Chapter 2

Analysis of human reliability in accidents and incidents in a chemical industry

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ABSTRACT
Human Reliability has increased its space in environments where processes have a higher level of danger and among them are the chemical industries. In these industries, the periods in which maintenance interventions occur to guarantee the reliability of the equipment and operational continuity are recurrent. During interventions, the pace at which activities are carried out becomes faster, in addition to having a greater turnover of people performing the services. Therefore, this whole scenario makes the work environment more vulnerable to risks and it is the moment when risk analysis methodologies occupy a strategic place. To acquire greater support in carrying out the activities, maintenance procedures are elaborated, however, studies show that these are often unknown and/or misused. In this sense, this study aims to understand the importance of using the human factor approach in ensuring safe work environments, analyzing Human Reliability through the PUMA methodology, and associating with concepts such as psychological safety, the role of leadership and Communication. In addition, the study analyzes the root cause of some accidents and incidents that have occurred, using some methodologies such as the Cause Tree and associating them with concepts considered important for Human Reliability.

Keywords: Human Reliability, Maintenance Intervention, Psychological Safety, Root Cause Analysis. Accident.

1 INTRODUCTION

Within engineering, human factors are studied from what is called *Human Reliability Analysis* (ACH). The first work of ACH emerged in the 1950s, and these were intensified after major industrial accidents known worldwide. The first in which the intensification of studies was noticed after its occurred was the accident nthe American nuclear power plant *of Three Mile Island*, Pennsylvania, in which onNovember 1, 1979, a commission appointed by the then President of the United States, Jimmy Carter, came to the conclusion that the accident had been caused by human failure. In addition,there are accidents in Bhopal (1983), Chernobyl (1986) and Fukushima (2011),for example, which reinforced the need to improve the development of human reliability analysis techniques and the importance of the human factor (MATURANA, 2017).

In the first studies on Human Reliability, its importance was considered to be about 15% notthe total risk in industrial accidents. Currently, its importance corresponds to 60% to 80% of the total risk. It is believed that the change is associated with a greater understanding of the relevance of the human factor in ensuring operational safety as opending on the advance of improvements in equipment maintenance plans, better selection of materials and designs (SPURGIN, 2010).

In work environments that there is a risk associated with its operation, such as in chemical industries, it is important to have a good risk management and understanding of safeguards (control barriers) that can assist in the process of ensuring safer industrial environments.

Incidents are occurrences with the potential to cause some kind of damage that can culminate in an accident, but for this to happen it is necessary that a root cause is involved. The human reliability analysis process seeks to understand the root causes involved in industrial accidents and incidents and to propose the most efficient treatment for the specific case.

Because the analysis of human factors and how they can influence the guarantee of safe environments is considerably complex, it is important to understand concepts such as vulnerability. Brené Brown (2019) conceptualizes vulnerability as being the courage to act when one cannot control the outcome, so leaders have the challenge of predicting how human behavior will be in high-risk situations and what tools, procedures and techniques can support them and how they should be available.

At the same time, Brown (2019) asks the following question "Can you imagine how difficult it can be to make your brain understand the fundamental role of vulnerability for leadership when one is rewarded daily for eliminating it?" (BROWN, 2019, p. 42).

Dealing with human actions and providing subsidies so that work environments have fewer risks requires further and targeted studies. For an entire organization to be able to build increasingly secure processes, it is necessary that people have confidence in each other and this, in turn, is the accumulation and overlap of small moments and mutual vulnerability over time (BROWN, 2019).

Thus, it is perceived that thereare a number of factors that influence the analysis of human behavior and its impacts in the face of accidents and incidents. In this perspective, the evaluation of human reliability is a process that examines human actions and their reactions to accidents, seeking to predict risk in routines, including in the operations of a factory that works with processes of high dangerousness (SPURGIN, 2010). This assessment may use some risk analysis tools, root cause analysis, and error-elimination techniques, as will be seen throughout this study.

2 JUSTIFICATION

This work arose from the perception of the relevance of the theme and, together with this, still existing scarcity of information on Human Reliability in the chemical industries, aiming at contributing to the advancement of understanding of the theme with the development of this.

3 GOALS

General Objective: To analyze the occurrence of accidents and incidents, in the light of Human Reliability during the Maintenance Interventions of a chemical insum industry.

Specific Objectives:

- Check the importance of human factors in ensuring safe industrial environments.
- Analyze accidents and incidents with contribution of the human factor and what were their root cause.
- Understand how psychological security interferes with the number of human errors and failures.
- Map points of improvement in the processes studied to mitigate errors.

4 METHODOLOGY

For the development of this work, we carried out the study of the theory stems from the theme both in the matter of behavioral analysis of the human being, as well as in the analysis of accidents and incidents. In order to find the importance of the human factor in industrial accidents, the Tree of Causes methodology was used to identify the root cause of each event and subsequent *application of the Perceptions, Unable, Motivation, Ability* (PUMA) methodology, where through this it is possible to understand which treaties are most appropriate for eliminating risks and avoiding the occurrence of unwanted events.

The monograph is subdivided as follows: In chapter 1, the introduction is presented that includes the definition of the problem, the justification, the motivation, the accreditation of the researcher with the proposed theme, the description of the theme, the general context for the research, as well as the general and specific objectives. In chapter 2, entitled Theoretical Reference, presents the concepts that will support this research, such as Human Reliability, Psychological Security, Vulnerability, Industry 4.0 and Root Cause Analysis. Chapter 3, entitled Methodology, brings the methods used for the Analysis of the Root Cause of accidents and incidents, as well as the methods of Human Reliability Analysis. In chapter 4, Case Study: Analysis of Human Reliability in a chemical insum company, data regarding the study of accidents and incidents that occurred during a decade in the company in question and all relevant information of these companies are shown. The results of the study are presented in chapter 5. Finally, chapter6 shows the final considerations of the research.

5 THEORETICAL FRAMEWORK

It is notorious the progress of studies on Human Reliability in companies in some specific sectors,especially in those where there is a risk associated with its operation, as in the chemical industries. The Human Reliability Analysis is defined as the probability that a system that requires human actions, tasks or work will be successfully completed within a required period (FIGUEROA & SOUZA, 2011).)

In industrial plants that work with high dangerousness, reliability is an extremely important factor for ensuring safety in operations. According to the Human Reliability Reference Standard (API-770),

human error is human action or lack thereof, which exceeds an acceptance limit (tolerance) that are predefined by the system with which the human being interacts. At the same time, it is defined that when designing machines, work environments and operations, human factors should be taken into account, that is, these must be in accordance with human needs, capacities and limitations (D.K. LORENZO, 2001).

When analyzing this human factor, it is understood that some skills can influence for a possible error, such as communication. In industries that work with high criticalchemical processes, any change in process variables: temperature, pressure and flow, should be managed and, if necessary, reported. To do this, it is necessary to create a work environment where people express themselves, share information, contribute experiences, take risks and work with each other to create lasting value (EDMONDSON, 2020).

The problem of omission of information, complacency and staying in the comfort zone rather than positioning ourselves in the situation, although keeping us safe in personal terms, these behaviors can result in a performance below expected, as well as putting the organization at risk (EDMONDSON, 2020).

Therefore, it is important to dedication, especially of leadership, to the discovery of new waysto detect errors and prevent them. This, in turn, also plays an important role in maintaining a work environment where people feel safe enough to collaborate with suggestions for improvement in processes and procedures, preventing them from being discomplied with.

Nowadays, especially with the creation of new work patterns, it is perceived that it is increasingly common for teams to have members working in different places around the world. These teams face challenges such as communication, especially those reported in relation to the use of electronic media. Thus, from studies on the subject, it was found that psychological security helped teams overcome the challenges of geographic dispersion, besides feeling less anxious about what others might think of them, becoming more able to communicate openly (EDMONDSON, 2020).

Amy Edmondson (2020) defines psychological security as the belief that the work environment is safe to take interpersonal risks, she further states that "Psychological security is present when colleagues trust each other, respect each other and feel able – even obliged – to be frank." (EDMONDSON, 2020, p. 8).

In addition to the difficulty of communication with the other members, professionals who are working remotely have difficulty approaching and creating a bond with their work team, which is also a factor that also hinders the establishment of psychological security, furthersharpening the creation of a transparent, integrated and safe work environment (EDMONDSON, 2020).

human reliability and industry 4.0

There is a moment of industrial transformation called Industry 4.0, where profound changes are witnessed in all sectors, marked by the emergence of new business models, the desconti nuity of operators and the reformulation of production, consumption, transport and logistics systems. All these changes mark a time of uncertainty, where this industrial revolution is characterized by being even faster than the other,

broader and deeper, besides involving the transformation of entire systems (companies, industries and the whole society) (SCHWAB, 2016).

In addition to all this transformation within industries, in society there is also a change in the way of trabalhar and communicating, as well as in the madities of expressing, informing and having fun. Therefore, it is increasingly perceived the human factors influencing the continuity and operational mode of the industries (SCHWAB, 2016).

According to Amy Edmondson (2020), for an organization to truly thrive in a world where innovation can make a difference between success and failure, an innovation that is very present in Industry 4.0, it is not enough to hire intelligent and motivated people. For intellectual work to flourish, the place where one works must make people feel able to share their knowledge, that is, it is necessary to be psychologically safe.

It is believed that the current worker's fear is that he will be replaced by the machine, porém, what distinguishes man from the machine is the power of creativity. Psychological security has as results, among others, creativity, as well as behaviors that detect the need for change or that help teams and organizations to make changes, a capacity that has been increasingly valued in the professional profile of employees.

Amy Edmondson (2020) adds that in a psychologically safe workplace, people are not hindered by interpersonal fear if they feel willing and able to accept the inherent risks of frankness, tending to communicate openly more and more, verbalizing their concerns and, from these statements, it is possible to infer that Psychological Security is a requirement for success in competitive industries.

Analogous to this, Brené Brown in his book A cpray to lead (2019) stresses the importance of knowing how to deal with vulnerability and build trust, which in turn are pillars of psychological security, to become part of the rise of audacious leaders, as can be seen in the excerpt highlighted below:

> While we are concerned about the possibility that automatic learning and artificial intelligence will take our jobs and dehumanize work, we are intentionally or not creating cultures that, instead of valuing unique gifts of the human heart (such as vulnerability, empathy, and emotional education), try to block them. (BROWN, Brené. 2019 p. 90).

Like the importance of Psychological Security for Human Reliability in industries, a Gallup survey in 2017 found that only 3 in 10 employees strongly agree with the claim that their opinions count at work. Gallup calculated that by "changing the ratio to 6 out of 10 employees, organizations could achieve a 27% reduction in turnover, a 40% reduction in safety incidents and 12% in productivity increase" (EDMONDSON, 2020, 18th place).)

In any challenging scenario in the industry, leaders have the role of building psychological security to stimulate learning and escape avoidable failures and set high standards, inspiring and enabling people to achieve them. At the same time, in the face of the constant incentive to innovation, they must be willing to take the job of taking away the fear of the organization to create conditions for learning and growth (EDMONDSON, 2020).

That is, the way in which people will be led will influence their way of working, especially in the highlight of safe behaviors, in the contribution of improvements in processes, in the relationship with the team, in the way they communicate, in the relationship with vulnerability, among others.

human reliability and procedures that support maintenance intervention

Interventions of marrest occur periodically with the aim of ensuring that all equipment or installation, process or not, has its physical integrity guaranteed in order to avoid possible damage to people's health, the environment and facilities. In these interventions, the processes are interrupted and thus the equipment stops working so that they can be inspected and, if necessary, the maintenance of this (VERRI, 2008).

In theinformation andin industrialoperations there are several documents that assist in the support of ensuring safety in operations. They are: Pre-task risk assessment, Work Permit, and power control (LOTO - *LOCKOUT* and *TAGOUT*). All of them are intended to ensure compliance and safety in operations, both with a prior evaluation and at the time of execution of the task, that is, they are important for the safety of maintenance services, but do not guarantee that the execution of the task is safe (KLETZ, 2013). In turn, for these to be safe, it is necessary to become a routine practice to fill and update these documents, in addition to ensuring understanding of the content present there.

According to David Embrey (2000 *apud* FIGUEIROA FILHO, 2010),, one of the main factors that affects productivity and can cause accidents is the rejection and misuse of routine procedures. These may be motivated because people prefer to rely on their own skills and ignore the procedures, because they think they already know enough of the procedures and do not choose to follow it, because they believe that if they follow it they will not be able to finish the process in the time required and, finally, people may not be aware of the and xistence of these procedures.

Analyzing the maintenance procedures, especially the ones mentioned above, it is perceived that these should be described in such a way as to ensure the understanding of the task performer, based on their skills and knowledge, and should always seek to improve in order to support the interaction between man, machine and system, thus avoiding the occurrence of incidents and deviations.

human reliability and incidents IN THE INDUSTRIES

In the study conducted by Souza (2000),based on the national data made available bythe Department of Occupational Safety and Health of accidents that occurred in 1997, we made an analysis of the underlying causes of accidentswith injury to workers at the oil refinery and the results can be seen in table 1 aba ixo.

Table 1: Basichealth of accidents with injury to own workers at the oil refinery in 1997

Basic Causes	N	%
Work factors	15	19
Design, construction, or assembly failure	13	16,4
Maintenance failure	13	16,4
Inappropriate attitude	13	16,4
Personal factors	11	13,9
Task planning failed	10	12,7
Decision-making error	1	1,3
Lack of knowledge	1	1,3
Improper storage of material	1	1,3
Unidentified	1	1,3

Source: Souza, 2000

From the identification of these causes for accidents in the year of study, it is possible to understand that human factors are highly linked to the causes of events, either directly or indirectly. Therefore, from the analysis of events that occurred over time, studies on human reliability have become essential also in industrial environments.

According to Verri (2008), a risk is a potential condition or event that if it occurs has a positive or negative effect on one or more project objectives. Moreover, in chemical plants, these risks are usually associated with negative effects and in large proportions.

For these negative risks, there are four treaties: prevenir, which aims to eliminate the root cause associated with this risk; transfer, which confers on the other party the responsibility of risk management (insurance, contracts, guarantees, etc.); Mitigate, which aims to reduce the probability of occurrence or impact of the risk; Accepting, in this case, the probability or impact of the risk is not altered. (VERRI, 2008)

According to Ruzzarin (*apud* MAPELLI, 2018), accidents can be classified according to their frequency category, which indicates the expected frequency for occurrence, and severity (consequence), which estimates the expected damage, in a risk acceptability matrix. Through this matrix, it is possible to visualize which scenarios present the highest risk and, consequently,come to be treated with priority, as illustrated below in Figure 1.

Figure 1: Risk Acceptability Matrix

Matriz de Aceitabilidade		Frequência				
		Improvável	Remoto	Ocasional	Provável	Frequente
Severidade	Catastrófica	RM	RM	RA	RA	RA
	Crítica	RB	RB	RM	RA	RA
	Moderada	RB	RB	RB	RM	RA
	Baixa	RB	RB	RB	RB	RM

Source: Mapelli, 2018

Where: RB (Low Risk) are acceptable and controllable scenarios, RM (Medium Risk) are acceptable scenarios, but actions should be proposed so that this risk becomes a low risk and AR (High Risk) are unacceptable scenarios and it is necessary to apply a complementary study.

The incidents are any unwanted occurrence that has thepotential to cause losses and these, in turn, are classified as an accident or near-accident. Accidents cause injury to people, damage to the environment and/or facilities, impacts on the community or damage to the Company's image and near misses have the potentialto cause all such damage (PEIXOTO, 2010).

Accidents linked to the best known person is damage are seen in Quadro 2.

Table 2: Best-known accidents linked to personal injury

Type of accident	Definition
Road accident	Accident suffered by the employee on the way from the residence to the workplace or vice versa with any means of locomotion, including vehicle owned by the employee or transport provided by the company, provided that there is no interruption or change of route for reasons unrelated to the work.
Personal accident (working)	An event that, in the exercise of work within the company or at the service of the company outside it, causes bodily injury or functional disturbance that causes death, loss or reduction of work capacity.
Fatal accident (AF)	Event that, in the exercise of work within the company or at the service of the company outside it, causes the death of the injured.
Work accident with leave (CAF)	Reportable accident in which it is determined by the medical area that the personal injury prevents the injured from returning to work on the day immediately to the accident or that results in permanent disability.
Accident at work without leave (SAF)	Reportable accident in which it is determined by the medical area that the injury does not prevent the injured from returning to work on the day immediately to the accident, provided that there is no permanent disability.
Process safety accident	Event occurred in production, distribution or storage facilities and involving chemical leakage and/or fire and/or explosion or environmental impact or economic losses related to the process. Process security events can result in CAF or SAF events.

Source: VERRI, 2008

6 ACCIDENT ANALYSIS

The unsafe conditions in which industries may find themselves are close to their consequences, which are accidents, but not necessarily the root causes of these conditions are clear. In the process of solving the problems encountered in operation, it is necessary to understand how and why safeguards have failed.

Security systems are based on the fact that it is not possible to change human nature, but rather to modify the conditions in which they work, in order to ensure more and more security to processes, people and the environment. On the other hand, managing human risk factors is not fully effective because human failures are always a possibility. For this reason, the error management process is as important as the product or service considered (CORREIA, 2007).

Root causes are the primary causes that generate the event whether it is a deviation, non-compliance, losses, incident or accident, they include personal factors and workingconditions. Root cause

analysis aims to address improvements in technical and social systems and identification can bebased on specific troubleshooting and analysis tools (D.K. LORENZO, 2001).

With this, before applying tools to analyze the motivation of human failure, it is necessary to analyze the root cause, which when corrected will prevent the recurrence of problema, through methodologies as can be seen in the later sections.

7 METHODOLOGY

The development of this work was based on the methodologies described in the sections detailedin the analysis of classification of accidents below.

7.1 METHODOLOGIES FOR ACCIDENT ANALYSIS

There are several methods for accident analysis in industrial environments, among them are the Method of 5 Whys, Ishikawa Diagram, Analysis of Control Barriers, Cause Tree, among others. These methodologies will be described below.

7.2 METHOD OF THE 5 WHYS

This methodology was used in the Toyota Production system to reach the true root cause. It consists of the question of the "why" of a problem successively, thus parading the cause of the effect and collaborating in the construction of more assertive hypotheses for its root cause (AGUIAR, 2014).

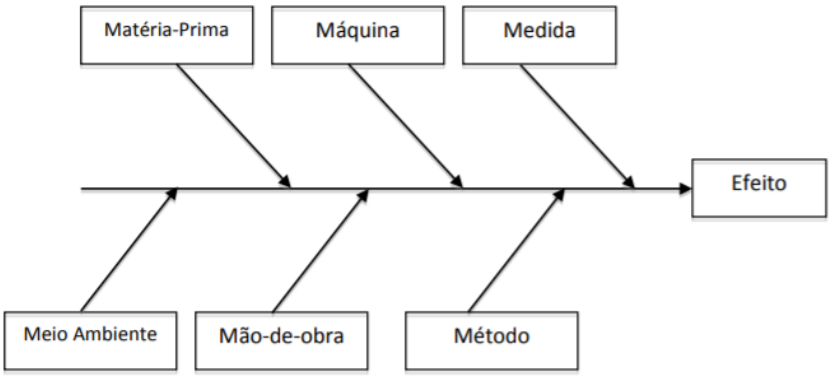
An example (OHNO, 1997 *apud* AGUIAR, 2014) of the use of this methodology is below:

> "1. Why did the machine stop?
> Because there was an overload and the fuse burned.
> 2. Why was there an overload?
> Because the housing wasn't lubricated enough.
> 3. Why wasn't it sufficiently lubricated?
> Because the lubrication pump wasn't pumping enough.
> 4. Why weren't you pumping enough?
> Because the pump shaft was worn and vibrating.
> 5. Why was the shaft worn out?
> Because there wasn't a screen attached and liquor squeals came in. "

Ishikawa diagram

Also known as Cause and Effect Diagram or Fishbone Diagram is a methodology that analyzes the problem from its relationship with the causes that can be classified as raw materials, machines, measures, environment, labor and method, these can be changed depending on the problem to be investigated. (AGUIAR, 2014). Figure 2 below illustrates the Ishikawa Diagram.

Figure 2 - Ishikawa Diagram



Source: AGUIAR, 2014

Control Barrier Analysis

Control barrier is the physical or administrative measure that exists to prevent people or equipment from unsafe conditions or damage. The analysis of these consists in identifying the control barriers belonging to the problem in question, evaluating their effectiveness, determining how and why the failure occurred, identifying where there could be barriers for the problem to be avoided and validating the information with a specialist. (AGUIAR, 2014). Table 3 below illustrates the methodology for analyzing control barriers.

Table 3 - Control Barrier Analysis Methodology

Consequences	**Barriers that could have prevented the event or problem**	**Barrier assessment (why barriers fail)**
(List one at a time and does not need to be in sequential order)	(Identify all applicable barriers for each consequence)	(Identify whether the barrier was missing, weak or not effective, and why)

Source: AMMERMAN, 1998 (apud AGUIAR, 2014)

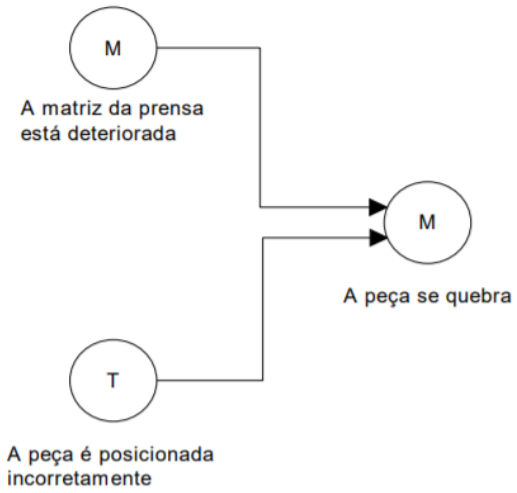
Tree of Causes

The Tree of Causes methodseeks and stabs the interrelation of the facts of the event, allowing a more in-depth analysis of the causes, identifying the factors involved in its origin, immediately to it and successive of it.

Thus, this method analyzes several possible causes and thus reveals the variations and deviations occurred in the activity from the detailed reconstruction and with the greatest precision of the event history. For this work, the Cause Tree was used to analyze the root cause of accidents and incidents (BINDER, 1997).

The construction of this takes place starting from loss, going back in time with possible causes within a chronological and logical order, as shown in Figure 3 below.

Figure 3 - Tree of Causes



Source: BINDER, 1997

In this example, the loss was the broken part and the causes "The press matrix is deteriorated" and "The part is positioned incorrectly."

7.3 METHODOLOGY OF CLASSIFICATION OF ACCIDENTS

From the definition of the root cause, as seen earlier, if confirming that human failure contributed to the occurrence of the incident, it is possible to apply a methodology to determine the reason for this failure. Some of these methodologies can *be Antecedent, Behavior, Consequences* (ABC) and *Perceptions, Unable, Motivation, Ability* (PUMA).

The first depictsbehavior-based actions, where antecedent s are factors (environmental, personal, organizational, etc.) that influencebehavior; behavioris the objectively observable act of the individual and *consequences that are direct results* of behavior and motivators or not of the repetition of behavior (DOCUMENTS INTERNOS DA EMPRESA STUDIED, 2018).

Perceptions, Unable, Motivation, Ability (PUMA) is a set of tools that uses observation to try to capture all relevant information about cognitive activities in a task, usually based on the video analysis ofsomeone performing it, through this analysis, calculates how the different types of tasks will affect the development of work individually and in (KIRWAN, 1997).

In this methodology, task analysis is a fundamental approach that describes and analyzes how the operator interacts with one system and with other people (KIRWAN and AINSWORTH, 1992, *a KIRpudWAN*, 1997). The analysis of cognitive tasks is fundamental for the development of the layout of the human-machine interface, for the development of procedural and training systems and for the analysis of errors, seeking to create a detail of human involvement with all the information necessary for the execution of tasks.

Perceptions, Unable, Motivation, Ability (PUMA) associates human failure with lack of skill, motivation or combination of both, and can occur in a systemic or isolated way, as can be seen in Chart 4.

Table 4 - Example of lack by Skill and Motivation

Lack of Skill	Lack of Motivation
Physicalinability (human capacity)	Procedures are not followed
Insufficient information to complete a task	Improper use or application of equipment
Inadequate or insufficient training, knowledge and experience	Modified or reduced task sequence
Hostile work environment (e.g. excessive heat, cold, noise, etc.) increasing the chance of errors	Ignored or by-passed warnings
Operational process (e.g. repetitive actions) increasing the chance of errors	Unknown equipment/process errors or failures not reported
Time or duration of work shift increasing the chance of errors	Authority to stop uncarried work when it should
Very complicated or onerous man-equipmentinterface increases the chance of errors	Equipment operating outside normal operating conditions
Lack of verification/review to ensure that difficult or important tasks are always completed correctly as per procedure	Change Management (MOC) not applied when changes occur in equipment or work scope or team structure or leadership
Missing, incorrect, insufficient or inadequate procedures	Routine checks and inspections not conducted
Improper communication pr	Theignored or by-past larmes

Source: Documents Internos da Empresa Studied, 2018

Having diagnosed the motivation of human failure, so that it is effective to eliminate the root cause to inhibit the recurrence of the error, it is necessary to draw up an action plan. Some actions that may betone adas are described in Chart 5.

If none of the factors in the table fit with the analysis, it is necessary to make an evaluation of the cause to understand which failure it correlates more , and the human failures are not limited to the motivations described in Chart 4.

Chart 5 below illustrates some actions that can be taken to eliminate some flaws by skill or motivation.

Table 5 - Actions for Skill and Motivation failures

Actions for Skill Failure	Actions for MotivationAl Failure
Specific individuals need more experience, skills and/or knowledge and these can be obtained with training	Develop trust with the team, connecting results to personal values
Specific task tools and instructions need to be reviewed/improved	Verify influence of leaders during critical work, fostering the approximation of leadership with the operational routine
Communication Process Needs to Be Improved	Seek strategies to improve communication with work team
Workflow needs to be improved	-

Source: Documents Internos Da Empresa Studied, 2018

All actions are applied in the best way to depend on each specific case and can not be only those described above tomitigate human errors, understanding that each event has its particularity of causes and treatments.

In this work, some accidents and incidents were studied to identifytheir possible causes, using the Tree of Causes methodology because judging as the most appropriate for this study, and the treatments are addressed considering the criteria and the relationship with human reliability through the PUMA methodology, as can be seen in the underlying sections.

8 CASE STUDY: ANNALISE OF HUMAN RELIABILITY IN A CHEMICAL INSUM COMPANY

The study presented here was prepared from August to December 2021. The company in question is a first and second generation producer of thermoplastic resins and basic chemical insums with a production capacity of more than 16 million tons/year, with more than 5,000 members.

For the company, Human Reliability is the conjunto of concepts and practices that aim to maximize human performance to eliminate any type of losses and deviations, based on 3 pillars: technology, management systems and behavior and culture.

In it, there is an action in a complex environment in which people, technology, processes and culture interact continuously and interconnectedly. Therefore, it is necessary to develop a new way of thinking, creating a culture with the habit capable of reducing the probability of failures and losses in operations and processes, reflecting in the attitudes and practices of daily life.

- Management system

- All persons must possess the necessary knowledge and skills to develop their work and the people involved in a critical role in operations must be certified and qualified, ensuring a safe and efficient performance.

- Operational leaders should understand how the work is performed and supervise with the vision of safety, understanding and respecting the work to be done. In addition to being aware of human signs such as tiredness, fatigue, insecurity to avoid risks, unsafe situations and shortcuts.

- All those involved in the operational routines should be aware of the risks, safeguards, consequences if there is failure of the protections or non-compliance with the procedure and along with this it is necessary that there is a good planning of the work, being able to identify the correct sequence of work.

- Reliability relates to good communication, being necessary to ensure that the content has been well understood, with messages (standards, procedures, specifications and work instructions) should be simple and effective, making clear the risks of tasks,co-ntroles and safeguards.

- Culture and behavior

- Continuous learning about how and why problems happen through methodologies (root cause analysis) to find possible triggers of critical events. Many of the causes can be related to human factors,

such as: use of shortcuts, distractions, poor planning, exaggerated self-confidence. Leaders should ensure that incidents, causes, and lessons learned are widely communicated and understood by all.

- Culture of security reports: without fear of retaliation or take the blame, afinal all are susceptible to errors.

- Technology

- Interaction between people and machines. The design and layout of the equipment should be designed to ensure people movement, concentration on tasks and communication, without risk to health and safety so that the interfaces between man and machine should be designed to minimize a potential human error.

In addition, it is understood as a fair culture that seeks not only to hold the organization or individual actions responsible in the face of incidents, but encourages the reporting of these and the responsibility and learning with the use of new methods of investigation. All these concepts will be based on a culture in which security is a non-negotiable value, sustaining and guiding all behaviors and actions.

Considering all the concepts that encompass Human Reliability in the company's view, the present study was based on reports of some accidents and incidents that occurred during the decade of study.

These reports contain the analysis of the events carried out by a multidisciplinary team. First, a survey was made of the facts of the event, listening to those involved in it, followed by analysis of the root cause and defined the negotiations for each event. Based on the information present in these reports, *the analysis perceptions, unable, motivation, ability* (PUMA) and suggestions of actions to eliminate the root cause of the events, as will be seen in the Results and Discussions section were performed.

The Maintenance Intervention period involves a large number of people from various specialties. These, being members belonging to the company itself that is undergoing intervention, or even of companies providing service. Given this larger number of people performing services, there is a need to manage risks in order to prevent the occurrence of some accidents and incidents, so the importance of the study of human reliability is perceived.

This research aims to analyze the importance of Human Reliability for safety during operation in industries, considering the context of organizational changes, human and governmental factors, the product market, competitiveness factors, among others, as can be seen below.

9 RESULTS AND DISCUSSIONS

The results of the study carried out in this study are presented in this section.

accident and incident analyses

The data of events that occurred in the company in question were extracted from the period of 10/01/2011 and 10/01/2021, a decade in which the human reliability analysis presented in this study will be performed. During this period, there were 5 maintenance stops in the company, as can be seen in Chart

6, and they focused on operating systems and the physical proximity of the scope, always respecting the systematics and operational logic. Table 6 below illustrates the year and duration of each maintenance intervention that occurred during the decade of study.

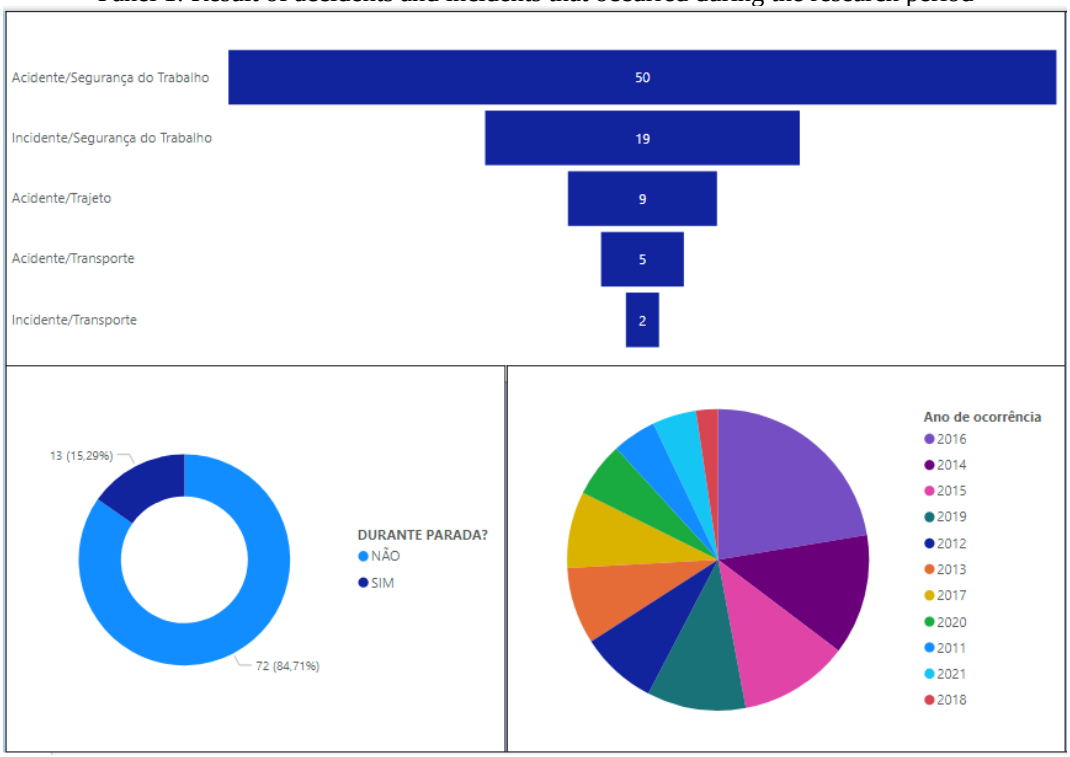
Table 6 - Maintenance Intervention Information

Year	Stop Duration
2012	14 days
2014	16 days
2016	19 days
2019	35 days
2021	38 days

Source: Prepared by the author (2021)

For better visualization of the role of human reliability in these events, only accidents and personal incidents related to occupational safety and accidents and incidents during the transport of material and on the journey during and to work were filtered for analysis. The events related to process safety, environment, patrimonial and material were disregarded, como can be seen in Painel 1 below:

Panel 1: Result of accidents and incidents that occurred during the research period



Source: Prepared by the author (2021)

When analyzing the studies of accidents and incidents that occurred, considering the period of 10/01/2011 and 10/01/2021, i.e., a decade, fifty accidents related to occupational safety, nine road accidents and five traffic accidents were found.

In relation to the incidents, nineteen related to work safety , two transport incidents were found. Of the total amount of accidents and incidents found, thirteen events occurred during maintenance

interventions and seventy-two events in normal plant operation. At the same time, the year in which there was a higher report of occurrences was 2016, as can be seen in Tabela 1, as follows:

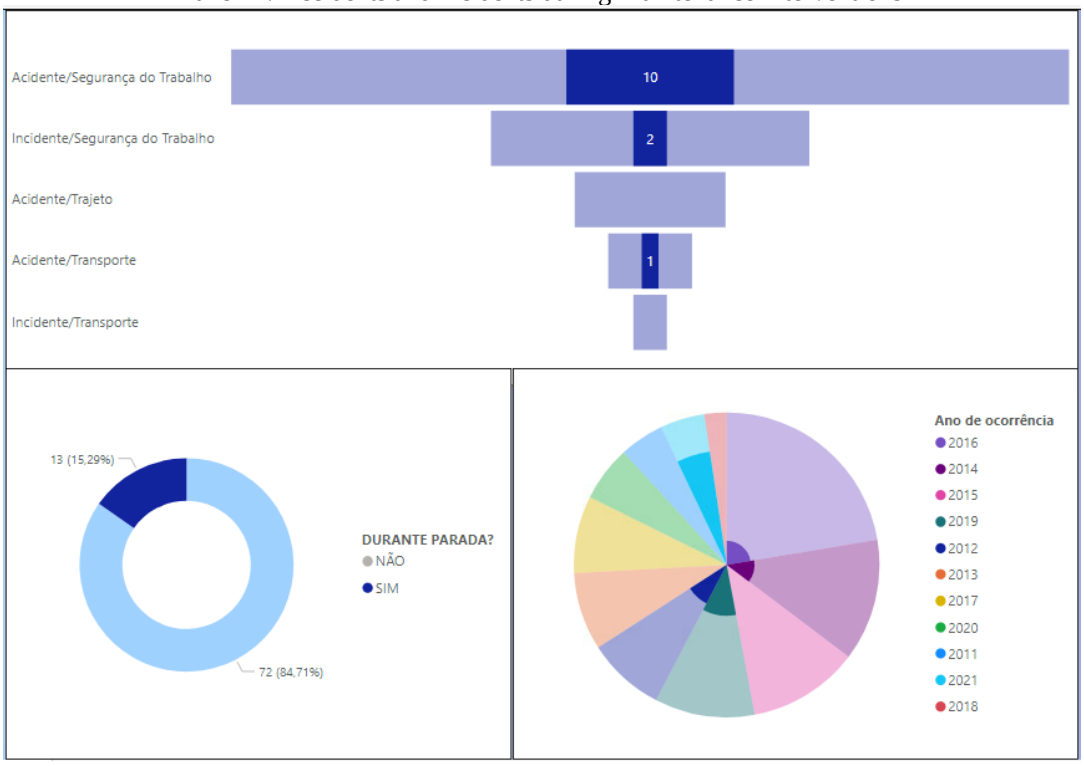
Table 1 - Occurrences per year of winds in the plant

Year	Occurrences
2011	4
2012	7
2013	7
2014	11
2015	10
2016	19
2017	7
2018	2
2019	9
2020	5
2021	4

Source: Prepared by the author (2021)

It is worth mentioning that,because of a better analysis of occurrences, only the events that occurred during maintenance interventions are addressed in this work. Thus, dthe data presented in Panel 1, the events that are studied were filtered and as a result we have Panel 2, as can be seen below:

Panel 2 : Accidents and incidents during Maintenance Interventions



Source: Prepared by the author (2021)

As can be seen in Panel 2, during the period analyzed, there were ten occupational safety accidents, two occupational safety incidents and one transport accident related to maintenance intervention. Two of these events occurred in 2012, two in 2014, three in 2016, threein 2019 and three in 2021.

It is noteworthy thats Panels 1 and 2 were generated fromthe microsoft power BI tool, where you can visualize the data using the unified platform for BI (business intelligence) in which you can obtain more in-depth analysis of the data.

10 RESULTS OF HUMAN RELIABILITY ANALYSIS

From the survey ofthe events, describedin the previous section, information regarding the description and negotiations of each of them were collected. For detailed analysis, in thisresearch, three accidents and one occupational safety incident occurred during the decade of study are addressed, these will be described in the sequence.

Some hypotheses that justify human failure were considered for the puma classification and analysis of the events. These hypotheses are described in the columns of "Relevant Facts" in tables 7, 8, 9 and 10 and include information obtained through the reports studied and also other factors that were created as possible in cada occurred, because the reports did not provide sufficient data. This information is indispensable for the association of PUMA factors related to each human failure.

Thus, in the sections below are described the events, as well as the mappingof theroot cause and PUMA analysis. In the figures where the cause trees are exposed, the blocks filled with gray coloration are classified as root causesof the events.

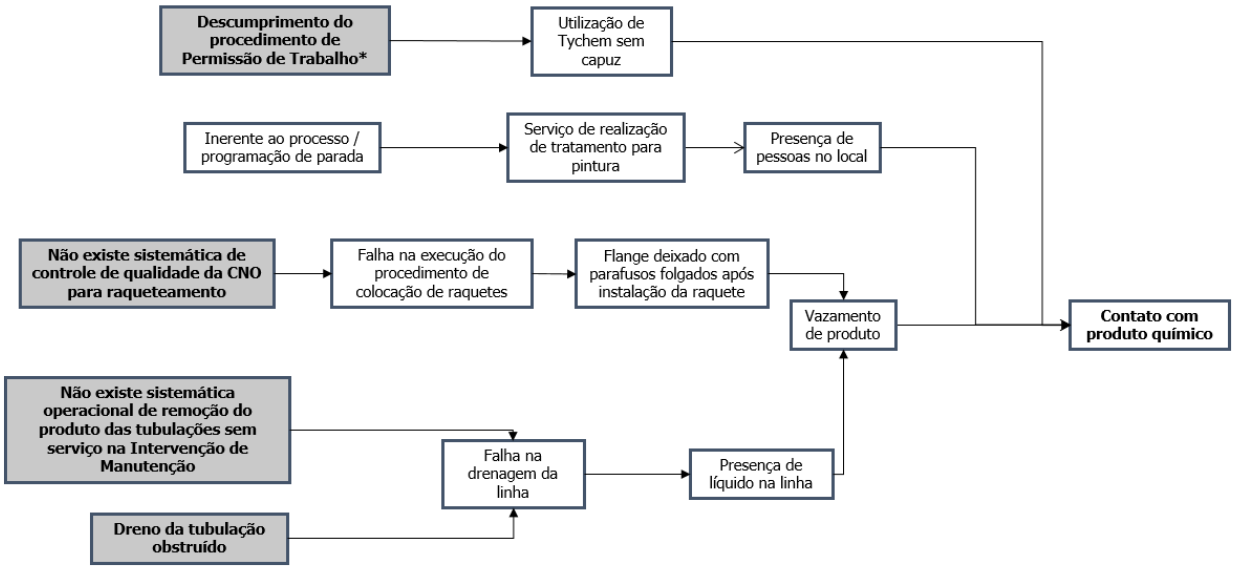
Accident 1 - Contact with Chemical in the Region of Pescoço

Accident 1 occurred in 2016 and is related to Work Safety and classified as the work-free worker 's (APS).

Event description: A member of the maintenance team, while positioning himself to resume service in the area, was hit by chemical spatter in the neck region and speculating. Immediately the same addressed the emergency shower, while the other performers were calling the leadership to inform about what happened and move forward with the actions of medical care.

The root cause analysis for the accident described above can be seen in Figure 4.

Figure 4 - Root Cause Analysis of Accident 1



Source: Prepared by the author (2021)

* Racketing - Insulation of a stretch of pipe.

As seen in the causes tree, Figure 4 above, the relevant facts related to puma analysis for this accident are:

Table 7: relevant facts and puma analysis of accident 1

Root Cause	Relevant Facts	Skill or Motivation	Isolated or Systemic
Non-compliance with procedure - Misuse of safety equipment	Training does not address the use of Personal Protective Equipment as relevantly	Motivation - Non-compliance with standards for inattention to the accomplishment of the task	Isolated
Failure to perform the racket procedure, in which the screws were loose and so there was product leakage	- Lack of operational retraining in relation to some activities, with the objective of ensuring the updating and maintenance of knowledge - Routineand low complexity tivity, generating self-confidence and modifying the work sequence	Motivation - Failure to perform the service due to lack of training; Routine checks and inspections not conducted by prioritizing other demands.	Isolated
Lines containing product during maintenance intervention	Lack of maintenance planning to ensure safer intervention	Skill - Lack of procedure for removing products from pipes without maintenance intervention services	Systemic

Source: Prepared by the author (2021)

As corrective actions forthis accident, it is possible to:

- Conducting behavioral dialogue with the team, emphasizing the importance of the use of personal protective equipment;

- Review procedure for racqueting service;

- Creation of procedure to systematize that the entire area is without products in the production lines during maintenance intervention period.

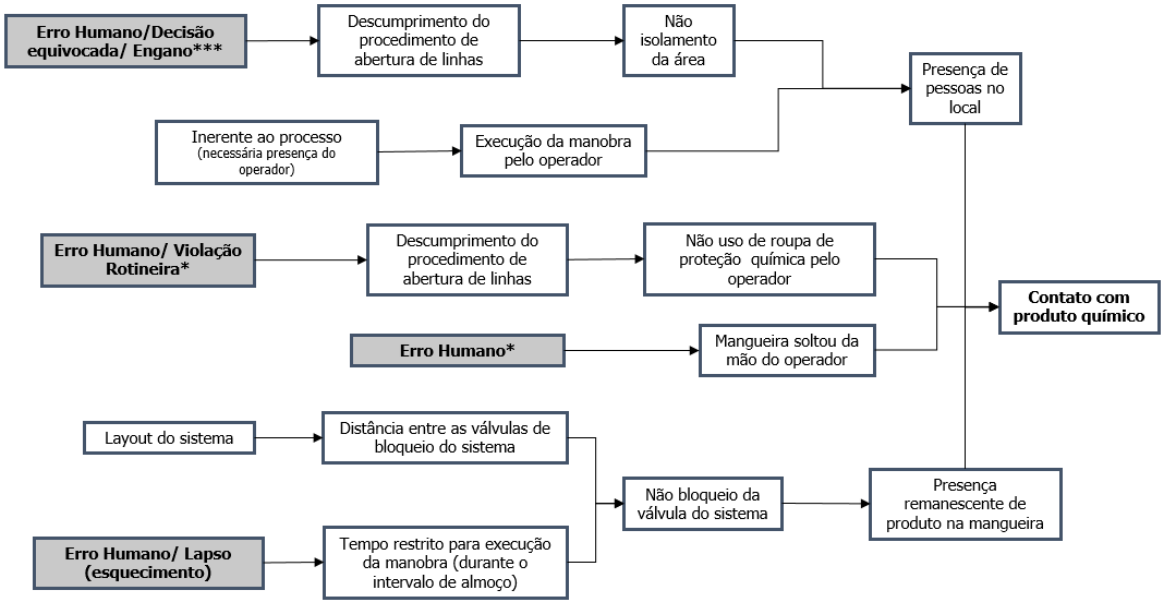
Accident 2 - Chemical Contact byD-detachment of Equipamento

Accident 2 occurred in 2016 and is related to Work Safety and classified as an accident at work without leave (APS).

Event description: Durante release of the separation vessel system, h hearscontact of the chemical produt inthe neck region, due detachment of the hose that was being used to purge the system.

The root cause analysis for the accident described above can be seen in Figure 5.

Figure 5 - Root Cause Analysis of Accident 2



Source: Prepared by the author (2021)

As seen in the cause tree, the relevant facts and puma analysis for this accident are seen in Chart 8.

Table 8: relevant facts and puma analysis of Acidente 2.

Root Cause	Relevant Facts	Skill or Motivation	Isolated or Systemic
Human Error - Member disconnected the hose and did not close the drain valve	Poorly elaborate procedure, making it difficult to understand the member	Motivation - Non-compliance with the procedure of opening lines due to lack of training	Isolated
Human Error - Detachment of the hose from the hands of the member.	Routine activity, generating self-confidence and modifying the way of working	Motivation - Use of equipment incorrectly due to lack of adoption of safe behavior	Isolated
Human Error - Non-compliance with protection standards	- Donot use personal protective equipment due to lack of safe behaviour; - Awareness of deficient risks (classification of scenarios with moderate severity).	Motivation - Falha in risk management	Isolated
System layout	Failure of operation in valve lock system because of the distance between points	Skill - Very complicated or costly man-equipment interface increasing the chance of errors	Systemic

Source: Prepared by the author (2021)

As corrective actions for this accident, it is possible to:

- Conducting behavioral dialogue with the team, emphasizing the importance of the use of personal protective equipment and the performance of services at appropriate times;

- Review procedure for opening lines;

- Review of the layout of the system.

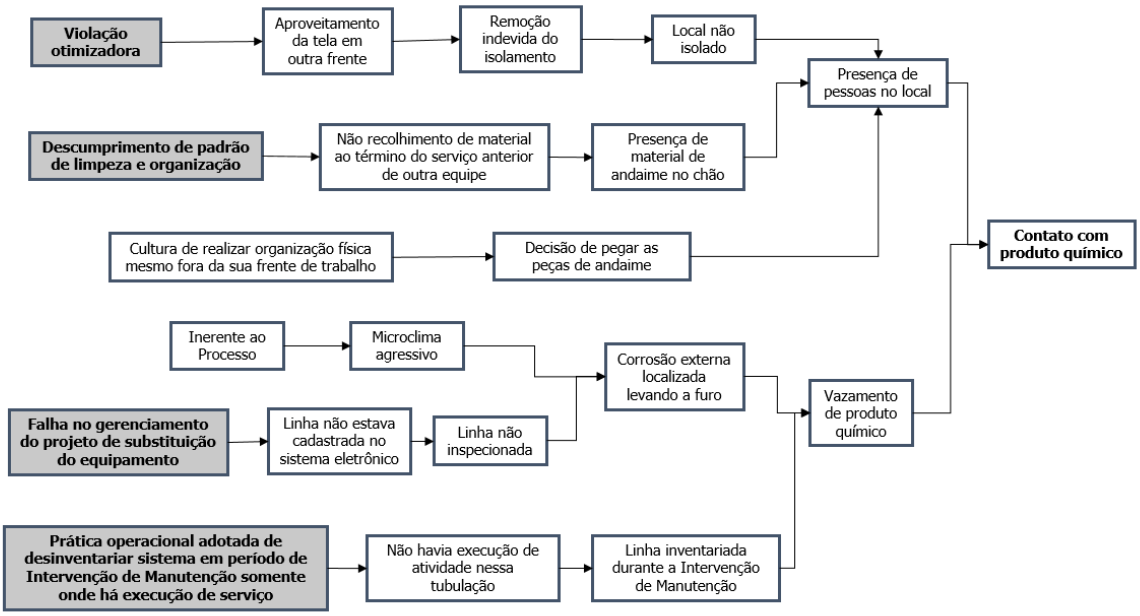
Incident 1 - Contact with ProductQ químico andm Area Isole

Incident 1 occurred in 2016 and is related to Work Safety.

Event Description: On day 1, a member prepared the area to wash and release the vessel in an area that is permanently isolated due to the presence of dangerous chemical.

On day 2, another member completed the internal washing of the vase and the post completed the service,headed for lunch. In this period, a third member realized that there were loose scaffolding parts in the region of this system. In order not to leave the loose parts in the area, he tried to collect them to put in the cart that was nearby and at this time received splash of the chemical on his arm and back. The root cause analysis for the incident described above can be seen in Figure 6.

Figure 6 - Root Cause Analysis of Incident 1



Source: Prepared by the author (2021)

As seen in the cause tree, the relevant facts and puma analysis for this accident are seen in chart 9.

Table 9: relevant facts and puma analysis of Incidente 1.

Root Cause	Relevant Facts	Skill or Motivation	Isolated or Systemic
Non-compliance with the standard of cleanliness and organization	Processo of poor communication between service teams (the member did not communicate to the responsible for the activity the presence of materials in the area)	Motivation - Non-compliance with the procedure for incomplete service (presence of materials still on site)	Isolated
Equipment replacement project management failed	Line drilled by fplanned inspection high (systematic management of poor maintenance)	Skill - Due to lack of maintenance management	Systemic
Optimizer Violation	Uninsulated site, allowing the passage and approximation of people (failure in risk management)	Motivation - Non-compliance with the procedure due to failure to perform the task and lack of technical knowledge	Systemic

Source: Prepared by the author (2021)

As corrective actions for this accident, it is possible to:

- Conducting behavioral dialogue with the team, emphasizing the importance of compliance with procedures;

- Conducting behavioral dialogue on the importance of isolating the area for performing services;

- Registration and review of data in electronic system;

- Conducting behavioral dialogue reflecting on personal and professional customs interfering in performing tasks in the safest way.

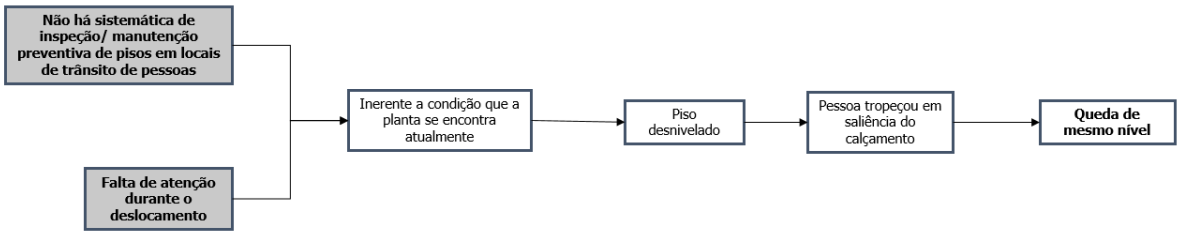
Accident 3 - Member fall during displacement

Accident 3 occurred in 2019 and is related to Work Safety and classified as an accident at work without leave (APS).

Event description: During commuting to participate in a meeting, member stumbled across the pavement and came to fall to the ground.

The root cause analysis for the accident described above can be seen in Figure 7.

Figure 7 - Root Cause Analysis of Accident 3



Source: Prepared by the author (2021)

As seen in the cause tree, the relevant facts and puma analysis for this accident are seen in chart 10.

Table 10: relevant facts and puma analysis of Acidente 3.

Root House	Relevant Facts	Skill or Motivation	Isolated or Systemic
Lack of systematic inspection/ preventive maintenance of floors in traffic locations	Classification of scenarios with moderate severity, and there are no complementary studies of risk analysis	Skill - Lack of infrastructure inspection	Systemic
Lack of attention during displacement	- Tirednessafter more intense work - Distraction when stirring in the celular	Motivation - Human error	Isolated
Uneven floor	Heavy rains during the event period, compromising the integrity of the floor	Skill - Hostile work environment increasing the chance of error	Systemic

Source: Prepared by the author (2021)

As corrective actions for this accident, it is possible to:

- Conducting behavioral dialogue with the team, emphasizing the importance of attention during displacement or performance of any activity;

- Preparation of the schedule of inspection and maintenance of irregularities in floors, streets and sidewalks throughout the industrial area.

Perante all root causes that have been exposed and understanding that factors related to human causes of failures by skill and motivation end up correlating to culminate in an unwanted event, it is notorious the importance of studies on human reliability in environments with high risk in the operation. Therefore, factors such as the review of procedures, the need to reinforce the importance of carrying out these and performing tasks with as much security as possible, together with the guarantee of a good comunication processand understanding of all are important for operational and personal safety.

As factors related to procedures were found in a large amount of the root causes of the analyzed events, the one described by David Embrey (2000) *apud* Figueiroa Filho, (2010) in the theoretical framework, that one of the main factors affecting productivity is the rejection of the misuse of routine procedures was confirmed.

At the same time, it is perceived that behavioral dialogues should be part of the routine of the operation and the guarantee of a psychologically safe environment is a crucial factor for the establishment of safe behaviors and the development of actions to eliminate the potential causes of human failures. Moreover, it is evident the importance of the role of leadership in the investigation of events and directing efforts to eliminate the causes of accidents, in addition to ensuring a work environment more conducive to safe behaviors and consequent guarantee of greater human reliability.

In addition, afterthe study and analysis of accident and incident reporting data, the point of vulnerability was perceived in the process of consolidating the relevant information of the events, where in the system there was a lack of relevant data for human reliability analysis at each time.

11 FINAL CONSIDERATIONS

This study aimed to analyze the occurrence of accidents and incidents, in the light of Human Reliability during the Maintenance Interventions of a chemical insum industry. At the same time, it verified the importance of human factors in ensuring safe industrial environments based on psychological safety and their interference in the lower number of human errors and failures. At the same time, from this study, we perceive the relevance of leader-led communication in the process of fostering safe work environments.

Regarding the importance of human factors in ensuring safe industries environments, it can be observed that in all events analyzed these contributed to the failure that occurred, being present in the root causes of accidents and incidents. Therefore, it is necessary to define risk analysis taking into account human factors for the definition of more efficient safeguards.

With regard to communication, it is understood the importance of this in the management of operational routines and the role of leadership in ensuring a work environment in which people are understood and feel psychologically safe to share thoughts that may come to aggregate in the development of activities. Moreover, communication is perceived by influencing the safe behaviors and carrying out the activities from the existence of the "traps of communication", where what is not always said is understood. As seen, individuals should always seek a safe culture, where safety is valued before rapiten in performing a task, dedicating attention and care to this and thus seek to eliminate the occurrence of accidents and incidents.

The main results showed that the misuse and ignorance of the procedures and work instructions are present in most of the root causes of accidents and incidents in industrial environments and, given that these are fundamental for the execution of activities, it is possiblethat in the execution of tasks during maintenance interventions they must beof critos for greater support during activities and consequent improvement of human performance and as important as its development is periodic updating, availability and easy access of these to members.

Therefore, the expectations before the study of the importance of the human factor for ensuring a safe environment were met, emphasizing that more and more incidents should be reported in a thorough manner, facilitating the identification of the root cause of the problems encountered in the company for further elimination and mitigation of errors. In addition, the events analyzed in this study should serve as knowledge for new strategies to emerge to promote Human Reliability.

As lessons learned in the development of this work arises the recommendation of consolidation of information about accidents and incidents in a single platform and in the most complete way possible, enabling the total management and analysis of events, not being necessary to define premises for this. Thus, it is believed to be more assertive to define new scopes of reliability, because from past errors it is possible to determine strategies to avoid them in the future.

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