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FMEA APPLIED AT SAFETY WORKS MANAGEMENT – A CASE STUDY

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ABSTRACT

This paper presents a method that aims to put the management of occupational hazards in optimization models of production processes. The use of the proposed tool seeks both to reduce the frequency with which accidents happen as to minimize the severity of these accidents. The tool also assesses the probability of potential accidents aiming to reduce them. The genesis of this work is an issue of practical research, which seeks the interaction of production and safety, where he implemented the FMEA tool (Failure Modes and Effects Analysis) with the focus on the management of occupational hazards, under the mapping production flow. The activity was considered the modification in a cutting plasma area in a metallurgical company. The application of FMEA tool focused on safety was conducted following methodological procedures for the use of the tool by applying risk analysis concepts aimed at eliminating the causes that could potentially result in accidents. Finally, it was found that the integrated approach using this quality tool with focus on security is a viable alternative for organizations that seek to evaluate the various failure modes that may occur during a process, may cause accidents to workers, so the use of the tool can evaluate the risks and prevent accidents.

Key Words: FMEA. Occupational Safety. Risk Management.

1 INTRODUCTION

"The company has the obligation to adopt risks control measures that may affect directly or indirectly the safe and health of the worker". (Brazilian Ministry of Labor and Employment, 2016).

This way it is necessary to perform for each activity a risk analysis to identify the risks and the control measures to minimize or eliminate this risks.

The risk analysis it is a systematic method of examining and evaluation all the steps and elements of a determined work to develop and rationalize all sequences the worker performs, identifying the potential risks of accidents that may cause damage to workers or property, written by Muniz (2011).

Therefore it is a critical tool of the activity or situation, with great utility to identify and prevent undesirable events, making possible the adoption of measures to prevent the safe and health of the worker.

The problem to be solved is an improvement in the occupational safety and health management through implementation of a quality tool with focus in safety, to improve the detection level of failure in the process, decreasing the probability of occurrence accident rate and occupational diseases, with the goal of introduce the FMEA (Failure Modes and Effects Analysis) concepts applied to safety, evaluating the benefits arising from its application. The FMEA with safety focus should prevent the occurrence of failures/risks that could potentially cause accidents. For that, a methodology is developed a methodology that allows analyzing and conceive actions that act preventively about the possible causes of accidents in a productive process.

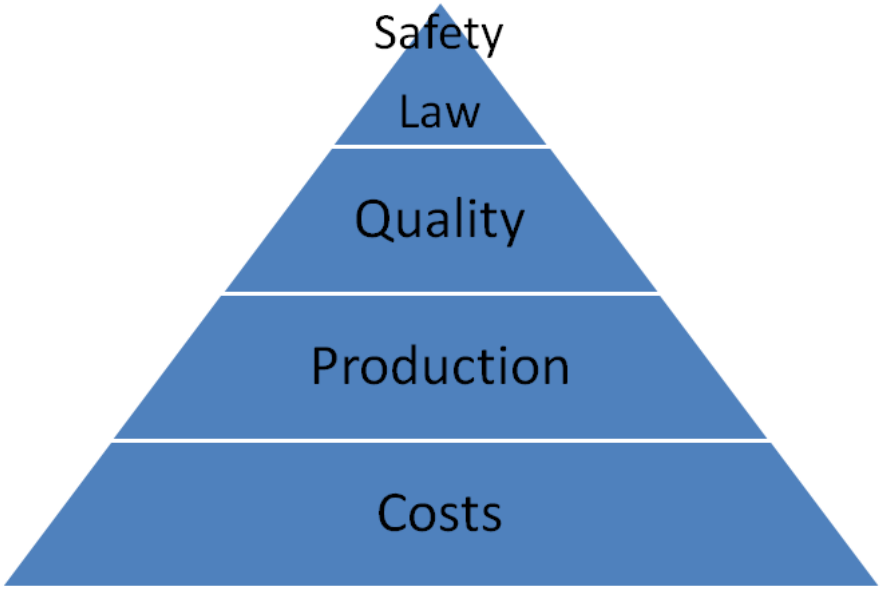
1.1 THE APLIED STUDY FIELD INDUSTRY: MAXION CRUZEIRO

The company analyzed is active in the automotive segment, divided into: Maxion Wheels that is world leader in wheels productions automotive and off-road wheels, Maxion Structural Components which is one of the main producers of automotive structural components in the Americas. (Maxion, 2016)

The Safety and Health system of the Cruzeiro plant has certified OHSAS 18001 granted by *Bureau Veritas Certification.* It is an effectively implemented system that permanently seeks the best practices among its daily activities of product manufacturing, aiming to guarantee the well-being of its direct or indirect employees, thus ensuring the operational continuity of the company.

The company has a pyramid of decision hierarchy, as shown in the picture 1.

Picture 1: Pyramid of Decision Hierarch



Source: Maxion Manual, 2016

2 MANAGEMENT AND ANALYSIS OF HAZARD AND RISK

> All Activity in a company has included risks that must be managed. The process of management of risks assist the making decision, taking into account the uncertainties and the possibilities of circumstances or future events (be intentional or unintentional) and the effects on the agreed objects. (ABNT NBR ISO/IEC 31010:2012)

The company is responsible for manage its risks by proposing preventive measures to neutralize or eliminate such risks

“The Risk Analysis involves two steps: Qualitative evaluation, in this step the risk is identified, described and estimated, and the quantitative evaluation the risks are measured and then treated”. (Muniz, 2011)

The process of qualitative risk analysis is the process of evaluation the impact and the probability of the identified risks. This process prioritizes the risks in accordance the potential effects of them.

The quantitative analysis the risk has the objective perform a numeric analysis of the probability of each risk and their respective consequence, through a risk survey attributing values to each consequence, identifying the more serious risks, it is prioritized in the process of risk control.

Therefore, in the risk analysis leaves registered all the types of hazards and risks existing in a workplace, as well the preventive measures and control to minimize or neutralize the exposition of the worker to these risks.

To start an effective risk analysis program, the following questions are usually posed: Which level ensure the worker safety? What makes a safe task? The processes ensure the safety of the worker?

The process of risk analysis allow obtain answers to each questions, identifying the potential risks (or hazards), determining the probability of this happen (the frequency) qualifying and quantifying the consequence (Severity).

“Risk is the combination of the probability of occurrence of a hazardous event or exposure with the severity of the injury or illnesses that may caused by the event or exposure” (OHSAS 18001:2007).

The standard define that “hazard is a source or situation or an act with potential to cause damage to worker, or a combination of them. (OHSAS 18001:2007).

The risk management is the systematic application of policies, procedures and practices for the establishment of contexts for the identification, analysis, evaluation, monitoring and communication of risks. (AS/NZS 4360:2004).

This evaluation allows determine the origin, the nature and the effects of the risks, making possible the adoption of risk measures control that must be developed from the planning, leading to possible elimination of risks or the reduction of them an acceptable levels through engineering measures.

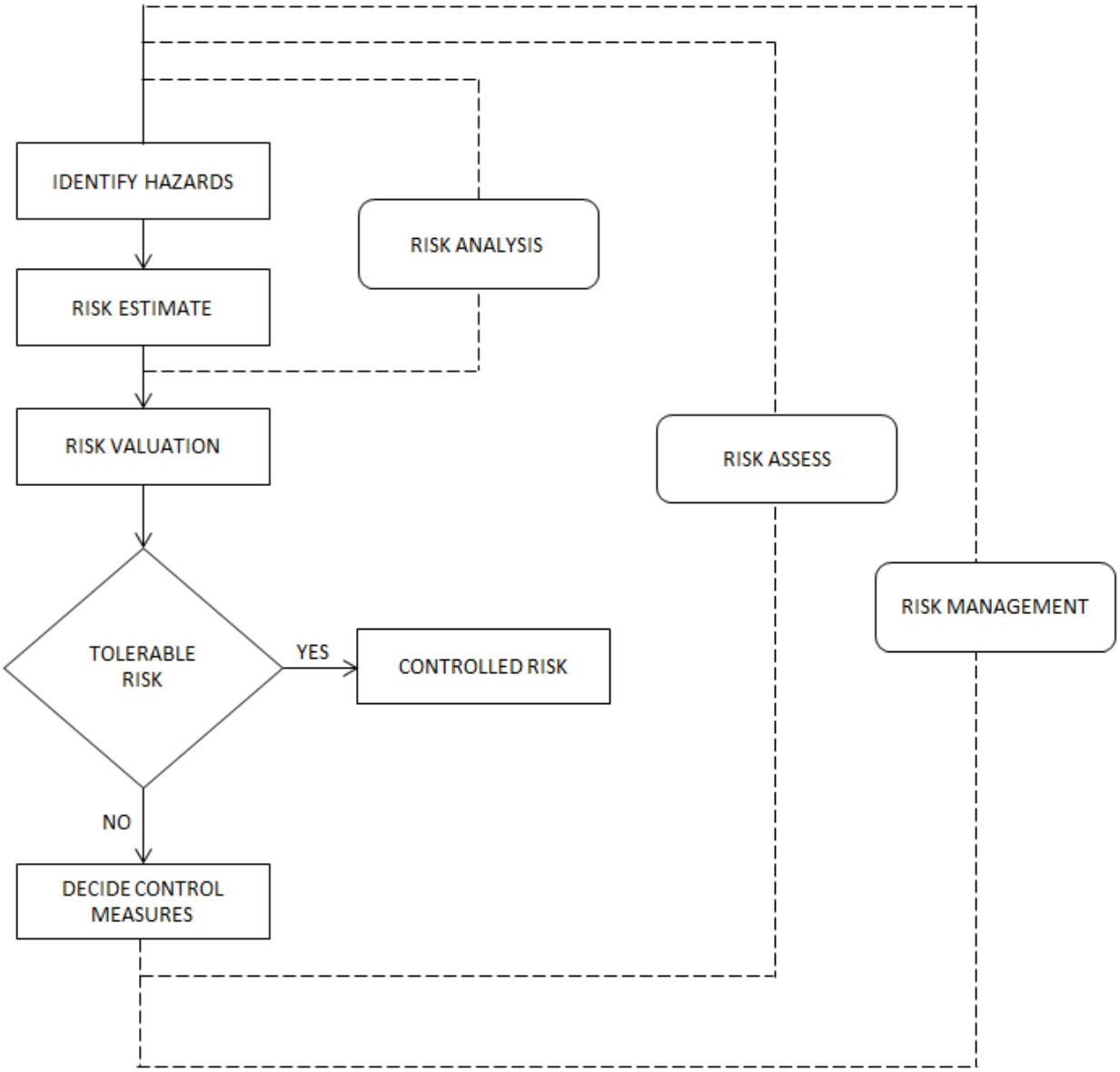
“The risk assessment, involves two steps: qualitative evaluation, in this step the risk is identified, described and estimated, quantitative evaluation, in this case the risk is measured for subsequent treatment.” Muniz (2011). The Picture 2 presents the main policy elements for the implantations of a safety management system.

Picture 1: Risk Management Model

Source: FUNDACENTRO, 2005

The Picture 3 presents a risk management model that is included: identified, assess, analysis, and risk management.

Picture 2: Risk Management - Model of the Company



Source: Maxion (2016)

According to Martins (2006) the process of risk management, as any decision making procedure starts with identification and a problem analysis.

Risk analysis is a process in with accident risk situations are analyzed continuously and systematically, with the aim of ensure that all activities are analyzed and their risks are identified and characterized, written by Muniz (2011).

3 FMEA – FAILURE MODES AND EFFECTS ANALYSIS

According CARPINETTI (2012), “The FMEA tools, is a great tool used to risk assess into the company, its use enables continuous improvement”.

> The Failure Modes and Effects Analysis is a technique that offers three distinct functions: is a tool to problems prognosis, is a procedure to develop and execution of project, process or new services or to review it; in the last, is a diary of the project, process or services. (PALADY, 2004 p.5)

MORETTI (2006), "The use of FMEA tool enables define a set of corrective and preventive measures, besides propose method that help minimize the potential failure modes".

> Although it was developed with the focus of new products projects and process, the FMEA methodology for its great utility came to be applied in several ways. Therefore it is currently used to decrease process and product failure and decrease the probability of failure in administrative process. Has also been employed in specifics applications as risk analysis in work's safety engineering and food industry. (TOLEDO; AMARAL, 2006 p.2)
> The development and execution of FMEA produce costs, however, when done effectively they can result in a significant return of reliability and quality. This return is obtained trough of the cost reduction with failure, gathering a collective knowledge with all the team that comprising how the project may fail. (PALADY, 2004 p.5)

According Aguiar and Salomon (2007) "when a company invest in prevention effectively in terms of implementation the returns are right in reducing costs with failure.

> Five basic elements should be included in all successful FMEA, that are: 1) Planning of FMEA; 2) List of the failure modes and their effects; 3) Prioritization and isolation of the most important failure modes; and 5) Monitoring of the actions necessary to develop an efficient FMEA and the actions suggested by it. (PALADY, 2004 p.21).
> The FMEA tool é basically developed in two major stages: in the first stage the failure mode is identified. In the second stage the Number of Priority Risk – NPR is determined, that is, the number score of these failure. (PUENTE, 2002).
> The FMEA include many of charts that are used in the assess of three criterion on a scale of 1 to 10, the higher number assigned to the criterion, the greater the risk. The interpretation of these values is done by calculation the Risk Priority Number, it is obtained through the result the multiplication of the analyzed factors that are: Severity, Occurrence and Detection. (CARPINETTI, 2012)

The charts 1, 2 and 3 presents a model with the relation of the severity, occurrence and detection, while the picture 5 presents a FMEA form.

Chart 1: Severity Scale

Severity of scale of Effects of Failure modes	Severity Index
Effect not perceived by the customer	1
Very Insignificant effect, perceived by 25% of customers	2
Insignificant effect, but perceived by 50% of customers	3
Moderate effect perceived by 75% of customers	4
Pretty critical effect, perceived by the customer	5
Pretty critical effects, which disturb the customer	6
Critical effects, which makes the customer a little unsatisfied	7
Critical effects, which makes the customer considerably	8

unsatisfied	
Critical effects, which makes the customer totally unsatisfied	9
Dangerous effects, that puts makes the customer's life in risk.	10

Source: Palady, 2004.

Chart 1: Occurrence Scale

Scale for assessing the occurrence of causes and failure modes	Occurrence index
Remote, improbably	2
Low chance of occurrence	3
Low number of occurrence	4
Expected an occasional number of failure	5
Moderate Occurrence	6
Frequent Occurrence	7
High Occurrence	8
Very High Occurrence	9
Certain Occurrence	10

Source: Palady, 2004.

Chart 2: Detection Scale

Detection scale for causes and Failure modes	Detection Index
It almost certain that will be detected	10
Very high probability of detection	9
High probability of detection	8
Moderate chance of detection	7
Average chance of detection	6
Some probability of detection	5
Low probability of detection	4
Lower probability of detection	3
Remote probability of detection	2
Almost impossible detection	1

Source: Palady, 2004.

Picture 3: FMEA Form

FMEA - Failure Modes and Effect Analysis

Description [Project/Process/Service]
_____
_____
_____
_____
_____
_____

Department/Team
Project _____
Production _____
Reliability_____
Quality_____
Providers _____
Customers _____

Documentos Afetados
ES _____
PFD _____
PC _____
Contract _____

Page_____ of _____
Original _____
Date ____/ _____/ ____

Aprovals

Lifting _____
Inspection Plan_____

Functions	Failure Modes	Effects	S	Cause	O	Controls	D	Recommended Actions	Status

Source: Palady, 2004.

4 FMEA WITH SEFETY FOCUS

The FMEA is a tool used to detect Failure before that happens, proposing corrective and preventive measures for each failure modes identified by FMEA.

Making an analogy of failures with accident, since as cited by the legislation the accident is an unwanted event that can bring consequences to the worker, therefore we an consider the accident a fail.

To apply the tool with safety focus specifically in safety management, the accident independent of injury will be treated as an effect of failure modes.

Similarly to FMEA of process or product, the FMEA with safety focus should follow the methodology procedures written by Carpinetti (2012), Palady (2004) and Puente (2002).

Adapt the charts of severity, occurrence and detection suggested by Palady (2004) so that reflect questions about safety and occupational health has developed the charts 4 to 6.

Chart 3: Severity Scale

Effect	Severity of the Effect	Severity Index
Dangerous without previous warning	Fatal accident without previous that the accident will happen. E.g. Explosion	10

Dangerous with previous warning	Fatal accident with previous warning that the accident will happen. **E.g.** rupture of a crane steel cable (the cable unraveling is a type of warning)	9
Very High	Accidents with very serious injuries (invalidity), Occupational Illness and/or REL (Repetitive Effort Lesions)/WMSD (Work-Related Musculoskeletal Disorders). E.g. Hearing Loss, Lung Diseases, Hand Loss	8
High	Accident with serious injuries (from 3 to 6 months away). E.g. surgery caused by fall / electrical shock	7
Moderate	Accidents with moderate injuries (01 month away). E.g. finger loss	6
Low	Accident with small lesions (15 days away). E.g. Cuts, burns	5
Very Low	Accident with risk of absence from work (01 week away). E.g. small cuts.	4
Smaller	Accident with small risk of absence from work (03 days away). E.g. Small cuts	3
Almost Accident	Accident with a small risk of absence from work (just observation)	2
None	Without accident	1

(Source: Maxion, 2016)

Chart 4: Occurrence Scale

Probability of Fail	Rate (Reference)	Occurrence Index
Very High	01 accident a day	10
Almost Inevitable	01 accident a week	9
High	01 accident every 15 days	8
Frequent	01 accident a month	7

Moderate	01 accident every 02 months	6
Occasional	01 accident every 03 months	5
Low	01 accident every 04 months	4
Smaller	01 accident every 06 months	3
Remote	01 accident per year	2
Improbable	No accidents registered in the last 03 years	1

(Source: Maxion, 2016)

Chart 5: Detection Scale

Detection	Criteria: Probability of detection based on frequency of verification	Detection index
Almost Impossible	Without actual control of the accident risk	10
Very remote	The risk of accident is annually verified	9
Remote	The risk of accident is verified each 03 months	8
Low	The risk of accident is verified each 06 months	7
Smaller	The risk of accident is monthly checked	6
Moderate	The risk of accident is checked each 15 days	5
Moderately High	The risk of accident is weekly checked	4
High	The risk of accident is daily checked	3
Very High	The risk of accident is checked each work shift	2
Almost Certainly	The risk is over control – 100% verified	1

(Source: Maxion, 2016)

The Severity, Occurrence and Detection index, was developed according to the company's need, making an analogy to the methodology written by Carpinetti (2012).

The Picture 6 presents an adaptation of the FMEA form to be used with the focus on safety through the risk management.

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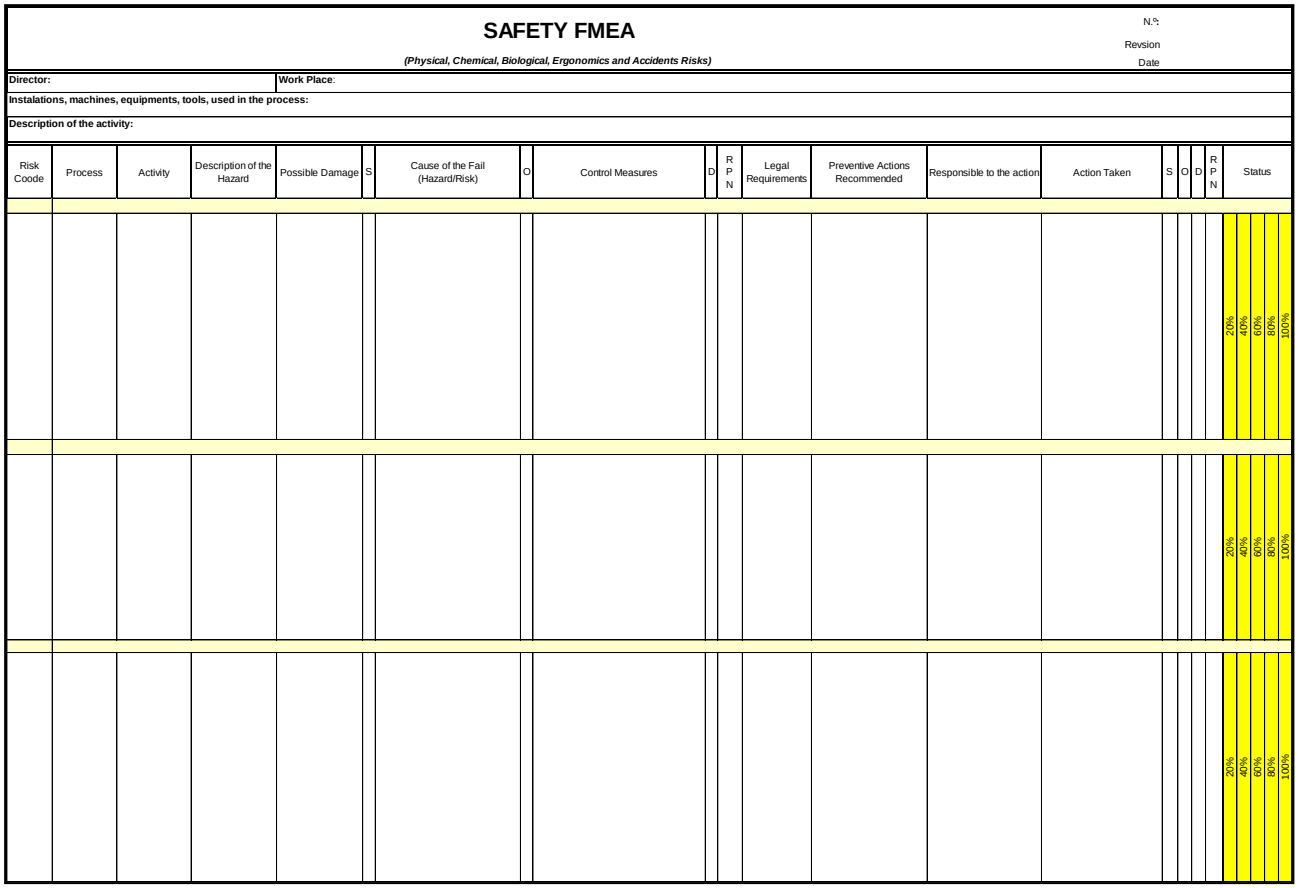
Picture 4: Safety FMEA Form



SAFETY FMEA

(Physical, Chemical, Biological, Ergonomics and Accidents Risks)

N.º:
Revsion
Date

Director: **Work Place**:

Instalations, machines, equipments, tools, used in the process:

Description of the activity:

Risk Coode	Process	Activity	Description of the Hazard	Possible Damage	S	Cause of the Fail (Hazard/Risk)	O	Control Measures	D	R P N	Legal Requirements	Preventive Actions Recommended	Responsible to the action	Action Taken	S	O	D	R P N	Status
																			20% 40% 60% 80% 100%
																			20% 40% 60% 80% 100%
																			20% 40% 60% 80% 100%

(Source: Maxion, 2016)

4.1 HOW TO ELABORATE THE FMEA WITH SAFETY FOCUS:

In according to the model proposed by Palady (2004) has an adapted header so that it contains the work place evaluated by FMEA, a description of the machines and equipment used on the work place, and finally a description of the activity, developed by the worker.

The FMEA form with Safety focus is composed by:

- **Risk Code:** in this first step after the completing the header the person responsible for the FMEA should codify the risks evaluated in the work place, this action aims to facilitate and catalog the possible risk situation that can be found in each task developed in the work place.
- **Process:** In this step the responsible of the work should be described what process is being evaluated;

- **Task:** This step is very important because should be described the project phases in analyze.
- **Hazard:** Description of the hazard coming from the exposure to risk.
- **Possible Damages:** Description of the possible damages coming from the exposure to the hazard/risk, that is, what is the consequence to the exposure.
- **Severity:** Used to assess the nature of the damage.
- **Cause of the Fail:** The cause of the hazard/risk by which the fail may be occurring described in terms of something that can be corrected or controlled.
- **Occurrence Degree:** It is the probability that a failure will occur.
- **Control Measures:** It is the measures adopted to control of the risk and hazard coming from each activity, these measures can be, risk elimination, engineering control, administrative measures and finally as last option the use of Protective Personal Equipment according to current legislations.
- **Detection Degree:** it the probability assessment that process control will detect hazards / risks.
- **RPN – Risk Priority Number:** It is the product by Severity, Occurrence and Detections. The bigger the RPN more critical the risk, what makes it a priority in taking action for its control.
- **Legal Requirements:** It is the standards, procedures, regulations, instructions when applicable to the hazard.
- **Preventive Actions Recommended:** Describe which actions will necessary to minimize or eliminate the risk.
- **Responsible to the action:** Person responsible to making action, describe in this item the deadlines to each action proposed.
- **Action Taken:** Describe all actions effectively taken to minimize and/or eliminate the risk.

The evaluate of severity, occurrence and detection of FMEA must be remade after the implementation of the improve, since there is an improvement implemented the degree of detection improve and the probability of occurrence of the problem will decrease, therefore a new RPN is calculated.

The severity degree remains unchanged when the new RPN is calculated, because if an accident will happen the severity of damage will not be altered, there is no change in the severity of the injury.

5 DEVELOPMENT OF ACTION RESEARCH METHODOLOGY (FMEA)

5.1 METHODOLOGY OF RISK ASSESSMENT – BEFORE THE IMPLEMENTATION OF FMEA TOOL.

The work place where the methodology FMEA with safety focus was applied is a process of plasma cutting.

The Plasma is the fourth state of matter. For the best known substance, water, you have ice, water and steam. If we add energy in the form of heat to the solid (ice), we will have the change of state to the liquid (water) and if more heat is added we have the gas (vapor). When a substantial amount of heat is added to the gas, it becomes Plasma. (Hypertherm, 2016).

CNC thermal cutting machines require a table of support to hold the metal plate where the shapes are cut.

> To reduce the level of emission of pollutants, it is necessary that the table of cutting be fitted with a system of absorption or exhaustion of these pollutants. In this way, the most common types of tables used in Brazil are **wet table**, or tables of **water** (wet cutting) and he aspirated tables (downdraft tables). (Manual Esab, 2016).

In the line of Plasma Cutting at the company where the FMEA was applied, the table cutting is wet table, as shown in the Picture 7 and 8.

Picture 5: Plasma Cutting

Source: Maxion

Picture 6: Wet Table

Source: Maxion.

Because of some problems with the plasma cutting process in the use of wet cutting, the Industrial Engineering of the company did a study and proposed a change in the process of the plasma cutting tables, initially the change would occur in two of the tables that use water for aspiration model, since the first meeting when the Industrial Engineering proposed the changed the safety area was involved starting the first FMEA with Safety focus into the company.

As determined by the current legislation, the company is required a risk assessment for each activities performed by the employees and issue Service Orders with the preventive measures to avoid accidents and occupational Illness.

The company performs the risk analysis of the activities performed by the employee during a production process, this risk analysis was carried out superficially, once the employee described their activities and automatically the risks were qualified, with the effects of risk exposure and solutions that is the measures controls of risk.

This model was developed in a summarized way, as follows:

1- Description of the activity
2- Risk
3- Effect
4- Solutions

The Picture 9 presents a model of the method used at the company, it is possible to analyze that the risk was qualified but this method does not consider the additional risks in the process, the peripheral risks. That is the risk around the place work that may influence the activity and potentially cause an accident, for example, the need to perform a Lockout

at the energy source when setup is performed, the risk of involuntary actuation or performed by someone else does not included in the activity of setup. This risk was not considered in the actual method of risk assessment.

The model adopted before the implementation of the improve leaves some gaps in the analysis whereas the measures to control of additional risks just was taken after the occurrence of some unwanted event.

Picture 7: Model of Risk Assessment – Before of the Improve

RISK ASSESSMENT

TASK OR PROCESS _____ EQUIPMENT _____

DATE ___/____/____ _____

RESPONSIBLE _____ PAGE:

TASK	RISKS	EFFECTS	RIKS FACTORS	SOLUCTIONS

SIGNATURE OF PRODUCTION COORDENATOR SAFETY SIGNATURE

Source: Maxion

The chart 7 presents the accidents occurred in the plasma cutting in 2015 and the respective corrective measures.

Chart 6: Plasma Accidents 2015

DESCRIPTION OF THE ACCIDENTS	CORRECTIVE ACTIONS
When the employee was handling the steel sheet it hit against his right hand causing injury	Installing of prolonger on the plate handling device leaving the employee away from the risk zone;
To leverage a steel plate with the help of a lever it escaped and hit the employee's right ear causing injury.	Removal of the leverage of the process
When the employee was handling the steel sheet it hit against his right hand holding his little finger between the steel and the table causing a small fracture.	Change the system of Movement steel sheet.
When the employee put the steel sheet on the cutting table the scrap hit against his right hand causing fracture with stitches	Include gloves of Kevlar in the process.
When the employee was taking the scrap of the table it hit against his forearm causing cut with stitches.	Include sleeves of Kevlar in the process.

Source: Maxion, 2016.

According the regulatory standard deal with Protective Personal Equipment, in the risk assessment and adoption of preventive measures, the indication of Protective Personal Equipment should be the last resort to be used for control of Occupational Risks. (Brazilian Ministry of Labor, 2016)

If the accidents had been analyzed and the corrective measures had been adopted this accidents wouldn't happened. It can be estimated that all accidents would be predictable if the risk analysis was elaborated together maintenance, engineering and production areas, starting the process analysis using some tools risk analysis as "What If", this methodology presuppose possible fail in the process it could be realized with a Brainstorming with the areas involved to solve a problem.

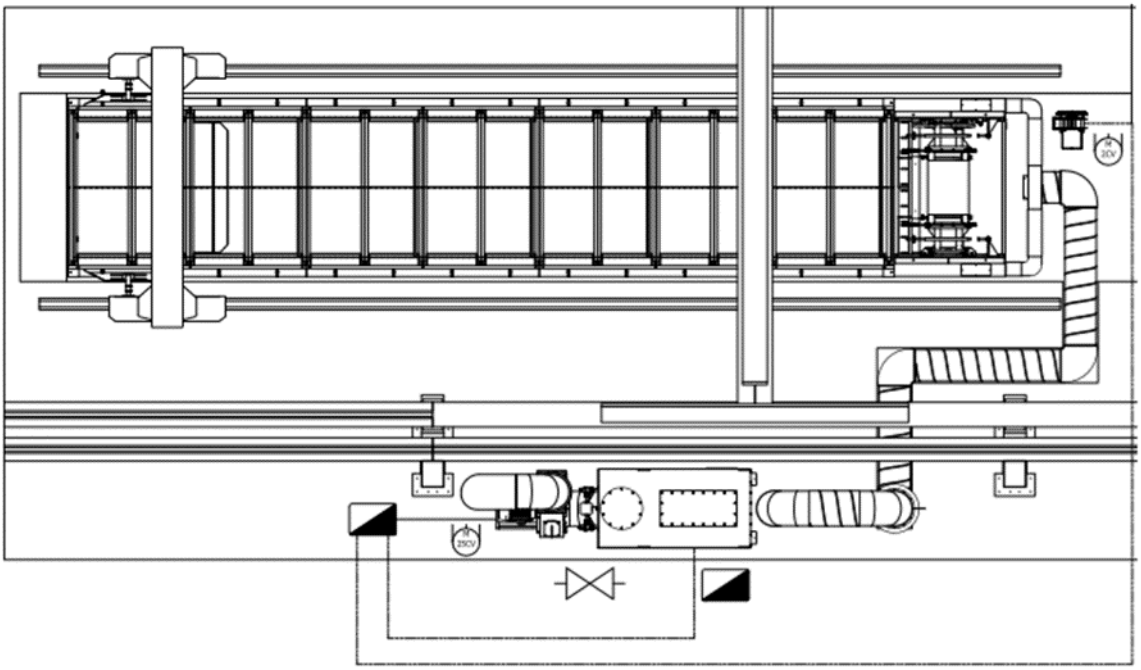
5.2 RISK ANALYSIS METHODOLOGY – AFTER THE IMPLEMENTATION OF FMEA TOOL

According proposed in the chapter 4, similarly to process or product FMEA, the FMEA with safety focus should follow the methodology procedures written by Carpinetti (2012), Palady (2004) and Puente (2002).

The work began in January of 2016 with a multidisciplinary team to develop a project to change one of the plasma cutting tables with water for the aspiration system; the safety was involved in order to perform the risk analysis of the project still in its initial phase.

The multidisciplinary team was composed of: Industrial Engineering, responsible for the project, Manufacturing Engineering, Industrial Safety, Civil Maintenance and Machinery and Equipment Maintenance. The picture 10 presents the drawn of the project of the table with aspiration system.

Picture 8: Plasma Cutting with Aspiration System



Source: Maxion, 2016

During the presentation of the Project it was necessary to perform a Brainstorming of the possible safety failures in the process, were considered the past occurrences of accidents and the occurrence that could happen with the implantation of the new project, the chart 8 presents the Brainstorming developed by the multidisciplinary team.

Tabela 7: *Brainstorming*

Fall of plate
Sucker Fail
Ergonomics problems in scrap removal
Risk of cut because of size of scrap
Removal of ruler to clean
Problems in the aspiration system of Machine
Risk of trampling by the tractor
Movement of the powder bags
Excessive noise during the cut
Risk of burn because of the plasma temperature
Material Movement
Electrical Shock
Explosion / Fire

Source: Maxion 2016

After the realization of Brainstorming, was started the process of risk analyze of the work place. Was analyzed each activity performed by employee in the work place, in accordance the activity, was identified the hazard and possible damage. The chart 9 presents the risks identified during this analysis.

Chart 8: Identified Risks

Item	Risco
01.00	Inhalation, ingestion, absorption by contact of harmful chemical substance (Chemical Hazard)
02.00	Non-ionizing radiation (Physical Risk)
03.00	Continuous, intermittent or impact noise (Physical Risk)
04.00	Impact of people against something (Risk of Accident)
05.00	Impact suffered by person (Risk of Accident)
06.00	Fall of people with level difference (Risk of Accident).
07.00	Fall of person of the same level (Risk of Accident)
08.00	Imprisonment in, under, or between objects (Risk of Accident)
09.00	Friction, abrasion, puncture or cutting (Risk of Accident)

10.00	Repetitive effort uncomfortable and lack of organization (Ergonomic Risk)
11.00	Contact with high temperature materials (Risk of Accident)
12.00	Non Atmosphere Electrical discharge (short-circuit) (Risk of Accident)
13.00	Atmosphere electrical Discharge (Risk of Accident)
14.00	Accident in the movement of material (Manually or mechanic movement) (Risk of Accident)

Source: Maxion, 2016

After the identification of the possible damages, was attributed to each hazard a severity degree of the damage, it means how severe the injury could be if it happened.

After it was identified the possible failure modes, in others words the possible cause that could cause damage. Identifying the failure modes it was possible to analyze the occurrence degree, in this case the indices was assigned in accordance the chart 5, considering the accidents occurred in 2015, therefore, the failure modes that had not registered occurrence was assigned the index 1 and the failure modes that had registered occurrence assigned the indices in accordance the quantity of accident. This to approximate the document as well as possible to reality before the process start.

Following with the analysis after to determinate of the occurrence degree, the measures of control was suggested, it could be Eliminate, Engineering Measures or adopt a Personal Protective Equipment – PPE, it is the last resource which should be adopted when trying to control a risk.

After was realized the identification of the detection degree of the problem, in others words the risk factor, the company established based on the literature about FMEA that the detection would be evaluated as follows: “the greater the probability of the occurrence of an incident the higher the detection rate” (Maxion, 2016), on this way the engineering department developed the chart number 6 to determinate the detection index.

With the severity, occurrence and detection index, the Risk Priority Number was calculated, which should indicate to the project and safety managers which activity is more dangerous to the worker identifying which the actions in this area should be prioritized.

In the safety area, the control measure usually will have a legal requirement, so the next step of the safety FMEA is determine which legal requirement must be complied.

After analyzing the legal requirement, preventive actions should be recommended for the eliminations of possible potential cause. Then determine the area responsible for taking the recommended actions and the deadline for implementation.

After the person responsible for the actions taken finish this actions the FMEA form must be completed, identifying which actions have been effectively implemented, this actions must be evaluated and approved by the safety department.

Finishing the analysis of the actions taken a new RPN is calculated as described in Chapter 4.

The Annex 1 shows the safety FMEA performed by multidisciplinary team.

6 RESULTS

With the application of the FMEA tool with safety focus there was a decrease in the probability of occurrence of failures, such as incidents and / or accidents, this was possible through the study of the main causes of accidents happened at this work place.

The tool made it possible to increase the level of fault detection that could possibly cause an accident.

With the application of the tool, there were any accidents in the work place since February 2016, when the work place was released for production.

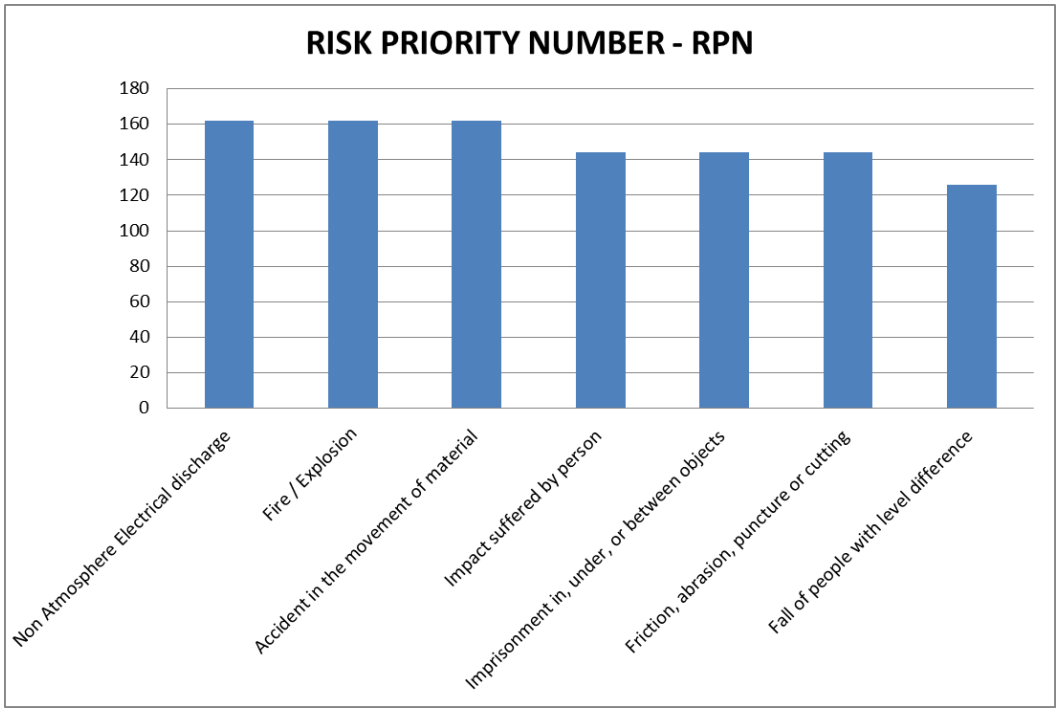
The picture number 11 shows the new model of the plasma cutting table with aspiration system, already installed and in operation.

The picture 12 shows a risk prioritization graph with the following classification criteria: the higher Risk Priority Number NPR makes the risk a priority in the process of take measures for control of these risks. In Annex 1 is available the Safety FMEA elaborated with all the identified risks.

Picture 9 PLASMA CUTTING – ASPIRATION SYSTEM

Source: Maxion.

Picture 10 – Risk Prioritization



Source: Maxion.

7 CONCLUSION

With the application of FMEA tool in the process of risk analysis arising from action research the results obtained with the new methodology implemented achieved benefits in the respective areas: safety, process, production and quality, because with the use of FMEA tool with safety focus it was possible to analyze the new process considering occupational risk management while the project was being developed.

The production improved avoiding downtime by unidentified risks or accidents providing a more productive and safe process. With the use of the tool it was possible analyze that the hazards and risks may not be difficult to identify, however perform a management work with the main objective of reducing the number of hazards and risks requires organization and determination by the company.

As assessed, the risk analyze of a work place depends on everyone involved and all the information must be organized in order to achieve a common goal, eliminate the

risks of operations by monitoring and controlling the possible causes that may lead to an accident or occupational illness. The work of risk analyze is necessary because besides being able to be worked with data of events occurred, it is also possible to work with data of incidents or events that are possible to happens.

After of the risk analyze has the Risk Priority Number – RPN, shown in this study, this RPN allows the risk management by the company, because this number presents to the company which risk should be prioritized in the process of management. The occupational risk management as presented in this work does not finish in the RPN, it must also act on the actions to be taken, after this step, must be planed the investments to perform each action reported in the safety FMEA, the document (FMEA) should be kept constantly update to seek a continuous improvement.

The FMEA must be applied within the company to assess new projects or process change to analyze the aspects referents the safety, keeping on this way an alive tool within the company.

The evaluation of the FMEA methodology allowed the verification of a preventive tool in the actions generated and their degrees of priority within the risk analysis, however, the tool would not had the positive results for the company if it had not been developed by a multidisciplinary team.

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ANEXX I – SAFETY FMEA

SAFETY FMEA

N.º: 1
Revsion 0
Date 1/10/16

(Physical, Chemical, Biological, Ergonomics and Accidents Risks)

Director: Wheels | **Work Place**: Plasma Cutting

Instalations, machines, equipments, tools, used in the process: Plasma Cutting, Suction Cup, Crane, electromagnetic system, industrial scissors, hand tools

Description of the activity: Production of plate through plasma cutting

Risk Coode	Process	Activity	Description of the Hazard	Possible Damage	S	Cause of the Fail (Hazard/Risk)	O	Control Measures	D	RPN	Legal Requirements	Preventive Actions Recommended	Responsible to the action	Action Taken	S	O	D	RPN	Status
01.00	Inhalation, ingestion, absorption by contact of harmful chemical substance (Chemical Hazard)																		
01.01	Preparation of wheels	Production of plate through plasma cutting	Inhalation of metallic fumes from the cutting process in carbon steel or silicon: iron, manganese and copper	Change in lung function, irritation, change in nervous system	8	Fail of aspiration system to the metallic fumes coming from Plasma Cutting	1	Hierarchy of Control Measures a) Elimination: N/A; b) Replecement: N/A; c) Controls of Engineering: Apiration of the metallic Fumes; d) Administrative / Organizational: Monitoring and measure - Program of Protection of Enviromental Risks, Maintenance, Training e) Personal Protective Equipment - PPE:Respirators against dust and fumes (If Tolerance Limit is exceeded)	6	48	Brazilian Regulatory Standard Numbers: 6; 9 and 15.	Install exhaust system to contain metal fumes Preventive Maintenance of Exhaust fans Conduct monitoring and measurement of the concentration of metallic fumes in the environment	Engineering Safety department Maintenance	Installed suction exhaust system Prepared by the maintenance a plan of preventive maintenance of the exhaust system Measurement of the concentration of metallic fumes in the environment, carry out annual monitoring	8	1	4	32	20% 40% 60% 80% 100%
02.00	Non-ionizing radiation (Physical Risk)																		
02.01	Preparation of wheels	Production of plate through plasma cutting	Exposure to ultraviolet and infrared radiation in plasma cutting processes.	Burning, irritation, eye injury.	7	Lack of torch protection to eliminate the risk of radiation exposure.	1	Hierarchy of Control Measures a) Elimination: N/A; b) Replecement: N/A; c) Controls of Engineering: Isulate the torches; d) Administrative / Organizational: N/A e) Personal Protective Equipment - PPE:Safety glasses with dark tint	6	42	Brazilian Regulatory Standard Numbers: 6; 9 and 15.	Monitoring of the lack of protection in the plasma cutting torch.	Production Manager Safety department	Check list for daily checking of equipment conditions Audits on check list	7	1	4	28	20% 40% 60% 80% 100%
03.00	Continuous, intermittent or impact noise (Physical Risk)																		
03.01	Preparation of wheels	Production of plate through plasma cutting	Exposure to continuous, intermitent or impact noise	Physical and mental fatigue, irritability, temporary hearing loss, and professional deafness.	8	No use of ear protectors provided by the company; Improper use of the ear protector during the production process; Use of sound equipment during production;	1	Hierarchy of control measures: a) Elimination: N/A; b) Replecement: N/A; c) Controls of Engineering:Locking the noise source d) Administrative / Organizational: Measure / Monitoring; Medical Monitoring; Training e) Personal Protective Equipment - PPE: Ear Protector	8	64	Brazilian Regulatory Standard Numbers: 6 and 15.	Monitoring of the use of PPE; Implementing a Hearing Conservation Program Medical monitoring for employees Monitoring of the non use of sound equipment within the manufacturing area	Production Manager Safety department	Implementing a Hearing Conservation Program Medical monitoring for employees Internal awareness campaign regarding the prohibition of the use of sound equipment, Internal Audits regarding the use of the PPE.	8	1	4	32	20% 40% 60% 80% 100%
04.00	Impact of people against something (Risk of Accident)																		
04.01	Preparation of wheels	Production of plate through plasma cutting	Iimpact of people against stationary objects or in motion.	excoriation; contusion injury; Lacerating injury; Traumatism	3	Workspace without organization; Incorrect flow of parts. Lack of signage of parts storage locations.	1	Hierarchy of control measures: a) Elimination: N/A; b) Replecement: N/A; c) Controls of Engineering: Define of flow parts d) Administrative / Organizational: Signage e) Personal Protective Equipment - PPE: N/A	6	18	Brazilian Regulatory Standard Numbers:8 and 26	Layout Suitability Signage of area for placing buckets and parts Standardize the inflow and outflow of materials	Production Manager Safety department Engineering	Training of operators Adequacy of the layout to open the corridor to enable the creation of a safe pedestrian path	3	1	4	12	20% 40% 60% 80% 100%
05.00	Impact suffered by person (Risk of Accident)																		
05.01	Preparation of wheels	Production of plate through plasma cutting	Impact suffered by falling objects	exoriation; Contusion injury; Injuries of various severities, amputation	8	Do not operate the siren while moving materials; Exceeding the maximum load capacity established on overhead cranes; Do not carry out the checklist of the industrial equipment before the start of the working day; Lack of preventive maintenance in cranes, forklifts, hoists, gantry and suction cups	3	Hierarchy of control measures: a) Elimination: N/A; b) Replecement: N/A; c) Controls of Engineering: Define of flow parts d) Administrative / Organizational: Instruction of the equipment used to movement materials; Training of the operators e) Personal Protective Equipment - PPE: N/A	6	144	Brazilian Regulatory Standard Numbers: 8 and 11.	Implement a primer for industrial vehicle operators; Implement Check List for industrial equipment; Perform corrective maintenance on equipment;	Production Manager Safety / HR Maintenance	Implement a primer for industrial vehicle operators Internal Audits; Preventive and corrective Maintenance; Implemented check list for industrial equipment before the start of the working day;	8	1	3	24	20% 40% 60% 80% 100%
06.00	Fall of people with difference of level (Risk of Accident).																		
06.01	Preparation of wheels	Production of plate through plasma cutting	Fall of people with level difference	exoriation; Contusion injury; fracture; Injuries of various severities.	7	Lack of protection on the perimeter of the table during removal of the scrap from the inside of the table Lack of signaling Excessive spacing between plasma cutting table rulers	3	Hierarchy of control measures: a) Elimination: N/A; b) Replecement: N/A; c) Controls of Engineering: Install adequate protection around the table d) Administrative / Organizational: Training of the operators e) Personal Protective Equipment - PPE: N/A	6	126	Brazilian Regulatory Standard Numbers: 8; 12; 26 and 35.	Install adequate protection around he table Safety Signaling	Production Manager Safety deparment Engineering	Made a movable protection that must be placed before cleaning the table Decreased spacing between cutting table rulers Training of the operators	7	1	4	28	20% 40% 60% 80% 100%

07.00	Fall of person of the same level (Risk of Accident)																						
07.01	Preparation of wheels	Production of plate through plasma cutting	Fall of person of same level	exoriation; Contusion injury; fracture; Injuries of various severities,	2	Slippery and / or uneven floor; Lack of signage and organization of the workplace; Non-use of PPE; No floor maintenance	3	Hierarchy of control measures: a) Elimination: N/A; b) Replecement: N/A; c) Controls of Engineering:N/A d) Administrative / Organizational: Signaling; Floor cleaning and maintenance plan e) Personal Protective Equipment - PPE: Safety Shoes	6	36	Brazilian Regulatory Standard Numbers: 8; 6 and 26.	Signage of the site with bands, fixed and mobile protection; Cleaning and organization of the area; Monitoring of the use of PPE	Production Manager Maintenance	Internal audits Floor Maintenance Installation of expanded screen bracket on table to better secure of the rulers	2	1	5	10	20%	40%	60%	80%	100%
08.00	Imprisonment in, under, or between objects (Risk of Accident)																						
08.01	Preparation of wheels	Handling of plates by overhead cranes, forklifts, gantry, hoists and suction cups Removal of scrap from plasma cutting tables	Imprisonment in basements or between moving objects, machinery and equipment	exoriation; Contusion injury; fracture; Injuries of various severities.	8	Fall of plates of overhead creane, gantry forks, hoists and suction cups. Suction cups; Lack of maintenance	3	Hierarchy of control measures: a) Elimination: N/A; b) Replecement: N/A; c) Controls of Engineering: Install Protection on machines,control of equipment acquisition, d) Administrative / Organizational: Signaling; e) Personal Protective Equipment - PPE: N/A	6	144	Brazilian Regulatory Standard Numbers: 8 and 26.	Preventive maintenance on overhead crane, hoists, gantry and suction cups. Periodic inspection in chains of bridges and suction cups; On The Job Training; Safety signs.	Production Manager Maintenance Safety department	Overhead crane preventive maintenance, hoists, gantry and suction cups. Periodic inspection in chains of bridges and suction cups; On The Job Training; Safety signs.	8	1	3	24	20%	40%	60%	80%	100%
08.02	Preparation of wheels	Cleaning of the table of cutting	Imprisonment in basements or between moving objects, machinery and equipment	exoriation; Contusion injury; fracture; Injuries of various severities.	8	Do not perform LOTO	3	Hierarchy of control measures: a) Elimination: N/A; b) Replecement: N/A; c) Controls of Engineering: Develop device to aply LOTO, d) Administrative / Organizational: Training of Operators in the Dangerous Energies Control Program; e) Personal Protective Equipment - PPE: N/A	6	144	Brazilian Regulatory Standard Numbers: 8 and 26.	Training of operators in the Dangerous Energy Control Program - LOTO; Analysis of the machines for the elaboration of the procedures for applying LOTO Arrangement in the areas of power blocking devices and locking stations	Production Manager Safety deparment HR	LOTO training report for employees Provide procedures on machines; Internal audits that include monitoring of the use of locking devices	8	1	3	24	20%	40%	60%	80%	100%
09.00	Friction, abrasion, puncture or cutting (Risk of Accident)																						
09.01	Preparation of wheels	Removal of scrap from plasma cutting tables	Friction, abrasion, puncturing or cutting (by pulling, stepping, kneeling or handling objects without vibration)	excoriation; Puncture-shearing injury; Perforating injury	5	No use of PPE; Scrap drop; Manual removal of scrap Use of lever to remove the grids	3	Hierarchy of control measures: a) Elimination: N/A; b) Replecement: N/A; c) Controls of Engineering: Protection of Machine, Safety signage d) Administrative / Organizational: Training of Operators; e) Personal Protective Equipment - PPE: Safety glass, PVC Gloves, gloves and kevlar hose, safety shoes.	6	90	Brazilian Regulatory Standard Numbers: 6; 8 and 26.	Preventive maintenance in hoist, crane and cup suction; Periodic Inspection Training of the operators Safety Signage	Production Manager Maintenance Safety	Internal Audits; Preventive and corrective Maintenace; Training of the operators; Install of safety signage Instalação de placas de segurança. Change of the layout to be possible the use of the cup suction to take the scraps Prohibit the use of lever to removel the rulers	5	1	8	40	20%	40%	60%	80%	100%
09.02	Preparation of wheels	Production of plates trought plasma cutting. Handling of plates, scrap and plates	Friction, abrasion, puncture or cutting (by foreign body in the eyes)	Eye lesion	8	No use of PPE;	3	Hierarchy of control measures: a) Elimination: N/A; b) Replecement: N/A; c) Controls of Engineering: Protection of Machine, Safety signage d) Administrative / Organizational: Training of Operators; e) Personal Protective Equipment - PPE: Safety glass.	6	144	Brazilian Regulatory Standard Numbers: 6; 8 and 26.	Monitoring the use of PPE	Production Manager Safety department Management	Internal audits that include monitoring of employees' use of PPE	8	1	3	24	20%	40%	60%	80%	100%
10.00	Repetitive effort uncomfortable and lack of organization (Ergonomic Risk)																						
10.01	Preparation of wheels	Perform scrap cutting through manual scissors.	Excessive effort when lifting, carrying, unloading, pulling, handling objects	sprain; dislocation; Trauma of the spine, tendon and muscle; Osteo joint injuries	8	Scrap drop; Manual removal of scrap	3	Hierarchy of control measures: a) Elimination: N/A; b) Replecement: N/A; c) Controls of Engineering: Suitable equipment for cutting the scrap d) Administrative / Organizational: Training of Operators; e) Personal Protective Equipment - PPE: N/A	6	144	Brazilian Regulatory Standard Number 17	Implement Workplace exercise twice a week	Safety department Medical Department	Implement Workplace exercise twice a week; Follow up of employee participation in the workplace exercise	8	1	4	32	20%	40%	60%	80%	100%
10.02	Preparation of wheels	Remove of the scraps of the plasma cutting	Excessive effort when lifting, carrying, unloading, pulling, handling objects	sprain; dislocation; Trauma of the spine, tendon and muscle; Osteo joint injuries	8	Scrap drop; Manual removal of scrap	3	Hierarchy of control measures: a) Elimination: N/A; b) Replecement: N/A; c) Controls of Engineering: Suitable equipment for cutting the scrap d) Administrative / Organizational: Training of Operators; e) Personal Protective Equipment - PPE: N/A	6	144	Brazilian Regulatory Standard Number 18	Use of suction cup to remove the scraps of the table plasma cutting	Production Manager	Change of the layout to be able the use of suction cup to remove the scraps	8	1	3	24	20%	40%	60%	80%	100%
11.00	Contact with high temperature materials (Risk of Accident)																						
11.01	Preparation of wheels	Removing the rulers for cleaning the bottom of the table	Contact with objects in high temperature	Burns of 1º, 2º and 3º degree	5	No use of PPE; Lack of signaling Lack of process temperature control	3	Hierarchy of control measures: a) Elimination: N/A; b) Replecement: N/A; c) Controls of Engineering: Process control of temperature d) Administrative / Organizational: Training of Operators; e) Personal Protective Equipment - PPE: Grafatex gloves	6	90	Brazilian Regulatory Standard Numbers: 6 and 26	Monitoring the use of PPE Control process temperature	Production Manager Engineering Safety	Internal audits that include monitoring of employees' use of PPE Process temperature control on the machine control panel Safety signage	5	1	4	20	20%	40%	60%	80%	100%
12.00	Non Atmosphere Electrical discharge (short-circuit) (Risk of Accident)																						
12.01	Preparation of wheels	Production of plate through plasma cutting	Non atmosphere electrical discharge	Burns of 1º, 2º and 3º degree	9	Exposed electrical cables Lack of machine ground	3	Hierarchy of control measures: a) Elimination: N/A; b) Replecement: N/A; c) Controls of Engineering: Grounding of panels and plasma cutting tables. d) Administrative / Organizational: Training of Operators; e) Personal Protective Equipment - specific PPE to electrician	6	162	Brazilian Regulatory Standard Numbers: 10	Grounding the machine Electrical cables insulated and arranged in conduits and electrodes	Production Manager Engineering Safety Maintenance	Measuring the grounding of machines Monitoring of equipment conditions (maintenance inspection)	9	1	4	36	20%	40%	60%	80%	100%
13.00	Atmosphere electrical Discharge (Risk of Accident)																						
13.01	Preparation of wheels	Production of plate through plasma cutting	Fire, explosion by chemical reaction or combustion	Burns of 1º, 2º and 3º degree	9	Presence of flammable materials on site, Hot metal contact with combustible material. Drop of scrap in the hoses and wiring of the caterpillar.	3	Hierarchy of control measures: a) Elimination: N/A; b) Replecement: N/A; c) Controls of Engineering: Fire fighting system, fire brigade, safety signage, suitable storage of products, explosion-proof lighting system. d) Administrative / Organizational: Training of Operators; e) Personal Protective Equipment - Not applicable (use for intervention or combat only).	6	162	Brazilian Regulatory Standard Numbers: 8, 20; 23; 26	Implement a system to fight claims; Keep location clean and organized.	Production Manager Safety Department HR	Internal audits; Implanted fire fighting system (hydrants and extinguishers); Emergency brigade. Implanted fixed protection on the crawlers of plasma cutting tables	9	1	4	36	20%	40%	60%	80%	100%
14.00	Accident in the movement of material (Manually or mechanic movement) (Risk of Accident)																						
14.01	Preparation of wheels	Production of plate through plasma cutting	Atmospheric electric discharge	Burns of 1º, 2º and 3º degree	9	Lack of grounding of the shed	1	Hierarchy of control measures: a) Elimination: N/A; b) Replecement: N/A; c) Controls of Engineering: lightning rod system; d) Administrative / Organizational: Monitoring and measuring, Inspection and preventive maintenance, Training; e) Personal Protective Equipment - N/A	4	36	Brazilian Regulatory Standard Numbers: 10	Grounding of the shed	Safety Departament Maintenance	Atmospheric Discharge Protection System Report	9	1	2	18	20%	40%	60%	80%	100%