1 Introduction

In the manufacturing industrial scenario, the automotive industry stands out as one of the largest in the world, being responsible for the production of millions of new vehicles every year. Therefore, functional machinery safety in the production of these vehicles has always been a concern for their manufacturers. The automotive industry's production chains are considered critical from the perspective of functional safety [1], as the process has highly robotized lines. In addition, the complexity of these processes has increased considerably in terms of new technologies to make them increasingly flexible.

According to [2] one of the objectives of the functional machinery safety standards is to provide reference values (thresholds) for the probability of the occurrence of failures, which, when observed, allows to verify that the system is "safe". This objective is similar to the definition of functional machinery safety given by [3], where the safety requirements describe the characteristics that a system must have to be considered safe. Functional machinery safety is achieved by reducing the risk to an acceptable or tolerable level and can be seen as an extension of the reliability technology [4] with the development of equipment and with the direction of information and intelligence.

Functional machinery safety also addresses existing cases of severity and hazards and uses techniques such as redundancy and diagnostics [5] to avoid the consequences of failure on equipment. Accidents and injuries are the main products of bad management of functional machinery safety. In addition, more impacts and additional costs with technical and human resources may arise as a result of this deficient safety management. With this, the need arises to accurately identify possible failures related to machinery and equipment and to check what are the requirements that must be met for better safety management, minimizing the risk of accidents.

This article aims to raise elements of the relationship between accidents and functional machinery safety in a Brazilian subsidiary of a French automotive company. By relating these elements with data from the company, it is possible to identify safety flaws that are related to problems in Functional Machinery Safety Management (FMSM), making it possible to identify the root of accidents and check if they are caused due a deficient safety management, poorly sized protective equipment or other aspects (cultural, unsafe acts, negligence).

2 Methodology

The development structure of this work is carried out in three main parts, which are: (i) literature review, (ii) development and data collection and (iii) analysis of the results and final considerations. The first part, literature review, focuses on investigating and conceptualizing the domain related to the machinery safety management and the evaluative space established by the data obtained about work-related accidents.

In order to identify the cause of accidents and their correlation between failures in machinery safety, from the perspective of the safety management, it is necessary to determine the origin of accidents and the circumstances under which they occurred. Therefore, aspects related to the evolution and culture of accident prevention are contextualized.

The second part it is collecting and processing data on accidents that have occurred, based on a quantitative and periodic data collection. Subsequently, the data obtained are subjected to a diagnostic analysis to structure and classify what are the types of recorded accidents, their severity and what caused them. The data comes from accident reports recorded weekly by the company's safety department.

The third part is dedicated to the analysis of the results and the final considerations on the analysis performed and the results obtained, concluding on the strong relationship between FMSM and human factors involved. The proposed methodological approach is presented (see Fig. 1).

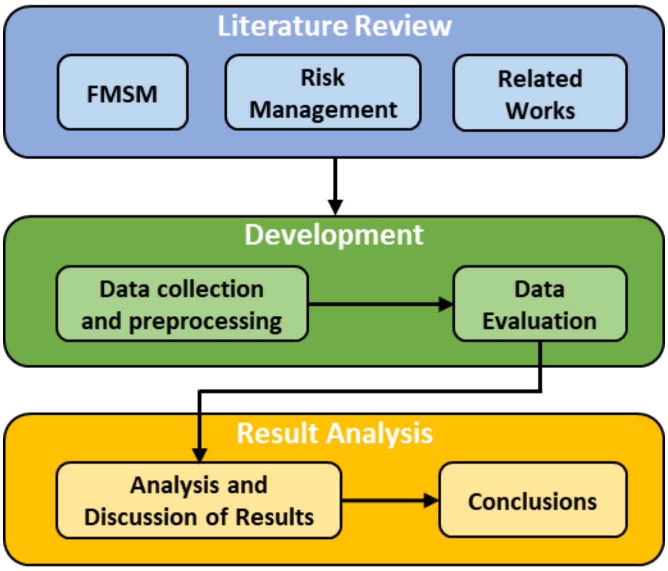

Fig. 1. Methodological structure followed by the paper.

3 Literature Review

According to [6], safety can be defined as the absence of risks for factory employees or the public. Ideally, safety would be guaranteed if all risk is eliminated. However, considering that there will always be some risk, safety is achieved by reducing the risk to a level considered acceptable or tolerable.

3.1 Functional Machinery Safety Management (FMSM)

To [6] the functional machinery safety is part of the general safety that depends on the correct functioning of the equipment, process or machine, that must have been correctly designed and installed guaranteed by an assessment of risks. The safety-related parts of the equipments must perform their functions correctly, and keep the equipment (or system) safe, or enter a safe state when a failure occurs [5].

The concept of functional safety is given by the International Electrotechnical Commission - IEC 61508 published and revised in 2000 and 2002, respectively, being adopted as a basic functional safety standard by many countries and industries [2]. A IEC 61598 uses a general safety lifecycle as a technical framework for safety-related systems to achieve the safety integrity level (SIL) required for safety functions [7]. The performance criterion for functional machinery safety is only applicable to safetycritical equipment and / or safety-related functions [8].

The most basic concept in functional safety is the safety function. A safety function defines an operation that must be performed to obtain or maintain safety. A typical safety function contains an input subsystem, a logical subsystem and an output subsystem [9]. The safety function is a design function, while the safety integrity is the probability that the safety-related system will satisfactorily perform the necessary safety function considering all established conditions and within the indicated period of time. [10].

The time from the unsafe state to the safe state is critical. A safety function can, for example, consist of a sensor to detect that a machine guard is open, allowing a PLC to process the data and act in time on a drive with a safe torque input that stops a motor from operating before something been inserted in the moving parts [11].

Functional safety addresses the confidence in which equipment will perform its safety function when needed. Thus, there is an active form of safety, in contrast to the others. In your research,[11] gives an example of the situation of an engine that shuts down quickly enough to avoid damage to an operator who opens a guard or a robot that must operate at reduced speed and strength when a human is near. According to [12], the functional safety standards provides guidelines for identifying desired performance and managing the protection system throughout the safety lifecycle, covering the specification, design, implementation, installation, commissioning, operation, maintenance, modifications and deactivation activities associated with the protection system.

3.2 Risk Management

The activities inherent to human beings, since the beginning, are intrinsically linked with a potential for risks. And, relatively often, they result in injuries, temporary or permanent damage to the ability to perform tasks and deaths It was with the emergence of the first industries that work accidents and occupational diseases spread, taking great proportions. Improvements came with specialized and trained workers for handling equipment that needed special care to ensure greater protection and better quality [14].

The FMSM and work safety must act in a joint and complementary manner, in order to minimize the risks of accidents and guarantee the functionality of the machines and equipment [15]. Accidents, whether or not causing injury to the worker, negatively influence production through loss of time and other consequences such as: material losses, decreased efficiency of the injured worker on returning to work, increased labor renewal, increased premiums accident insurance and employee morale affected [13].

As the concern about repairing the lesions increased, scholars such as H. W. Heinrich and R. P. Blake, pointed out another approach [16]. They indicated the importance of actions aimed at preventing accidents before they became a concrete fact. The engineer H. W. Heinrich in his studies reached the following proportional result: 1: 29: 300, that is, 1 disabling injury for 29 minor injuries and 300 accidents without injuries, this proportion gave rise to Heinrich's pyramid [16]. Expanding these studies, engineer Frank E. Bird Jr., analyzed accidents in 297 companies, representing 21 different industry groups with more than 1,750,000 workers, reaching a ratio of 1: 10: 30: 600. One disabling injury, 10 minor injuries, 30 property damage accidents and 600 incidents [17].

From these relations 1-10-30-600 it is possible to conclude that the action effort must be directed towards the base of the pyramid and not only to the events resulting in serious or disabling injury [16]. This is because, major injuries are rare events and therefore, many opportunities for learning about prevention are available in less serious events, especially incidents, first aid and unsafe acts [18]. A study carried out in 2003 showed a large difference in the proportion of serious accidents and near misses, finding that for each death there are less than 300,000 risky activities[17]. Risk management is defined as a methodology that aims to increase confidence in an organization's ability to predict, prioritize and overcome obstacles in order to achieve its goals as a final result [14].

Work safety, in order to be assimilated as a prevention of accidents in the industry, must be concerned with the preservation of the physical integrity of the worker, but it must also be considered as a factor of production (risk impact) [15]. It is understood, therefore, that efforts in an attempt to eliminate, reduce, control or even finance the risks, if economically viable, are of paramount importance for the healthy development of a company [19]. Risk management can also be defined as a formal process, as the present uncertainties are systematically identified, analyzed, estimated, categorized and treated. In this way, it aims to balance the results of profit opportunities with the minimization of losses, allowing the continuous improvement of the decision process and the increasing improvement of the organization's performance [20].

4 Development

In order to understand the nature of accidents, it is necessary to consult the recorded accident historical. Subsequently, it was necessary to gather all the data collected and eliminate data related to incidents and risk situations, leaving only the cases of actual accidents, that is, where there was at least one victim. This data includes information about company accidents, what is the frequency of accidents, what are the risks involved, if similar accidents are repeated and by what factors. This makes it possible to group accidents and classify them, either according to their nature or severity.

4.1 Data collection and pre-processing

The data query was made through a data history of accidents that occurred, formed by daily records. The accident record is released weekly and takes place in the form of a Daily Safety Dialogue (DSD), which must document any accident occurring within 24 hours at the latest. The DSD describes information such as the location of the accident, its date, how it happened, its severity and the preventive measures taken in this regard. According to the company's internal rules, corrective measures must be applied immediately, according to the hierarchy of preventive measures adopted by the company.

In the format in which the data were recorded and collected, classic concerns about data collection and pre-processing such as problems with incomplete data, data duplicity, lack of standardization and data veracity (bias, noise and abnormalities) [21] have not been identified. During the 28-week period of data collected, 40 accidents and 5 incidents occurred. Therefore, it was not necessary to minimize the data collected.

4.2 Analyze

The analysis of the accident and the identification of the root causes must be carried out after its occurrence, with a deadline of one week. The analysis of the company's accident causes follows an internal standard established in a way that classifies the accident according to the type of contact that occurred, the immediate causes, the basic causes / roots and the prevention programs (nonexistent, not fulfilled, with information missing or poorly described). The immediate causes are subdivided into two groups, which are when acts are below standard, and conditions are below standard. Substandard acts are characterized by unsafe behavior or unsafe acts committed by the collaborator, being the total or partial cause of accidents or incidents. Sub-standard conditions are defined as conditions that generate or increase risks in the workplace, not allowing the employee to perform his function safely. These conditions (substandard) can be the total or partial cause of an accident or incident.

The basic causes (or roots) are subdivided into two groups, which are related to human factors and labor factors. Human factors include aspects such as: physical/physiological capacity, mental/psychological capacity, mental/psychological tension, lack of knowledge, lack of skill and poor motivation. Regarding work factors, the following factors are considered: leadership and/or supervision, engineering, logistics, maintenance, equipment and tools, work patterns and abuse or mistreatment.

Accidents that have occurred can be correlated with a bad FMSM, either due to failures in protective equipment installed on machinery and equipment or poorly installed or dimensioned protective systems and equipment. However, accidents can be related to human factors, unsafe, ergonomic acts, unsafe conditions at the workplace and even equipment failures that are not automated and do not have any protection system. Considering this, it is evaluated what caused the accident and who is responsible for it. The classifications for the reasons for the accidents were made as follows: Unsafe acts, equipment failure (automated), equipment failure (nonautomated), ergonomics problems and failures in the operating procedure.

For the classification of accident liability, the following factors were considered: Operator, workstation/unsafe working condition, problems with Personal Protective Equipment (PPE) and problems with machine/equipment protection systems. Regarding the classification of the severity of the accident, the company adopts the following classification: FR0 - Accidents where there is a visit to the outpatient clinic and an occupational accident communication document is issued. FR1 - Any accident related to work activity that is characterized by the following conditions: amputation, avulsion, concussion in the head, fracture or dislocation, cut, nonsuperficial burn, electric shock injury, exposure to products or substances harmful to the organism, choking, temporary hearing loss, fainting or loss of consciousness, eye damage or hernia. FR2 - Accidents with leave from work for more than 24 hours. According to internal company standards, fatalities must be counted separately, not as FR1.

5 Results

Considering the data collection in the 28-week period, Fig. 2 presents a graph related to the reasons for accidents that occurred in that period. It is evident that most accidents are related to unsafe acts, that is, any behavior or conduct that, from an unnecessary decision, can generate problems in the workplace or accidents. Next, there are problems related to the workplace, which are characterized by aspects ranging from poor hygiene or poor organization, to aspects related to equipment wear and lack of maintenance, leaving the workplace unsafe for employees perform their tasks in a functional and safe way. As the third place in the reasons for accidents, there is a failure in non-automated equipment, that is, equipment which does not have or cannot have protection systems installed. Most of these equipments are hand tools used in the workplace to assist in the performance of functions, they are tools such as hammer, wrenches, screwdrivers, pliers, etc.

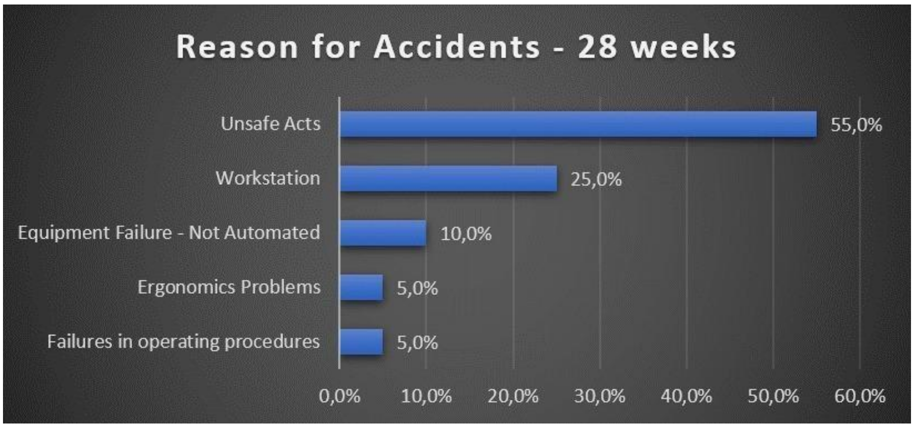

Fig. 2. Graph of the reasons for accidents that occurred in the company over the 28-week period.

Figure 03 shows a graph related to the liability of the accidents that occurred, that is, who or what was responsible for causing the accident and about who is to blame. Most accidents are related to the employee, when associating this with the main reason for the accidents (shown in Fig. 2), it is evident that the employee is the biggest culprit for committing unsafe acts and increasing the risks, causing the accidents. Secondly, regarding the fault of accidents, the position is of problems at the workplace and of unsafe conditions, that is, the employee was not to blame directly, as it was another situation at the workplace that caused the accident, which can be tool failure, equipment failure, lack of maintenance, cleaning problem, poor storage of parts and equipment.

Fig. 3. Graph of the liability for accidents that occurred in the company over the 28-week period.

Fig. 4 shows a graph regarding the severity of accidents. Most correspond to accidents at level FR0, which are accidents considered mild, where there was only passage through the clinic. Secondly, regarding the severity of accidents, there are FR1 level accidents, which are more serious accidents that may or may not result in longer absences.

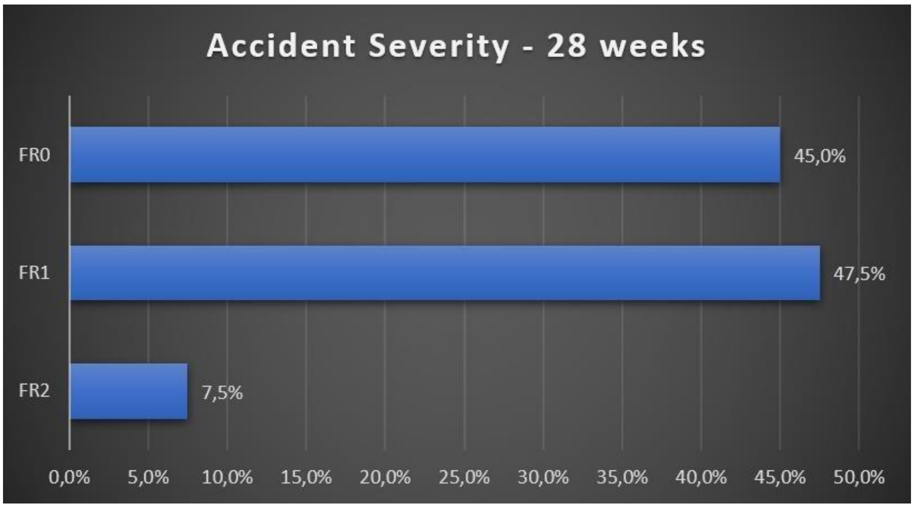

Fig. 4. Graph of the severity of accidents that occurred in the company during the 28-week period.

5.1 Conclusion

With the growing culture of accident prevention and safety of machinery and equipment in the industry, there is a need to know the nature of the aspects that cause accidents within the company. At first, this research addresses the importance of functional machinery safety and consolidates the approach to the culture of preventing work accidents within the factory environment. The result obtained in this research was expected and consistent with the reality, as the internal and external safety audits carried out on the automated machines and equipment measure the level at which security is found and guarantee the standard, making adjustments if necessary. It is evident that the company is adequate in the technical part of safety engineering and in reaching the fulfillment of technical standards that regulate the level of safety of the installations of the systems and protective equipment on the machines. However, the high levels of insecurity related to work accidents and the high incidence of problems in the workplace reinforce a cultural and behavioral failure in preventing accidents. Even with a high policy aimed at accident prevention, programs and information campaigns on safety work, most accidents are due to an unnecessary and negligent risk exposure from the employee himself when he behaves in an unsafe manner, increasing the risks . On the other hand, the part that competes with FMSM is being well attended, ensuring the safety and performance of safety equipment when necessary. The results obtained allow us to assess the quality of the FMSM and define the best direction for accident prevention in the company.

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