context there is yet another concern for these professionals: the severe acute respiratory syndrome coronavirus 2 - SARS-CoV2 (Von Dorinalen, et al., 2020; Pan, et al., 2020). In a recent study, Huh, (2020), pointed out to health professionals how there is a high rate of infection when transporting patients. In this way, professional ambulance drivers are severely exposed.

The transmission of the new corona virus is the focus of several studies (Lo Guildici, et al., 2020; Ferioli, et al., 2020; Anfinrud, et al., 2020; Huh, et al., 2020). Previous studies discussed the transmission of SARS - CoV2 by various means, including Speech droplets (Anfinrud, et al., 2020). Aerosols are responsible for carrying SARS-CoV-2 and the etiological agent of Coronavirus Disease-2019 (COVID-19). This infection spreads mainly through direct contact with Flügge micro droplets or core droplets that remain suspended as aerosol (Ferioli, et al., 2020). In healthcare attendance, virus was widely distributed on floors, computer mice, trash cans, and sickbed handrails and was detected in air ≈4 m from patients (Guo, et al., 2020). A specific protocol should be applied to reduce the risk of infection in addition to measures that prevent the spread of infection from a patient to another person or medical tools and equipment - cross-infection (Lo Giudice, et al., 2020).

Recommendations on face masks vary across countries and we have seen that the use of masks increases substantially once local epidemics begin, including the use of N95 respirators (without any other protective equipment) in community settings (Feng, et al., 2020). Universal face mask use in the community has also been discouraged with the argument that face masks provide no effective protection against coronavirus infection (Feng, et al., 2020). One important reason to discourage widespread use of face masks is to preserve limited supplies for professional use in health-care settings. Then there is a need for the rapid development of products that can be an option for masks and face shields, ensuring the supply of essential PPE to healthcare workers (Ferioli, et al., 2020)

The need to increase the speed of product creation and implementation has made the use of 3D prototyping an ally in the development of new products and their use in the industry, which have been growing gradually in recent years and generating innovations (Langefeld, et al., 2017; Thomas,& Venkat, 2016; Briantais, 2017).The development using CAD (computer-aided designs), allows the complete analysis of the project design, its assembly or even the operation of the designed mechanism. (Gomes, & Wiltgen, 2020). Combined with 3D printing techniques, it is possible to create prototypes with acceptable costs, allowing the performance of tests in relation to the shape, ergonomics and physical application of the physical prototype in a practical and efficient way (Takagaki, 2012), with the main focus on component development functionalities, prototypes and shapes of objects in a short period of time, and respecting the specifications required for the final product (Volpato, 2017).

The product development process (PDP) consists of steps that evolve over time and that integrate tools, methods and technologies capable of helping to reduce development time and costs. Design for manufacture and assembly (DFMA), quality function deployment (QFD) are examples of tools used in PDP. Computer aided design (CAD), computer aided manufacture (CAM), virtual prototyping (PV) and physical prototyping (PF) can also be cited as examples of technologies used in the PDP. (Da Silva, 2011) years and generating innovations (Langefeld, et al., 2017; Thomas, & Venkat, 2016; Briantais, 2017).

According to the reference model of Rozenfeld, et al., (2006) the product development process is composed of three macro phases called pre-development; development and post-development. The three macro phases are subdivided into the following stages: (i) strategic product planning; (ii) project planning; (iii) informational project; (iv) conceptual design; (v) detailed design; (vi) preparation for production; (vii) product launch; (viii) monitoring of the product / process; (ix) discontinue the product.

In the initial stages of the PDP where different conceptions, shapes, ergonomic analysis and other variables are used, various types of three-dimensional representations of the product are used, for example, mockups, volumetric models, mock-ups, presentation models, among others (Volpato, 2017). With the evolution of product development, it is necessary to use different physical prototypes, which evolve together with product development (Da Silva, 2011). In this sense, 3D prototyping can reduce the cost and time of product development, identifying possible failures in CAD stage and making companies that adopt this process more competitive in the market (Relvas, et al., 2012).

One of the methods commonly used in failure analysis is the FMEA (failure mode and effect analysis), which is widely described in the literature (Helman, et al., 1995). Ford (2011) describes the FMEA as a systematic group of activities that intends to: (i) recognize and evaluate potential flaws in a product or service and its effects; (ii) Identify actions that can eliminate or reduce the chances of the potential failure occurring and (iii) document the process. Its basic objective is to identify the failure modes, their basic causes, their effects, and what is the impact of these effects on the final product. Once established the relationship between the fault, its causes and its effects, indices are determined that assess the probability of the failure occurring, the severity of its effects and the ability to detect the fault and block it before its effect is perceived by the client (Vanni, et al., 1998). From 1970 the FMEA started to be widely used in the most diverse industries in the engineering sector (Banghart, et al., 2018).

Its biggest highlight was in the auto industry, being introduced by Ford Motor Company as a process of continuous improvement to identify and minimize potential flaws in its production system (Ford, 2011). The FMEA allows a hierarchy of risks, prioritizing the failure modes according to a coefficient called risk priority number or RPN - risk priority number. This number is a result of the multiplication of three independent indices - severity (S), occurrence (O) and detection (D) - and vary from 1 to 10, from the best to the worst reality (Stamatis, 2003). Table 1 shows the FMEA indices and the risk prioritization by the RPN.

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Table 1. Index for severity (S), Occurrence (O) and Detection (D), and classification by RPN - risk priority number, for FMEA application.

Severity Index (S)			
Index	**Qualitative Scale**	**Potential Failure Consequences**	
	Minor / Secondary	No real impact failure	
2 e 3	Low	Almost insignificant failure	
4 e 6	Moderate	Failure has some discomfort	
7 e 8	Elevate	Failure has a direct effect on the operation	
9 e 10	Critical	Failure with real security impact	
Occurrence Index (O)			
Index	**Qualitative Scale**	**Frequency**	
1	Very Low	<= 1 in 1.000.000	0 - 0,0001%
2	Low	> 1 in 1.000.000 e <= 1 in 20.000	0,0001% - 0,005%
3	Low	> 1 in 20.000 e <= 1 in 4.000	0,005% - 0,025%
4	Moderate	> 1 in 4.000 e <= 1 in 1.000	0,025% - 0,1%
5	Moderate	> 1 in 1.000 e <= 1 in 150	0,1% - 0,675%
6	Moderate	> 1 in 150 e <= 1 in 80	0,675% - 1,25%
7	High	> 1 in 80 e <= 1 in 40	1,25% - 2,5%
8	High	> 1 in 40 e <= 1 in 20	2,5% - 5%
9	High	> 1 in 20 e <= 1 in 10	5% - 10%
10	Very high	> 1 in 10	>10%
Detection Index (D)			
Index	**Qualitative Scale**	**Detection**	
1	Very high	Control measures will almost certainly detect the existence of the failure	
2 a 5	High	Control measures have a high probability of detecting the existence of the failure	
6 a 8	Moderate	Control measures can detect the existence of the fault	
9	Low	Control measures have a low probability of detecting the existence of the failure	
10	Very Low	Control measures will almost certainly not detect the failure	
Risk graduation by RPN			
Risk grade/Criticality definition		**Measures Degree of Urgency**	
RPN < 40	Minor / Secondary	Improvement measures should be taken without urgency	
40 <= RPN <= 100	Moderate	Measures should be taken as soon as possible to decrease the likelihood of further degradation	
100<= RPN < 200	Elevate	Urgent measures must be taken to eliminate the causes	
RPN >= 200	Critical	Requires immediate action to eliminate the causes	
Severity Index (S)			
Index	**Qualitative Scale**	**Potential Failure Consequences**	
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4 e 6	Moderate	Failure has some discomfort	
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Index	**Qualitative Scale**	**Frequency**	
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4	Moderate	> 1 in 4.000 e <= 1 in 1.000	0,025% - 0,1%

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5	Moderate	> 1 in 1.000 e <= 1 in 150	0,1% - 0,675%
6	Moderate	> 1 in 150 e <= 1 in 80	0,675% - 1,25%
7	High	> 1 in 80 e <= 1 in 40	1,25% - 2,5%
8	High	> 1 in 40 e <= 1 in 20	2,5% - 5%
9	High	> 1 in 20 e <= 1 in 10	5% - 10%
10	Very high	> 1 in 10	>10%
Detection Index (D)			
Index	**Qualitative Scale**	**Detection**	
1	Very high	Control measures will almost certainly detect the existence of the failure	
2 a 5	High	Control measures have a high probability of detecting the existence of the failure	
6 a 8	Moderate	Control measures can detect the existence of the fault	
9	Low	Control measures have a low probability of detecting the existence of the failure	
10	Very Low	Control measures will almost certainly not detect the failure	
Risk graduation by RPN			
Risk grade/Criticality definition		**Measures Degree of Urgency**	
RPN < 40	Minor / Secondary	Improvement measures should be taken without urgency	
40 <= RPN <= 100	Moderate	Measures should be taken as soon as possible to decrease the likelihood of further degradation	
100<= RPN < 200	Elevate	Urgent measures must be taken to eliminate the causes	
RPN >= 200	Critical	Requires immediate action to eliminate the causes	

Source: Stamatis, 2003, Ford, 2011. Adapted.

Severity is the classification that indicates the severity of a possible consequence in the potential failure mode. Classifying the severity of the failure from 1 to 10, starting from a consequence without damage to catastrophic or irreparable damage. The FMEA occurrence is an estimate of the frequency or probability of failure mode occurrence. The best method to determine its value is through the use of real process data, however, in the case where there are no previous data for evaluation qualitative scales can be assigned based on the experience of the operators (Mcdermott, et al., 2009). Detection is the difficulty of having the fault detected before the failure mode occurs. For the maintenance area, the probability of Detection is conceptualized between very low and very high, relating concepts from 1 to 10 with the probability of the defect being detected (Stamatis, 2003; Mcdermott, et al., 2009).

With the obtaining of the numerical value for severity, occurrence and Detection, the "Risk Priority Number" (RPN) is determined, which is composed of the product of the three factors of the FMEA (Mcdermott, et al., 2009). This value is responsible for giving a numerical classification to the risk modes, so it is possible to create a risk prioritization list, so that new control measures will be determined and corrective actions will be applied (Stamatis, 2003).

According to Stamatis (2003), there are three main types of FMEA: a) FMEA of system; b) product FMEA; and c) Process FMEA. System FMEA (or concept) is used to assess system failures in the early stages of conceptualization and design. Product FMEA is used to evaluate possible product design failures before being released for manufacture. (Fernandes, & Rebelato, 2006; Miguel, & Segismundo, 2008).

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In recent work, FMEA is used to identify and prioritize risk to the user of the process or system. More recent studies implemented the FMEA for occupational safety using the reference table of Indexes S, O and D, proposed by Cavaignac, & Uchoa (2018), and scored the least in the adversity of choosing the Indexes became less subjective (Santos, et al., 2019; Dias Júnior,& Cavaignac, 2019; Jorge et al., 2019, Mota, & Cavaignac, 2019; Pacheco,et al., 2019)

Table 2 is proposed by Cavaignac, & Uchoa, (2018), as a quick reference tool for professionals who elaborate, execute and research about the safety of work, in order to reduce the difficulty of using the FMEA reported by Laurenti, et al., (2012).

Table 2. Reference table for Severity (S), Occurrence (O) and Detection (D) Indexes

Severity (S)		**Occurrence (O)**		**Detection (D)**	
Index	**Severity nature**	**Index**	**Occurrence nature**	**Index**	**Detection method**
1	No real impact	6	Impact suffered	1	Visual Inspection
2	Irrelevant Trauma	5	fall with level difference	2	Tactile test / manual test
3	Trauma requiring first aid	5	Impact against	3	
4	Temporary disability without leave	5	Excessive or inappropriate effort	4	
5	Temporary disability with short absence	5	Pressing or trapping	5	checklist application / test sequence before task
6	Temporary disability with long absence	5	Fall from same level	6	
7	Partial permanent disability	4	Noise exposure	7	
8	Total permanent disability	4	Nocive substance exposure	8	Instrumental inspection/mechanical tests
9	Death of those involved in the process	4	Electric shock	9	
10	Death of not involved in the process	3	Friction or abrasion	10	Lack of effective tests
		3	Extreme temperature exposure		

Source: Cavaignac, & Uchoa, 2018. Adapted.

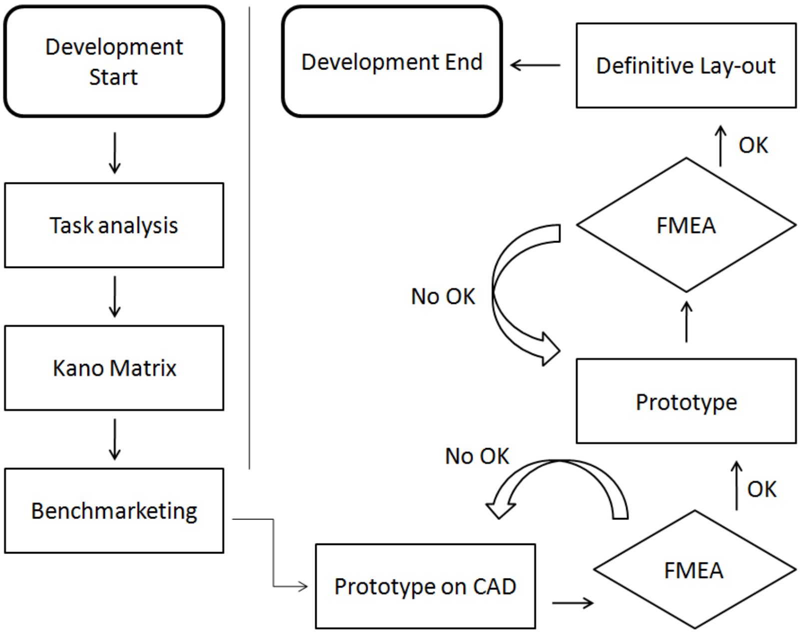
The Occupational Safety Failure Modes Effects Analysis (OS-FMEA) has been developed in recent works in order to facilitate the application of the tool by professionals in the area of risk management (Lima, et al., 2019). OS-FMEA has been applied lately in civil construction processes, such as execution of works at height (Jorge, et al., 2019; Mota,& Cavaignac, 2019), execution of maintenance services in electrical networks (Dias Júnior & Cavaignac, 2019), carpentry services (Jorge, et al., 2019), excavation works and sanitary facilities (Mota,& Cavaignac, 2019; Cavaignac, et al., 2019), demolition services (Santos, et al., 2019) and application started in industrial processes, as in processes involved in the metallurgical industry (Pacheco, et al., 2019) and in small welding and machining processes (Lima et al, 2019). These last two applications corroborate the application of the OS-FMEA methodology in the product development project in the area of mechanical parts - a use not found in previous literature.

In this sense, this work proposes to develop a protective device against aerosols for professional drivers - especially those involved in medical logistics. From the initial conception to the final piece, established product development management tools will be used. This work will use with greater emphasis the analysis of failure mode and effect - FMEA, together with prototyping 3d in CAD (computer-aided design). The use of FMEAis to identify possible faults of the part still in the development stage in CAD, in order to avoid rework and waste of time and materials.

2 METHODOLOGY

The present work used tools widely used in product development management - such as task analysis, kano matrix and bench marketing - to design the initial concept of the piece. From then on, a primary sketch was carried out in a CAD environment and from there, the application of FMEA in the digital prototype to mitigate possible failure modes before the realization of the physical prototype. Figure 1 shows the flowchart of the product development process.

Figure 1. Flowchart of the aerosol protective shield development process.



Source: author, 2020.

The application of FMEA takes place with two emphases: (i) the correct functioning of the system, and (ii) the security of the user - with the application of OS-FMEA. In this work, the FMEA Adapted model by Mota, & Cavaignac, (2019) was used in work safety, in synergy with the model proposed by Fernandes,&Rebelato, (2006), for product development. It is worth noting that this FMEA was applied in a situation where corrections could be applied, so a new generation of RPN was added to the applied corrections at the end. Table 3 below shows the proposed header, with the first part dedicated to system security, and the second part dedicated to user security.

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Table 3. FMEA model for application in the development of protective bulkheads

System safety application														
Failure	Failure mode	Basic failure cause	Occurrence (O)	Failure consequences in system	Severity (S)	Control methods	Detection (D)	RPN (SxOxD)	RISK	Corrective action	O	S	D	FINAL RPN
1º	**2º**	**3º**	**4º**	**5º**	**6º**	**7º**	**8º**	**9º**	**10º**	**11º**	**12º**	**13º**	**14º**	**15º**
User safety application														
Failure	Failure mode	Basic failure cause	Occurrence (O)	Failure consequences in system	Severity (S)	Control methods	Detection (D)	RPN (SxOxD)	RISK	Corrective action	O	S	D	FINAL RPN

Source: Author, 2020.

Due to the nature of the product - a protective screen to prevent the propagation of air droplets - it will also be used to simulate the behavior of the fluid in the part - through computational fluid dynamics (CFD). 3D prototyping was done with the aid of free software Freecad, and simulations in fluid mechanics were performed with the help of SIMSCALE, a cloud-based simulation platform, also free of charge.

FMEA can be used in synergy with QFD - quality function deployment (Fernandes, & Rebelato, 2006; Miguel, & Segismundo, 2008; Shaker, et al., 2019). The use of QFD can feed the FMEA considering each failure mode based on the interpretation of the "customer's voice" (Fernandes, & Rebelato, 2006). However, in this work the FMEA was used without these weights, in order to facilitate the application and optimize the necessary time for application of the tool - having seen the main objective is to create a development flowchart that avoids rework and optimizes the process of developing.

3 INITIAL DEVELOPMENT

3.1 TASK ANALYSIS

The task analysis explores the interactions between the product and its user, through observations and analyzes. The results of these analyzes are used to generate concepts for new products (Baxter, 1998). For the task analysis, the system was observed in loco, to understand its function, the parts that carry each task and possible necessary observations. Table 4 shows the result of the task analysis based on the observed situation.

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Table 4. Application of task analysis to the carburetor adaptation

Function	Observations	Function holder
Be attached to the driver's seat to allow easy adjustment of the driving position	It is necessary to ensure the compatibility of the connections (measurements of screws and nuts) and lay-out	• Part dimensions and layout • Manufacturing material • Bindings
Protect the driver against air droplets expelled by passengers	It is necessary that the lay-out ensures protection and the materials are sterilizable	• Part dimensions and layout • Manufacturing material
Ensure driver visibility	The material must have good transparency, and avoid light reflections	• Manufacturing material
Resist thermal, chemical and mechanical stress of function	Correct choice of materials, part layout and bindings is required	• Manufacturing material • Part dimensions and layout • Bindings

Source: author, 2020.

It is noticed that the part basically has four functions: (i) To be fixed to the driver's seat, allowing the regulation of the driving position; (ii) Protect the driver from air dropletslaunched by passengers; (iii) allow a good visibility to driver during your function; and (iv) resist the thermal, chemical and mechanical stress of the function. For this, it was observed that those responsible for fulfilling the tasks of the product are: (i) dimensions and layout of the part; and (ii) Manufacturing material; and (iii) bindings - it is important to choose the bindings appropriately to guarantee the durability of the piece.

3.2 KANO MATRIX

The Kano matrix is directly related to customer satisfaction and needs, so one can judge the basic requirements (essential attributes), expected and attractive of the product (Baxter, 1998). Table 5 shows the application of the Kano model to determine the basic, expected and attractive attributes of the part to be developed.

Table 5. Kano matrix to define part requirements

Basic requirements	Expected requirements	Attractions
• Protect the driver against air droplets expelled by passengers • Ensuring driver visibility	• Resistance to mechanical / thermal / chemical stress • Durability	• Low part purchase cost • Ease of installation • Be attached to the driver's seat to allow easy adjustment of the driving position

Source: author, 2020.

3.3 BENCHMARKETING

Through a quick search in internet search tools - news, scientific papers, it was possible to conduct a market study, focusing on the available options. Through this bench marketing it was realized that as a standard this problem is solved with head face shields. The face shields do not exempt the user from using a face mask, as they are not hermetically sealed. However, for the driving function, the face shields can offer ergonomic discomfort in the head region, showing that there is space for development.

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3.4 INITIAL CONCEPT

Through the initial application of the aforementioned tools, it was possible to elaborate an initial concept of the piece.

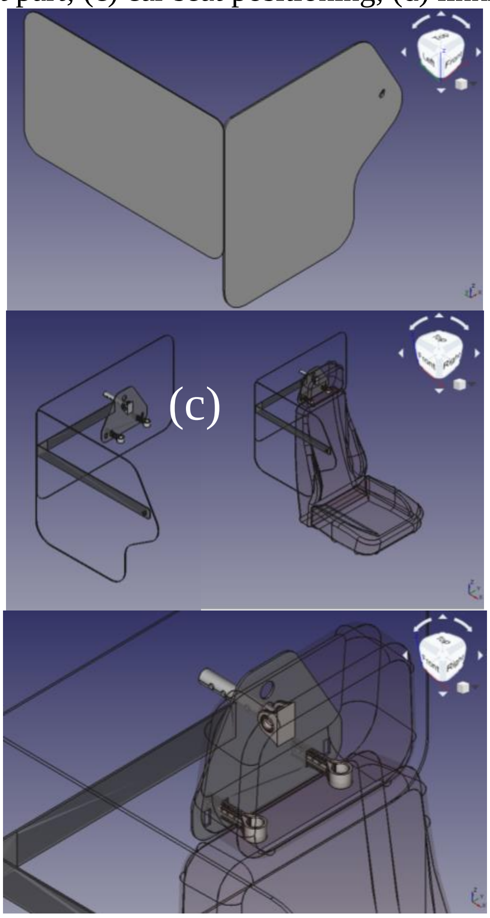
> "The main function of the part is to protect the driver against air droplets expelled by passengers, maintaining the necessary visibility for the function, and not be a difficult to driver rescue in event of an accident. It must be made of material resistant to chemical attack (alcohol), thermal attack (thermal energy from the environment, by convection or irradiation), in addition to having adequate mechanical characteristics. In addition, it is a differential to allow easy adjustment of the driving position."
>
> *The author, 2020.*

From then on, the 3d prototyping stage was started, for the subsequent application of FMEA and CFD.

4. 3D PROTOTYPING, FMEA e CFD

With the initial concept of the part, it was possible to sketch a layout that fulfilled the design requirements. Figure 2 shows the initial design of the prototype and figure 3 shows the suggested installation position in the driver's seat.

Figure 2. (a) initial layout of the prototype in solid part orthogonal section; (b)acrylic structure transparent part; (c) car seat positioning; (d) linking in the bank part.



Source: author, 2020.

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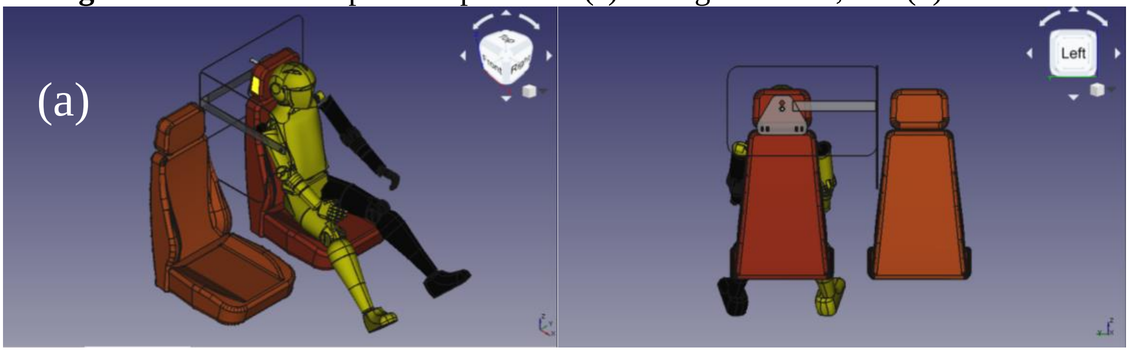
Figure 3. Driver's seat position protector (a) orthogonal view, and (b) rear view.



Source: Author, 2020.

From the initial 3d prototyping, it was possible to visualize the part and perceive possible initial conflicts in the project. List these inadequacies can be quite intuitive and solved objectively in practice. However, according to the Ford Company handbook (2011), the application of the FMEA in this step had the ability to document the identified problems and systematize their resolution, mainly showing the reduction in the risk potential after the application of corrective measures.

4.1 APPLICATION OF FMEA AND OS-FMEA IN PRODUCT DEVELOPMENT

For the application of FMEA in the development of the protector, an index of initial occurrence equal to 5 was assigned to all failure modes, due to the unique nature of the sample. The occurrence index for post-improvement RPN then works in a comparative way to the index of the initial situation. Table 6 contains the FMEA application with a focus on system safety - (i) false air intakes; (ii) incompatibility of systems; (iii) fuel leak; and (iv) restriction of air / fuel flow - and of the user safety - (v) fuel leakage; and (vi) injuries during installation / handling.

Table 6. Application of FMEA and OS-FMEA in the development of aerosol driver shield

SYSTEM SAFETY APPLICATION

Failure	**Failure mode**	**Basic failure cause**	**Occurrence (O)**	**Failure consequences in system**	**Severity (S)**	**Control methods**	**Detection (D)**	**RPN (SxOxD)**	**RISK**	**Corrective action**	**O**	**S**	**D**	**Final RPN**
Design/lay-out failure	Driver Shield fall	Bad vinculation choice/execution	5	Failure has a direct effect on the operation	8	Control measures have a high probability of detecting the existence of the failure	5	200	**Critical**	Ensure that the links in the seat are fixed / correct dimensioning of the part	2	2	2	8
	Systems incompatibility	Bad part sizing	5	Failure has a direct effect on the operation	8	Control measures will almost certainly detect the existence of the failure	1	40	**Moderate**	Ensure the correct dimensioning of the part / check drawing for the protector	2	1	1	2

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	Bad driver visibility	Dirt / scratched material	5	Failure has a direct effect on the operation	10	Control measures have a high probability of detecting the existence of the failure	2	100	**Elevate**	Correct choice of material that allows cleaning / easy replacement of worn parts	2	1	2	4
	air droplets passing by	Bad vinculation choice/layout	5	Failure has a direct effect on the operation	9	Control measures have a low probability of detecting the existence of the failure	9	225	**Critical**	Correction of the protector layout using simulation techniques - CFD	5	1	2	10
USER SAFETY APPLICATION														
User risk	Driver Shield fall	Bad vinculation choice/execution	5	Temporary disability without leave	4	Control measures have a high probability of detecting the existence of the failure	2	40	**Moderate**	Ensure that the links in the seat are fixed / correct dimensioning of the part	2	1	2	4
User risk	air droplets passing by	Bad vinculation choice/layout	5	Death of those involved in the process	9	Control measures have a low probability of detecting the existence of the failure	9	225	**Critical**	Correction of the protector layout using simulation techniques - CFD	5	1	2	10

Source: Author, 2020.

For the failure mode of driver shield fall, possible problems of fixing the shield to the car seat, such as wrong choices of binding devices or misuse of these devices, were pointed out as the basic cause of the failure. The option of fixing by a pair of clamps is given to facilitate the assembly of the shield in several different models of seats. the fall has a direct effect on the operation, soon it obtained a severity index equal to 8. Regarding the control methods, the current controls have a high possibility of detecting the causes of the failure before it happens - through manual verification of the adjustment / fixation from the part to the bench - obtaining the detection index 5.

After the corrective actions adopted - checking the fixation and ensuring the correct dimensioning of the fixing part - The probability of the failure occurring, besides the severity reduction - will not affect the functioning of the system, and the detection of good binding is easily accomplished through rapid manual tests. Thus, the total RPN dropped to 8, obtaining a secondary qualitative rating. For user safety, the driver shield fall can provoked an accident while driving – can hurting the driver and leaving him from his function. Post-corrections RPN was reduced to secondary risk too.

The system incompatibility has similar results, except detection index, that obtained 1 – a rapid assembly test on cockpit shows possible incompatibilities. A rapid assembly test shows bad visibility failure too. The driver shields needs be make of transparent material, that correctly choice of materials and layout ensure a RPN reduction to 2 and 4, respectly. The air droplets passing by needs special attention – the layout and bad vinculation can allows

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streamflow's with air contained air droplets hitting the driver face. This failure affects both system safety and user safety, obtained the highest RPN of the analysis. This failure only be detected and resolve by complementary techniques, like CFD.

4.2 CFD APPLICATION

The CFD application was motivated by the detection difficulty by the traditional control methods in the failure mode of air droplets passing. According to the FMEA application in the prototyping phase 3d in CAD, the difficulty of controlling this failure mode was identified and the need for auxiliary identification techniques was pointed out. In this case, the use of CFD-based simulation was proposed to observe how capable the initial lay-out was to stop air droplets.

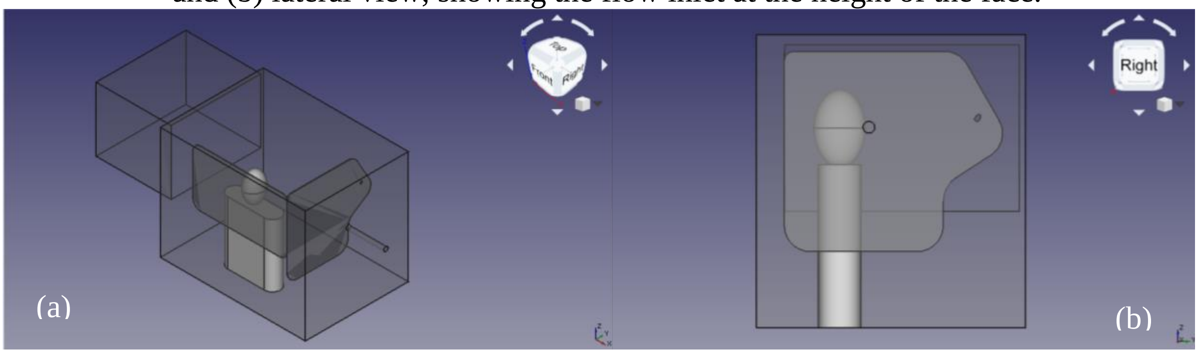
For that, boundary conditions were arbitrated. Zhu et al, 2006 reached the data of an air flow with a speed of 22 m/s during the cough. Regarding sneezes, previous works defines an air flow between 2 and 8 l/s (Grupta, et al., 2009), transversal flow area of 1.8cm² (Rahiminejad, et al., 2016), and a speed greater than 50m/s (Xie, et al., 2007). These parameters were used as a basis for the simulation. The premise was adopted that the worst situation would be a sneeze from the frontal passenger direct on drivers face, with no protection (face masks, sneeze on elbow and others), about 0.5m. It suggests a baddest situation of a driver receive an air Jet with 50m / s directly on face. This situation was studied by CFD, where driver shield was putted between "sneeze" air jet and driver. Due to computational costs, only two situationshave been studied and the discussion is reserved for qualitative comparisons. The table 7 shows the boundary conditions and references adopted on sneezing situation. Figure 4 shows the model developed and the simplification obtained for the CFD. Figure 5 shows the result of the CFD simulation for the model with driver shield and figure 6 the no shield model.

Table 7. Boundary conditions used to describe the sneezing phenomena

Boundarycontition	Value	Unit (si)	Reference
Transversal flowarea	1.8×10^{-4}	m²	Rahiminejad et al, 2016
Volumetricairflow	$2\text{-}8 \times 10^{-3}$	m³	Grupta et al, 2009
Air flowvelocity	50	m/s	Xie et al, 2007

Source: Author, 2020.

Figure 4. In-section view of the models tested in option to the initial model: (a) orthogonal and (b) lateral view, showing the flow inlet at the height of the face.



Source: Author, 2020.

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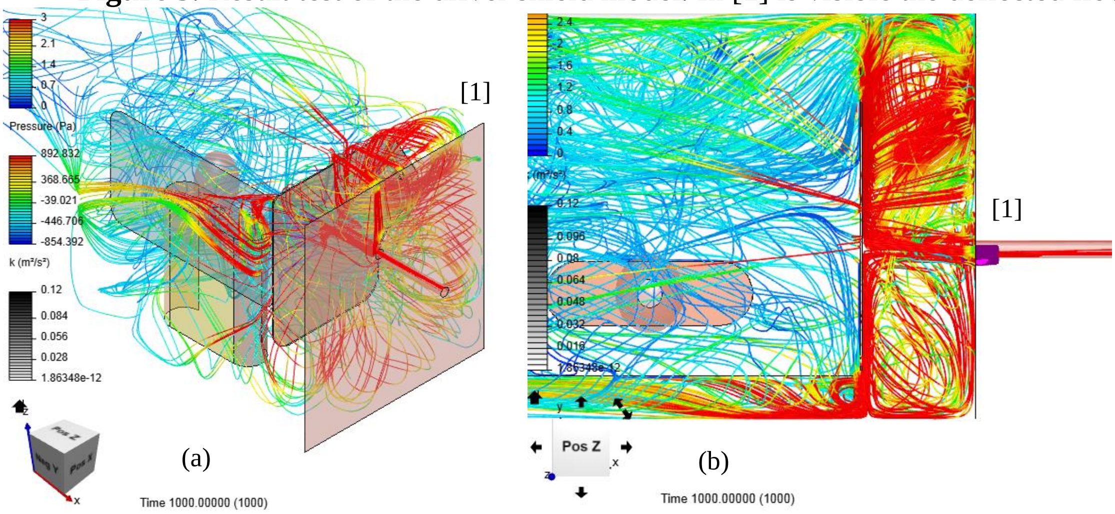
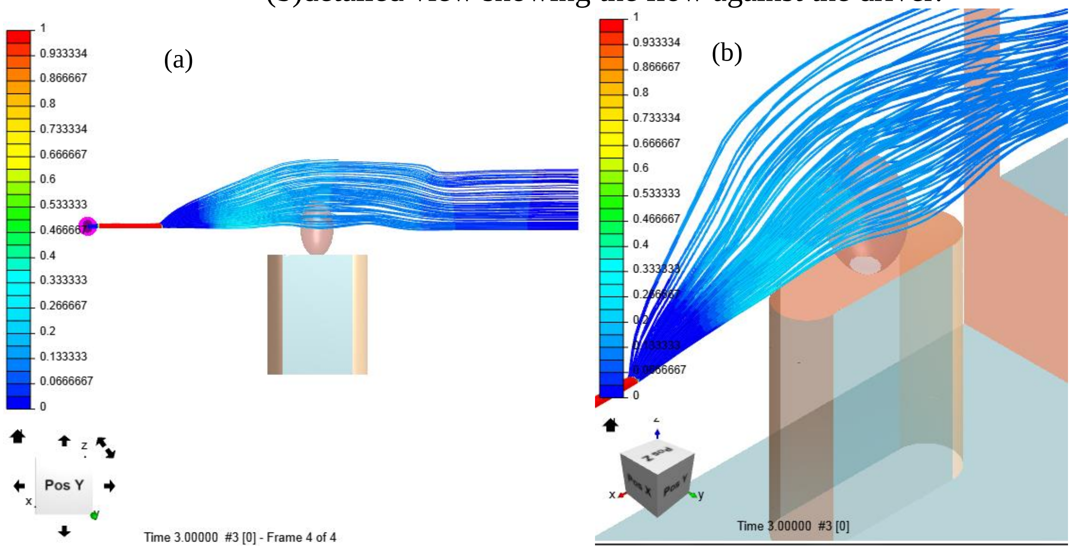
Figure 5. Result test of the driver shield model. In [1] is visible the deflected flow



Source: Author, 2020

Figure 6. CFD test result of the no shield model for drivers in (a) frontal view, and (b)detailed view showing the flow against the driver.



Source: Author, 2020.

5 CONCLUSIONS

This work used FMEA + CFD to optimize the aerosol shield driver development process. From the application of FMEA / OS-FMEA in the initial model of the part in CAD environment, 6 failure modes were listed, 4 related to system safety and 2 related to user safety. The possibility of applying the FMEA / OS-FMEA resulted in the reduction of RPNs obtained from the application of corrective actions still in the CAD environment, thus avoiding possible ineffective prototypes and optimizing the process in relation to time spent and avoiding waste of materials and inputs. Table 8 shows the failure modes with the respective initial RPNs, the corrective actions taken and consequently the new RPNs obtained after improvements.

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Table 8. Reduction of post-upgrade RPN for each failure mode identified

Failure type	Failure mode	Basic cause of failure	RPN (SxOxD)	Risk	Corrective actions	RPN Final	Risk	% RPN Reduction
SYSTEM SAFETY APPLICATION								
Design/lay-out failure	Driver shield fall	Bad vinculation choice/execution	200	Critical	Ensure that the links in the seat are fixed / correct dimensioning of the part	8	Secondary	96%
	Systems incompatibility	Bad part sizing	40	Moderate	Ensure the correct dimensioning of the part / check drawing for the protector	2	Secondary	95%
	Bad driver visibility	Dirt / scratched material	100	Elevate	Correct choice of material that allows cleaning / easy replacement of worn parts	4	Secondary	96%
	air droplets passing by	Bad vinculation choice/execution	225	Critical	Correction of the protector layout using simulation techniques - CFD	10	Secondary	95,5%
USER SAFETY APPLICATION								
User risk	Driver Shield fall	Bad vinculation choice/execution	40	Moderate	Ensure that the links in the seat are fixed / correct dimensioning of the part	4	Secondary	90%
	air droplets passing by	Bad vinculation choice/execution	225	Critical	Correction of the protector layout using simulation techniques - CFD	10	Secondary	95,5%

Source: Author, 2020.

From table 8 it is possible to observe that the failure modes initially had a moderate, elevate or critical risk. It is necessary to highlight that the failure modes of shield fall drivers and droplets passing obtained the highest RPN - 225 and 200, respectively, being classified as critical. These failure modes have great interference from the main function of the part - keeps the driver safe. They also had great difficulty in detecting the failure - the failure mode of air droplets passing, for example, required the use of the CFD to define the lay-out.

From the application of corrective actions, all failure modes reached the level of secondary risk - less than 40. All failure modes reached 90% or more of RPN reduction. However, it is worth noting that the air droplets passing failure mode achieved a post-improvement RPN of 10 - the highest of all, due to the residual difficulty of detecting the failure even after the improvements, requiring further studies focusing on that – CFD application with a quantitative approach.

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