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THE BENEFITS OF FMEA IN IMPROVING THE INDUSTRIAL PROCESS OF A CABIN AIR CARRIER

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A B S T R A C T

This paper aims to present improvement actions to reduce the failure risk of a new vehicle cabin air transporter developed in an automotive plant in the Sul Fluminense region by applying the Failure Modes and Effect Analysis (FMEA) tool. This analysis method enables the equipment to reduce some existing problems. Thus, it was possible to increase the demand for vehicles, expected by the end of the year 2018. For this purpose, a team was formed with employees from the main areas involved who raised the main failure modes of the equipment through the brainstorming technique. The FMEA worksheet was filled using the severity, occurrence, and detection classification tables to calculate the Risk Priority Number (RPR). Then, it was suggested to apply the technique with the necessary improvement actions for the failure modes, broken down in a 5W1H worksheet. In a conclusion, the importance of applying the FMEA before acquiring new equipment was demonstrated, avoiding waste, and guaranteeing the company's efficiency.

1. INTRODUCTION

Modern companies operate under constantly changing market conditions. Only those companies that can adapt quickly to changes in the external environment can survive in the competition. In this respect, the quality management system must be flexible and quickly customizable to changing requirements of the company's stakeholders. Only such a management system can become a useful tool in the hands of the company's management (Mascia et al., 2020; Rifqi et al., 2021; Safonova & Tatarnikova, 2020; Fonseca et al., 2022). The development of products, over the years, has moved from the handicraft culture from to industrial, then to manufacturing, responding to the demand for large quantities with a concern to insert quality into these products (Santos & Barbosa, 2006; Santos et al., 2017; Chen & Li, 2019; Jimenez et al. 2019; Costa et al., 2019; Sales et al., 2022).

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The guiding principle is that Quality must begin before manufacturing begins and capital allocations are made. In practice, this means that companies should start by establishing their quality goals, developing product features that meet those goals, developing processes capable of delivering those products, and establishing controls that enable operations to be conducted in a consistent manner (Doiro et al., 2017; Vieira et al., 2019; Rodrigues et al., 2019; Sá et al., 2019; Zgodavova et al., 2020). It is necessary to reduces waste, thereby reducing waste generation and contributing to sustainable industrial development (Santos et al., 2014; Araujo et al., 2021; Grangeia et al., 2020; Motta Reis et al., 2021).

Quality control can be defined as a part of quality management and business management, which is vital in almost all industries. Quality control is the process of analyzing, controlling, and managing all factors involved in the production that affect the product quality process while achieving uniformity of output that satisfies specific customer or user requirements (Barbosa et al., 2020, 2022; Bravi et al., 2019; Krotov & Mathrani, 2017; Sá et al., 2023). This involves inspecting products to ensure that the products conform to quality standards and that the work is being done correctly. Quality control can ensure consistency in production and that every product leaving the factory is of the highest quality. (Febriani et al., 2020; Salido et al., 2016; Suharno & Zagloel, 2019;Yülek & Santos, 2022; Craveiro et al., 2023).

Quality management brings with its optimizations for processes, evaluating their performance and improving their production line, whether in material use or in the manufacturing time of a product, in the work team, and in several other areas. But, it takes a high level of effort to apply quality management to a company, since it is a drastic change in the production line (Cardoso et al., 2022; R. Chen et al., 2020; Maged et al., 2019; L. Wang et al., 2017). There are many tools in quality management, such as Failure Mode and Effect Analysis (FMEA), Ishikawa diagram, Histogram, Pareto chart, Control chart, and many other tools available to improve the quality area of a company (Kleymenova et al., 2021; Maged et al., 2019; Suárez-Barraza et al., 2021).

According to the context of the quality tool applications, the paper presents three main research questions: using FMEA, is it possible to verify the needs in the design of a new cabin assembly equipment? With the use of this tool, is it possible to identify improvements in cabin capture devices? Is there still a possibility to avoid accidents and facilitate the interchange of parts with the use of this methodology? To answer these questions, this work has the objective of offering an analysis of the failure modes of the cabin air transporter, currently on the production line, in an automotive company in the Sul Fluminense region (where the study was developed), to provide actions for better future acquisitions of equipment, with more selective parameters, to verify the importance of the use of the FMEA tool in an automotive company to evaluate and analyze potential problems, through a cross-functional team, and to propose improvement actions for the new equipment and reduce the risk of its failure. This need is justified due to the economic and social importance of companies and their physical and organizational characteristics.

2. THEORETICAL FRAMEWORK

The development of products, over the years, went from handicraft culture to industrial, then to modern manufacturing, responding to the demand for large quantities with a concern to insert quality into these products (Costa et al., 2019; Sales et al., 2022; Talapatra et al., 2019). The manufacturing industry deals with different challenges to manage the complexity of the production process due to the demand for the diversity of products offered to customers (Klochkov et al., 2019; Matytsin & Rusakova, 2021; Silva et al., 2021).

A distinction is made between two perspectives with the regarding quality assessment in vehicle assembly. Product quality is concerned with the quality of a single component or vehicle, whereas production quality describes the efficiency of the process through to complete product quality - production quality is a conditional part of product quality (Bisbis et al., 2018; G. Popkova, 2020; Gomes et al., 2022; T. Wang et al., 2018). Consequently, a high level of production quality must be ensured to achieve high product quality without incurring extraordinary quality costs or defect costs. For this process to be reliable, a minimum of faults must occur during the assembly of the vehicle on the production line (Gewohn et al., 2018; Yan et al., 2019; Zhang et al., 2019).

In this scenario, a differentiated tool to minimize these potential failures before they happen is the FMEA, which supports the design process in reducing failure risks, being able to outline the dominant process problems so that improvement can be applied. It is useful to identify current and potential failures and their effects on systems and processes to define actions to reduce or eliminate the risk associated with each failure (Fattahi & Khalilzadeh, 2018; Ishak et al., 2019; Liu et al., 2019). This method assesses the severity of each failure relative to the impact caused to customers, its probability of occurrence, and its probability of detection before it reaches the customers' hands. Based on these three elements, severity, occurrence, and detection, the method leads to the prioritization of which failure modes carry the greatest risk to the customer (Arabsheybani et al., 2018; Mislan & Hardi Purba, 2020; Peeters et al., 2018). FMEA tools have become standard practice in companies in countries all over the world, in sectors ranging from aerospace, and electronics to automotive, it is also used in the food industry, the energy sector, and medical and pharmaceuticals. (Ishak et al., 2020; Mascia et al., 2020).

The application of an FMEA is vital for the development of new production-related equipment within an automotive industry to identify failure modes, their effects, and their causes before purchasing them, always trying to anticipate problems. In addition, the QS 9000 and ISO TS 16949 quality manuals require that automotive industries apply the FMEA throughout their entire production chain. (Bravi et al., 2019; Fonseca & Domingues, 2018; Nina & Hakim, 2020; W. Wang et al., 2018). Failure Mode and Effects Analysis is used in according to ISO 26262 to improve product quality. Through the application of the methodology learned from the FMEA standard, one can compare different variants of the prototype from an early concept phase and decide which design features will best fit the intended system requirements (Bahig & El-Kadi, 2017; Barbosa et al., 2022; Henriksson et al., 2018). The used method is a comparison of some types of car holder designs that is not limited to design only. Manufacturing and material are also discussed and compared. The method has applicability for the early product stage if it is conducted responsibly and documented accordingly (Febriani et al., 2020; Maftei et al., 2020; W. Wang et al., 2018).

3. RESEARCH METHOD

In this work, action research was developed because it refers to a process of change, based on the systematic collection of data, followed by the selection of a changing action, based on what the analyzed data indicate. Its importance lies in offering a scientific methodology for the management of a planned change (Kothari & Garg, 2019; J. S. D. M. Reis et al., 2020; Sampaio et al., 2022).

Regarding the approached method, in addition to analysis, interpretation, and data survey, a proposal of improvement actions for the problems of the studied company was carried out, together with its employees. Besides the FMEA principles, the 5W1H and Ishikawa diagram tools were used to support the case study. The study was conducted in a vehicle assembler in the Sul Fluminense region of Rio de Janeiro, which delimited the application of the FMEA method with the objective of raising the failure modes of one of the main equipment of the assembler, the vehicular cabin air transporter.

Figure 1 shows a top view of the vehicle cabin aerial transport process. This process consists of hoisting the cabin on Line 1 at point A and starting decking at point B on the same line. On Line 2, the assembled vehicle chassis returns empty from point C to Line 1.

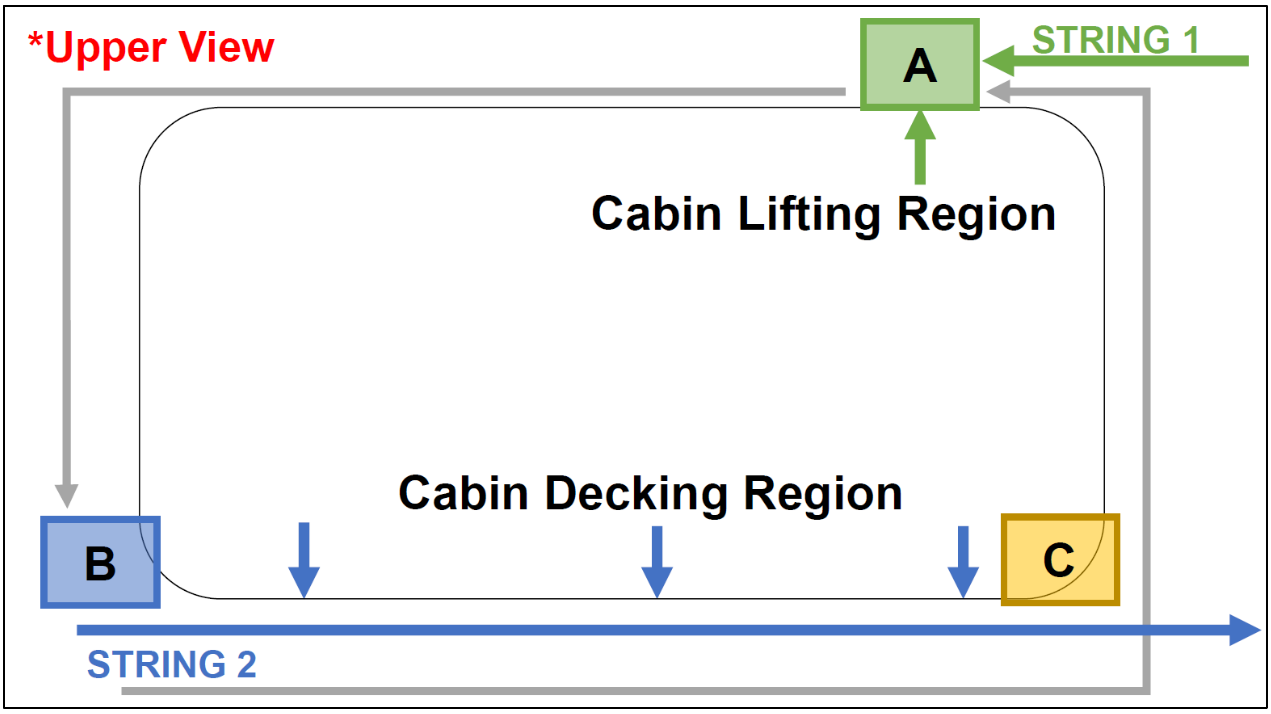

Figure 1. Schematic of the operation of the cabin conveyor on the production line

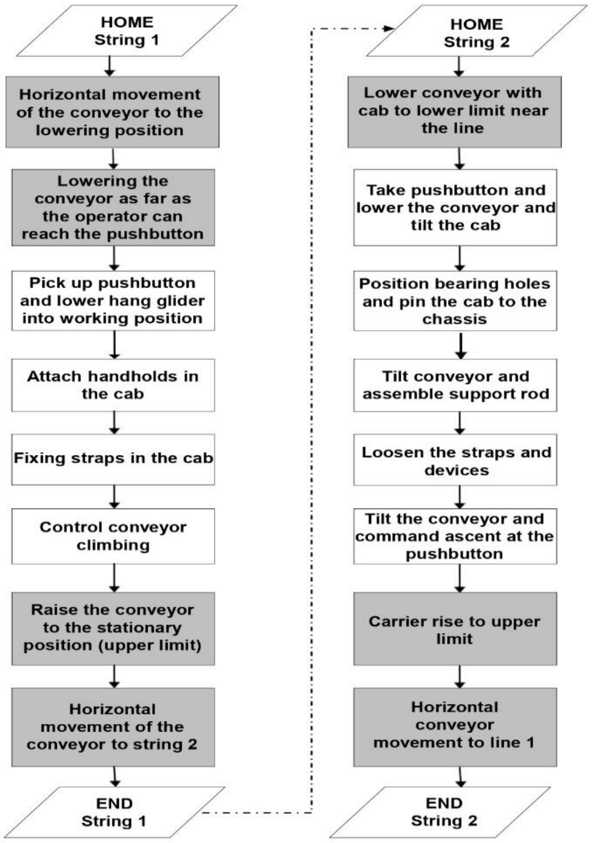

Figure 2. Flowchart of the vehicular cabin air carrier

Figure 2 shows the complete flowchart of the vehicular cabin air transporter. The blocks in gray indicate the automatic operation of the equipment and the blocks in white indicate the intervention of the employee on the equipment.

The application of the method was started with the choice of the participants who had more knowledge about the equipment from the areas of maintenance, safety, ergonomics, process, production, operation, and installation. In the first step, a block diagram of the equipment was prepared by the brainstorming tool, delimiting the most critical components of the equipment, which would be introduced by the FMEA method, as shown in Figure 3.

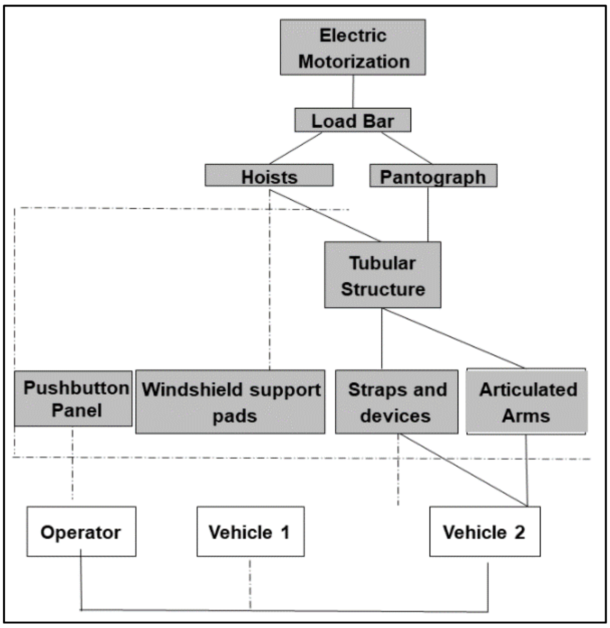

Figure 3. Equipment block diagram

The components of the cabin transporter were marked out after being analyzed. They were identified as: tubular structure, the buttonhole, the windshield support pads, the belts, the articulated arms, and the devices. In the second step, the unstructured brainstorming tool was used, where questions were raised about the problems faced by the cabin transporter. The data generated through brainstorming were grouped in an Ishikawa diagram, as shown in Figure 4.

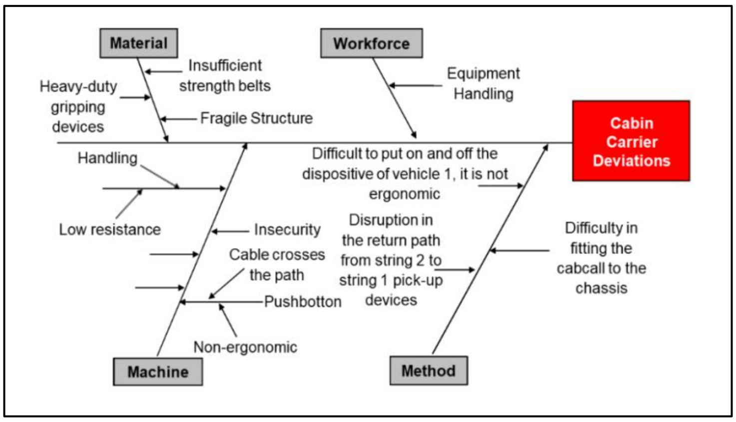

Figure 4. Ishikawa Diagram with causes raised by Brainstorming

In the last steps, the FMEA form was filled out by the company's internal team, based on the Automotive Quality Institute-IQA FMEA Reference Manual. The information related to function, potential failure mode, and potential failure effects were filled in with the information gathered in the previous steps. Next, the severity was estimated by the FMEA based on the failure effects on a scale of 1 (one) to 10 (ten). The evaluation criteria for rating the estimated severity are shown in Table 1.

Table 1. FMEA Severity Index

Effect	Criterion: Severity of Effect	Rating
Dangerous without warning	Very High Severity Rating - when a potential failure mode affects the safe operation of the vehicle and/or involves non-compliance with government regulations; no warning.	10
Dangerous with warning	Very High Severity rating when the potential failure mode affects the safe operation of the vehicle and/or involves non-compliance with government regulations; with warning.	9
Very high	Vehicle / item out of operation, with loss of primary function.	8
High	Vehicle / item in operation, but with degraded performance level. Dissatisfied customer.	7
Moderate	Vehicle / item in operation, with Comfort / Convenience items out of operation. Client faces a situation of discomfort.	6
Low	Vehicle / item in operation, but with Comfort / Convenience items at a degraded performance level. Customer experiences some dissatisfaction.	5
Very Low	Finish and Seating / Noise Reduction items are not in compliance. Defect observed by most customers.	4
Lower	Finish and Settlement / Noise Reduction items are not in compliance. Defect observed by average customers.	3
Much smaller	Finish and Settlement / Noise Reduction items are not in compliance. Defect observed by certain customers	2
No	No effect.	1

In Table 2, the respective product characteristics were broken down as critical character "D" or significant character "S", which required additional design or process control. However, it is necessary to note that the critical characteristic is the one that affects safety and/or legislation, and the significant characteristic is the one that causes strong impact on the customer and defines the potential cause of failure, which is summarized as a design deficiency, the consequence of which is the failure mode. After this step, the classification of the probability of occurrence of a failure during the life of the project was established on a scale from 1 (one) to 10 (ten), as shown in Table 2.

Next, the current project controls were broken down by listing the activities to prevent the occurrence of the cause/failure mechanism, the failure mode, or the activities to detect the cause/failure mechanism or the failure mode by both analytical and physical methods before the item was released for production.

Table 2. FMEA occurrence rate

Probability of Failure	Possible Failure Rates	Ratin g
Very high: failure is almost inevitable	≥ 1 in 2	10
	1 in 3	9
High: repetitive failures	1 in 8	8
	1 in 20	7
Moderate: occasional failures	1 in 80	6
	1 in 400	5
Low: relatively few failures	1 in 2000	4
	1 in 15000	3
Remote: failures are uncommon	1 in 150000	2
	≤ 1 in 1500000	1

Table 3. FMEA Detection Index

Detection	Criterion: Expected Detection by Project Control	Rating
Totally uncertain	Project Control will not detect and/or cannot detect potential cause/mechanism and subsequent failure mode; or there is no Project Control	10
Very remote	Very remote chance that Project Control will detect cause / mechanism and subsequent failure mode	9
Remote	Remote chance that Projects Control will detect cause / mechanism and subsequent failure mode	8
Very low	Very low chance that Project Control will detect cause / mechanism and subsequent failure mode	7
Low	Low chance that Projects Control will detect cause / mechanism and subsequent failure mode	6
Moderate	Moderate chance that Projects Control will detect cause / mechanism and subsequent failure mode	5
Moderatel y high	Moderately high chance that Project Control will detect cause / mechanism and subsequent failure mode	4
High	High chance that Projects Control will detect cause / mechanism and subsequent failure mode	3
Very high	Very high chance that Project Control will detect cause / mechanism and subsequent failure mode	2
Almost certainly	Design Control will almost certainly come to detect potential cause / mechanism and subsequent failure mode	1

Thus, it was possible to evaluate the ability of design control to detect the cause/mechanism and failure mode. The detection index in the FMEA design can vary from 1 (one) to 10 (ten) and the evaluation criteria suggested for the detection classification are in Table 3.

After severity, occurrence, and detection analyses, the Risk Priority Number (RPN) was found, which is calculated by the product of the severity, occurrence, and detection indices and established priority orders for taking preventive actions. The cut-off score determined by the FMEA project team for the need of a recommended action to minimize risk must be equal to or greater than 70. After the items are determined, a defined prioritization action is required for them, following an order from the highest severity, occurrence, and detection indices. The completion of the FMEA spreadsheet, followed by the nomination of the responsible for the action and the deadline for its execution, and a 5W1H checklist was prepared to allow a better visualization of the actions to be taken.

4. RESULTS AND DISCUSSIONS

Through the presented methodology and development, the FMEA form was filled in with the failure modes and effects, causes and controls, including severity, occurrence, and detection classifications, as presented in Table 4 (attached). Following the procedures internally adopted by the FMEA project team on the need for action, it was observed that all items will need a recommended action since their respective NPRs resulted in values greater than 70 (seventy).

According to IQA's FMEA Reference Manual, the focus of prioritization was based as follows (as per Table 4, Annex): failure modes with the highest severity between 10 and 9, whose cells were highlighted in red; failure modes with severity 8 (orange cell), 7 (yellow cell) and 5 (green cell), with causes that had the highest occurrence ratings 10, 9 and 8. The prioritization was adopted by the team to better serve the company and internal customers, maintaining a priority order of severity, occurrence and detection in a standard. Chart 4 will be presented on the last page after the References because it needs more space to be visualized. After completing the FMEA, a 5W1H checklist was prepared with the recommended actions for better visualization of the actions that need to be considered for the development and acquisition of the new equipment as presented in Table 4.

Table 4. Prioritization of recommended actions 5W1H

Prioritization of Recommended Actions - 5W1H				
Engineering structural calculation analysis	Analyze the structure of the articulated arm and the dimensions of the cabin bearing	To check for dimensional compatibility and avoid not reaching the correct position	In loco	Engineering
New design: eliminate handle auxiliary means or create transportation point on the equipment itself	Design a new device that is fixed to the conveyor	To avoid the transport of this device by the operators from line 2 to line 1 for reuse	Plant Engineering	Engineering
Change design of gripping device, looking for new place to fix it in the cab	Design a more practical and lighter device to attach to the cab	To facilitate the ergonomics of the operator's work and gain process agility	Plant Engineering	Engineering and Facilities Team
Test with commercial lock from a specialist supplier in the region	Test the cab lifting with another belt to ensure the safety of the activity	To prevent the belt from opening and causing some incident or accident	In loco	Maintenance
New project: communicate and standardize parts to manufacture interchangeability of parts	Together with maintenance, investigate the possible communication of components between cabin conveyors	To facilitate the interchangeability of parts and increase equipment availability	In loco	Engineering and Maintenance
Change the design of the support point of the vehicle 1 cabin on the conveyor by eliminating the cushion	Design another way to support the cab windshield of vehicle 1 when tilting the cab	To eliminate the conveyor cushion that generates a lot of inconvenience for the product and the process.	Plant Engineering	Engineering and Facilities Team
Create buttonhole support point in new design	Investigate a specific location for the buttonhole on the conveyor itself	To prevent the buttonhole cable from getting tangled in the route and damaging the cabin.	In loco	Engineering and Facilities Team

5. CONCLUSION

It was concluded that, with the use of the FMEA, it is possible to interpret the needs in the design of new equipment for the plant such as improvements in the structure of the equipment, where the plant would have a more resistant and easy to assemble equipment, which meets the increase in production demand expected by the plant; improvements in the cabin capture devices that need to be easier to handle, fit and, if possible, be coupled to the equipment itself eliminating the operator's work of searching for the cabin in line 2 to be coupled to the conveyor in line 1; have more resistant belts in the conveyor to avoid incidents or accidents with possible ruptures, which would cause the cabin being transported to fall; communication of equipment components facilitating the interchange of parts; need for a support for the hoist buttonhole, and elimination of the cushions that serve as support for tilting the cabin of vehicle 1. Therefore, it is feasible to apply the FMEA in a beneficial way for the entire cabin transporter plant, enabling the acquisition of new equipment with design improvements, reducing existing flaws in the production line and thus avoiding rework and financial waste for the company.

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