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Analysis of Reliability Mapping in Refining Industry: Identification of Critical Regions and Interventions in Complex Production Systems

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Abstract

The article aims demonstrate the importance of reliability mapping for decrease risks of shutdown and accident in critical activities. For mapping is needed to know the operational context, considering culture and deviations that between with other factors will be occasion total failure. The analyses of sociotechnical reliability need of mapping of human, operational, process and equipment reliability to occur, besides considering the system complexity and the social attractiveness, for that this way be possible the elaboration of efficient barriers. The reliability mapping demands tools in the area of social and human risk analysis, analysis of the task with the evaluation of the environment of the activities, project of work, analysis of human factors, identification of work behaviour for cultural transformation, leadership style for process safety, culture of guilt and fair culture, dynamic risk management, energy reliability and good energy practices. The Socio Technical Reliability Analyses – STRA is a more complete tool for the analyse of systems and decrease of risks. With this mapping, it is possible to identify the industrial areas that have the greatest influence on the losses occurred in the industrial context, after that it is possible use the information for make an using fault tree analyses & decision diagram. That provides for the manager makes decisions with a solid knowledge base. The methodology aims through application of tool, demonstrate the use in analyses of parameters and construction of sociotechnical reliability mapping, identifying the tasks, equipment and process that cause shutdown. After reliability assessment, it continued with barriers analysis using fault tree analyses & decision diagram tool. The conclusion is about understand different cause considering STRA and demonstrate the decision-making processes importance to take corrective and preventive actions.

Keywords: Reliability; Operations; Reliability, Factors;

1 Introduction

The article aims to demonstrate the importance of reliability mapping for industry sustainability through a case study in the application of the Socio Technical Reliability Analyzes (STRA) tool. In this paper, the mapping will indicate which vulnerabilities impact on Refining unit reliability. It is intended to elaborate tactical procedure for decision making about the contributing factors in the reliability of this system. By identifying the causes, priorities and impacts, it is possible to decide on actions in a timely manner by returning the industrial unit to its normal state, that is, operating at full load, specified quality and positive image maintained. Finally, it is proposed to provide a tool to assist in the maintenance of Organizational Resilience.

For this analysis to be carried out effectively, it is necessary to know the operational context, identifying cultural aspects, such as normalization of deviations, aspects of operational discipline, technical-organizational changes and communication, as well as process and equipment characteristics.

As discussed by Ávila [1], the STRA tool aims to increase the competitiveness of the production systems analyzed, reducing the number of failures and increasing the socio-technical reliability. Sociotechnical reliability, also known as integrated reliability, is calculated from knowledge of the operational context, human factors and technological constraints.

This paper continues to investigate reliability, but from a strategic point of view come into the discussion on organizational resilience. The STRA bases are applied to cases of the oil refining industry, with information from articles, interviews and actual data, making decision-making more evident regarding the resulting scenarios (normal situation, process uncontrollability, controlled stop and accident).

It should be noted that in complex systems, such as the refinery case, the risk is dynamic and involves a variety of task, process, equipment and human factors. In order to avoid deviations that generate accidents, a detailed risk analysis must be done, which will entail the construction of barriers with incisive action in the cause of the problem. Even though it is human, social and or technological in nature.

The complexity of this system comes from operational routine inserted in process characteristics, communication difficulties and inadequate task planning. This scenario indicates the existence of systemic failure in the operation. This failure can lead to reduced performance in production, downtime or in extreme cases accidents and disasters. Thus, being very important the case study as presented in this article, where will be made a link between all these factors in decision making and their consequences in the refinery.

1.1 Systemic Failure

Industrial technological development has been used to increase production and diversify the quality and types of products demanded by the Company. This increase in scale while preserving the image of accidents and environmental impact has brought the characteristic complexity of systems and organizations [2].

The technical complexity comes from new intricate and interconnected processes [3] that require a high level of automation. The reliability of complex systems may therefore not meet the standards expected by the Organization [4]. That is, in this type of industry there will be systemic failures (operation, equipment, instruments and or operators will suffer from failures).

The failures that occur in complex industrial systems represent losses, which can be financial, imaging and even human, on a large or small scale. Oliveira, Paiva and Almeida [5] state that although no system is indifferent to failures, in some cases failure is not an option as it can result in catastrophic events. Considering this, efforts must be made to identify inaccuracies and create barriers to prevent failures and to prevent emergencies and accidents.

Early diagnosis of process disturbances, equipment malfunction and other unwanted events plays an important role in terms of safety as well as improving process / equipment efficiency and providing better results in product quality assurance [6]. Thus, demonstrating the importance of a study of socio-technical reliability, indicating which areas are most at risk and finally how to proceed after the analysis, investing in the prevention and contingency of failures.

According to Gagliano [5], the most commonly used techniques such as Failure Mode and Effect Analysis (FMEA), Failure Tree Analysis (FTA), Cause and Effect Diagram, Pareto Diagram, Five Whys, among others, cannot always reach the root cause because they address the immediate cause, especially when physical, equipment, or process causes are identified. Thus, neglecting the impact of human and organizational interactions on the system, the socio-technical mapping then appears as an alternative to remedy this lack by analysing the entire physical and cognitive set.

1.2 Risk and reliability

According to Bharatiya [7] an example of industrial hazards is the handling of flammable products, which can cause fire, explosions and impact workers and surrounding areas as well as economic losses, plant downtime, environmental impact, damage to equipment, damage to company image. Therefore, it is necessary to analyse the risks to avoid the occurrence of failure events using physical barriers (PSV for example), cognitive barriers (redundancy in communication) and management barriers (more assertive decisions).

According to Ávila [8] the operational risk management model requires that technical and social aspects be correlated at different levels of normality / abnormality of processes with the consequences and impacts they produce on their own business, the environment and society. Keep in mind that risks are dynamic and must consider the influence of the ever-changing process, tasks, equipment, culture, and human factors for a good definition of management strategies.

1.2.1 SPAR-H

It is important to recognize the influence of human factors in the calculation of integrated reliability in the operational context. A complex industrial unit needs people who have the experience, the mind to avoid deviation and to make decisions. However, it is known about the variety of psychological stressors that influence the quality of information for the operational routine. This can lead to human errors, deviations or incorrect decisions.

SPAR-H [9] is a document that discusses human performance factors (PFS's), the relationship between these factors and the failure of the operation and may even involve accidents. SPAR-H describes eight PSF's for calculating human reliability: time available, stress level, complexity, experience / training, procedures, ergonomics, work ability and work process.

These factors, although classified as human, involve organizational, managerial aspects and depend on the type of process and product technology involved. On the basis of the discussion on sociotechnical reliability, technology and culture should be fully known to the reliability investigator.

According to Ávila [10], the Organization should understand about cultural events that cause variation in behavior and, if not perceived by the leadership, creates a climate of coexistence with deviations. These initial deviations if left untreated can lead to disaster. Therefore, in the construction of the study made in this article, using the bases of STRA [1], the human reliability in the refining process is calculated.

In this case, it is noted that due to the operational context differentiated by geographical, cultural and technological issues, the indicators resulting from reliability will differ from those resulting from human factors.

The relationship employees have with the company and its organizational culture will reflect on how the employee validates and understands the company's mission, vision and values, affecting its performance and satisfaction [11]. Considering that published employee policies are supported by leaders through real-world examples and that tools are available to carry out best practices in the operating routine, it facilitates agreement on organizational values by validating the company's mission and vision.

It should be remembered that the organizational climate may or may not improve employee productivity, a strong organizational culture, will have leaders who make quick and assertive decisions, and willing and committed employees.

1.2.2 Sociotechnical Reliability

Ávila [12] proposes that industrial reliability should not be analyzed independently and in isolation, that it is necessary to make a calculation that includes human, equipment, process and operational reliability through equations defined after complexity analysis and calculation.

The evaluation and calculation of integrated reliability, using the proposed method [12], has the function of showing that human failure has a considerable contribution to equipment failures. Built-in reliability enables better visualization of the operational context for decision making, without its decisions will only have a localized effect, not reaching the root cause of the problems.

Considering this, [1] proposed the STRA tool, which is represented by a block diagram to map sociotechnical reliability. This map assists management decisions made to improve productivity and industrial safety. The proposed equations (Table 1) for calculating human, process, equipment, operational and socio-technical reliability [12] will be used in this case study. In addition, it is necessary to classify the level of complexity and social attractiveness.

Table 1 – Sociotechnical Reliability Calculation

Cx= (1)*(2)*(3)*(4)*(5)*100000	STR=$(PR)^2$*ER*(HR*OR)^1/2	HR = NHEP* PSFc / NHEP*(PSFc-1)+1
OR=(100-(LOG(LC)/4)*100))	PR = (R/ΔL)	
Cx= Complexity OR =Operational Reliability	STR = Sociotechnical Reliability PR = Process Reliability ER= Equipment Reliability	HR= Human Reliability NHEP = Nominal human error probability PSF = performance-shaping factors

1.3 Oil Refinery

According to [13],

> *Refineries are continuously challenged to produce more and cleaner products from a broader range of feeds, preferably with limited or no capital investments. In the short term, changes in spot market prices for both crude oil and products have forced refiners to reevaluate their process options and planned investments in search of higher operational flexibility.*

Processes are always being reviewed and improved to increase the sustainability of refining units, in this case hydrocracking technology. This paper analyses the reliability of the assertive decision regarding the best plant availability and the smallest number of operational deviations.

This challenge of producing more and with differentiated input qualities requires high levels of skill and knowledge in the operating team demanding better team and leadership competency.

Combining improvements in technology and human performance factors avoids increased production costs due to reduced rework, reprocessing and unplanned downtime, avoiding double power consumption and labour application.

The new hydrocracking technology brings cost savings and increases profit margins and is a key factor in achieving faster setup change and keeping in sync with market fluctuations [13]. This chemical process is complex and requires great reliability to maintain quality production and financial return without process losses.

According to [14]:

> *the industry interconnections and controls complexity can bring characteristics that make it difficult to control processes and variabilities that are hidden in the system connections, flow information, and large data that travel through control signals present in the chemical industry.*

Refining technology is included as energy intensive where reliability concerns are increased. Since poor performance and downtime causes high energy loss [15].

Hydrocracking is highly exothermic indicating that temperature reduction is critical control for safety and production costs [16]. In the case of security events, fires and explosions can occur, bringing together the issues of management decision, technology and human error that cause accidents and plant shutdowns.

2 Methodology

The methodology of this work (figure 1) serves the Manager of Complex and High-Risk Industrial Units for safety events and production cost.

The initiation of the investigation requires (1) operational context analysis and complexity level classification with details on Process and Product Technology. To build the operational context, it is also necessary to study or analyse the level of safety and organizational culture. Safeguards already installed should be identified and the operating routine as well.

In the operational context, a preliminary identification will be made of the types of failure of this operating unit that cause downtime or loss of performance, thus indicating the functions, equipment, tasks and critical regions.

The operational context analysed will also be used for (2) the construction of reliability mapping. This mapping uses the bases of STRA [1], through the calculations and estimation of the integrated reliability. Expert knowledge and literature will identify the main systems that cause the refining industry to fail.

From the reliability diagram we investigate the most frequent and most severe type of failure due to technology, culture and impact on human factors. The (3) fault tree is made with systems with probability of explosion in case of sequential errors.

Safeguard operating modes (4) are discussed and analysed after the fault tree has been created. It is necessary for the manager to understand the modes that the failure can generate. With this knowledge, be able to discern the best option to maintain the normal functioning of the plant or return to the state of full availability.

The strategic point of view of this work culminates in the elaboration of the (5) Decision tree with actions. From this tree managers will be more likely to take the necessary steps to keep Resilience operational.

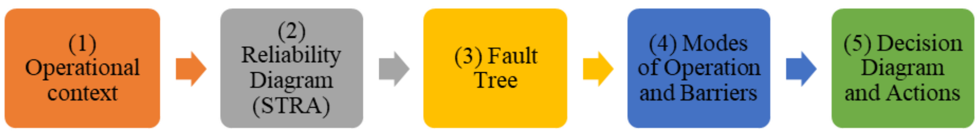

Figure 1 - Methodology

3 Case study and Discussions

This paper discusses a case study in a Brazilian oil refinery industry that uses hydrocracking technology. The database for the discussion of the results will be built on expert opinion, previous research data and articles already published.

In the application phase, an exercise was performed in a refining unit with hydroprocessing and hydrocracking technology (Figure 2). Refineries have constant challenges in using cleaner technologies. In addition, crude oil price fluctuations force them to re-evaluate the process [13]. As a result, refinery investments have focused on the hydrocracking process with catalytic systems.

These low-cost changes are related to operational flexibility, the industry's need to receive raw materials of varying purity and deliver different products. These changes are also used to increase the return on investment.

To meet these challenges, it is also necessary to study the socio-technical reliability. Despite this, equipment reliability is the most widely used for refineries based on the serial reliability of the hydrocracking process and its fractionator. What this article intends is to analyze reliability in an integrated way, using the combination of human, operational, process and equipment factors.

Equipment reliability is still the most widely used aspect for refinery reliability calculation, based only on the frequency of failures and the failure mode discussion (FMEA) [18]. Although this discussion is extremely important, social aspects are not considered together with the technicians, in other words, the analysis of human and organizational factors in conjunction with equipment and task analysis is not considered. For this, STRA [1] was used to construct a reliability diagram.

In this way we understand that the reliability diagram becomes more complex including the social and technical aspects at the same time. This makes fault analysis, decision tree and system reliability insight more complete to make managerial decision making more assertive.

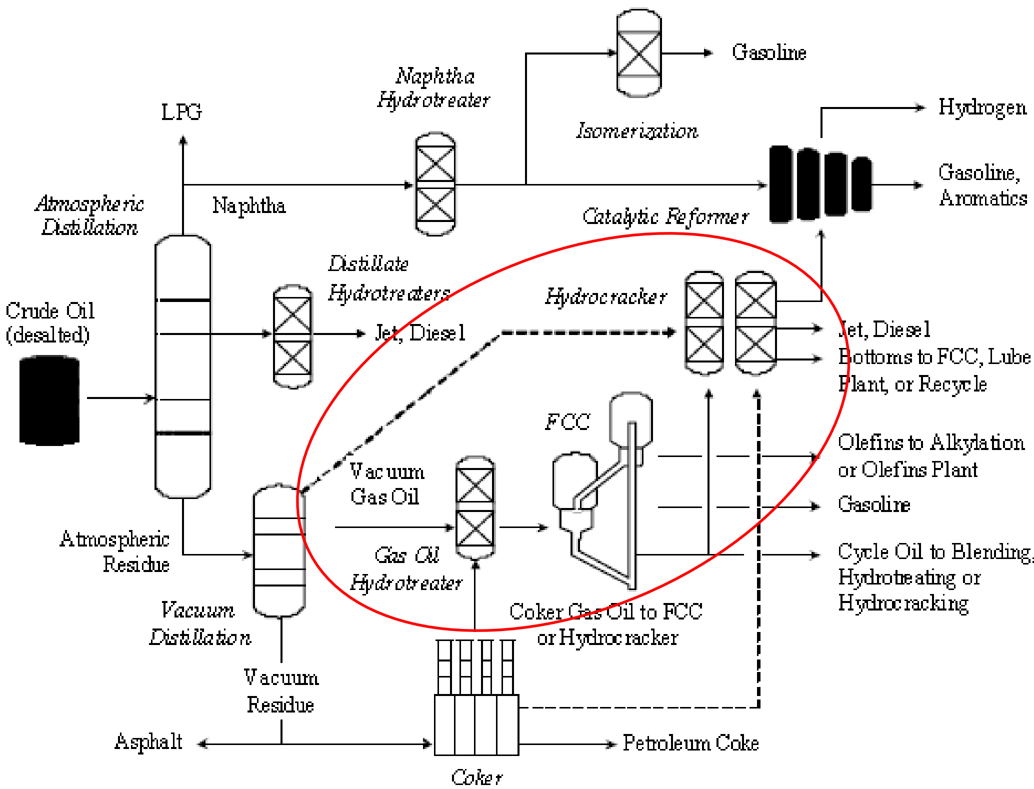

Figure 2 – Hydroprocessing Diagram

For the discussion of the case, the part of the plant highlighted with a red circle in figure 2 will be considered. Contemplating the hydrocracking, hydrotreating processes and the fluidized catalytic cracking unit.

3.1 Operational Context

The first step of the study is to know the operational context in which the analysis will take place, based on literary references and expert knowledge. Using the information required according to the STRA [1], it is important to describe that the refinery is in Latin America, Brazil, has an installed production capacity of approximately 320,000 bbl / d, started operations in 1950. Currently 31 types of products are refined daily, in a continuous process with 8-hour shifts and 10 days of scheduled shutdown per year.

With the need for better profit margins despite being an old plant, the technology was upgraded. In this article, the discussion will considering only these newer units, which use hydrocracking technology, so they have more automation and high complexity.

In this context it is important to emphasize the complexity of the refining unit, considered high according to the STRA guidelines. For integrated reliability analysis this is essential information.

Regarding cultural and management aspects, it is known from experience that underreporting and centralizing information to a slight degree is identified in regional culture. A certain conflict between policies and practices that cause failures, and there may be cultural and barrier degradation.

3.2 Reliability Diagram

Using the bases of STRA [1], it is necessary to map the main functions / activities / processes that affect production. That is, they cause a plant shutdown or greatly decreases production.

For the reliability analysis and better application of the study, a specific part of the hydroprocessing plant was limited. The studied part is composed by hydrotreating, the FCC unit and the hydrocracking, their union in the production process determines a system of high complexity and its stopping implies severe loss of production.

From the know-how of experts and the literature on the subject for the analysis, table 2 was built. It takes into consideration the characteristics of the treatment of deviations and failures in the routine, mapping the main points of production loss and risks of the operation.

Table 2 – Reliability analyses (only <10%)

Systems	Loses %	% functions/processes/activities
Maintenance	20	9% valves and pumps; 55% compressors; 9% pressure vessels; 8% pipe flanges; <10%
Process	30	20% FCC Unit; 8%Distillation; 9% Coker; 40% hydrocracking; <10%
Management/Culture	10	20% Performance reduction by inappropriate decision; 9% unreporting;
Utilities/ Efluents	5	; 20%wastewater treatment; <10%
Operational	15	25% LPG Sulfur Level; 30% Planning and Production Control; <10%
Safety	10	30% H2 Leak; <10% others

Table 2 defines the 8 main functions / activities / processes that affect sociotechnical reliability. Only those with a greater than 10% influence on losses are considered. We then proceeded to calculate the reliability through the equations (table 1) previously defined by Ávila [11], resulting in the block diagram (figure 3) that makes up the result of STRA [1].

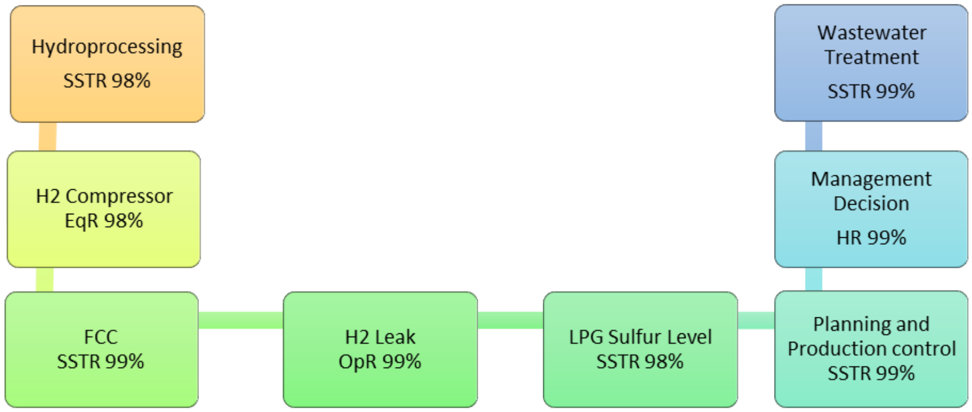

Figure 3 - Reliability Block Diagram of Hydroprocessing

Considering the diagram with established values based on articles and interviews with experts, the final result of reliability diagram is: 89.5%. This result indicates that the plant in this case study operates with a process runaway, which will be analyzed later.

3.3 Fault Tree

From reliability diagram formulated in the previous step, a fault tree was constructed (figure 4). For this the blocks with the highest risk of disaster were chosen, those that together with a spark generate explosion.

The blocks chosen were the hydroprocessing, the compressor and the FCC unit. These units, besides being vital for the maintenance of industrial resilience, also have a high risk. The union of uncontrolled leaks in these areas with small sparks can cause catastrophes, with loss of equipment, image and worse, lead to deaths.

For this explosion not to occur, there must be high reliability and a well formatted hazard containment decision process. This article counts on the construction of this process to help with the management decision.

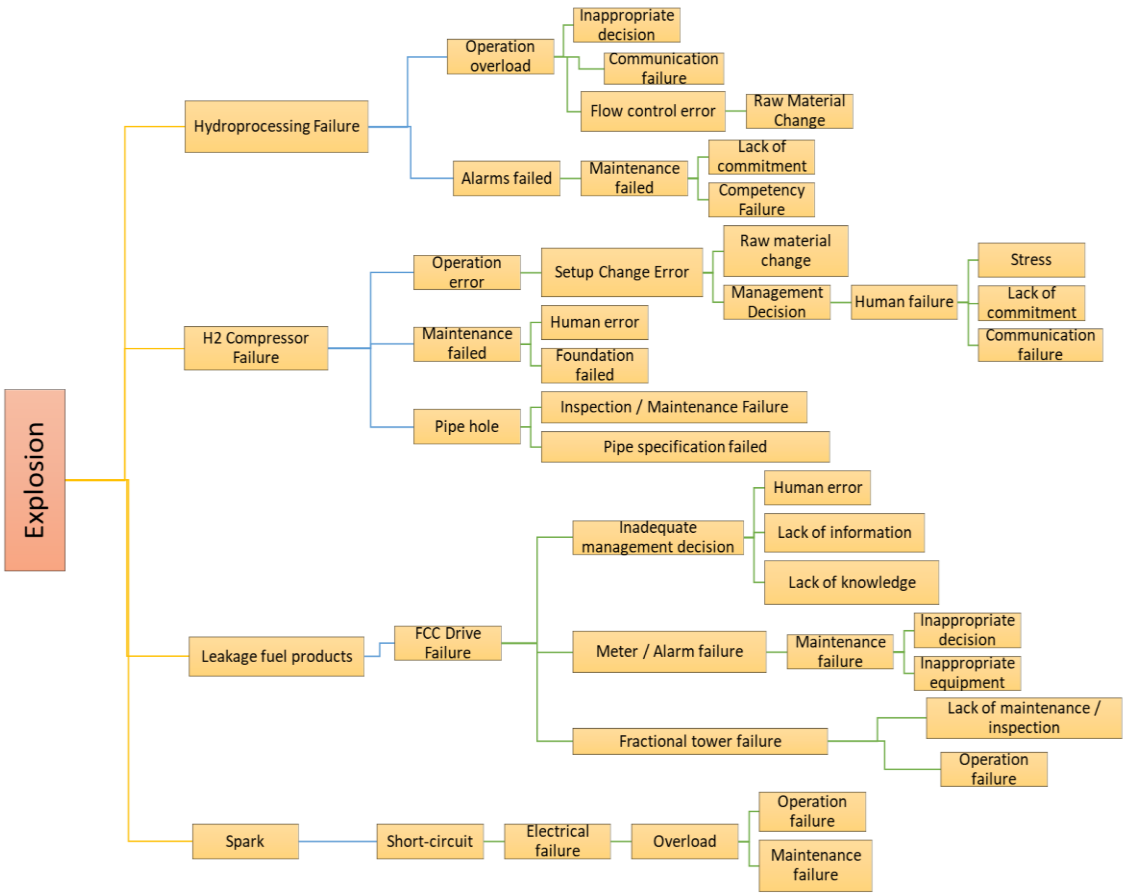

Figure 4 – Simplified Fault Tree

3.4 Modes of Operation

This article considered four modes of operation during the process. In the first case (1) the operation is normal, with no fault intensity, with maximum availability, performance and reliability. (2) After failure, there is a slight lack of control in the process, which decreases reliability and performance rates while maintaining availability, in which case there may be a decrease in production, but the plant is still in operation and decisions have been made correctly.

The third case (3) is controlled stop, after severe failure, the plant could not be resumed and the necessary maintenance leading to a controlled stop as a protective barrier, in this case often human error and / or delay in first decision to resume normality.

In the fourth case (4), the failure occurred and the decision to decrease or stop the plant in a controlled manner or to use an efficient barrier were inefficient or nonexistent, which led to the collapse of the process. Having an uncontrolled or exploding shutdown, financial loss of image and in worst cases the lives of surrounding employees or residents. The modes of operation are described in figure 5.

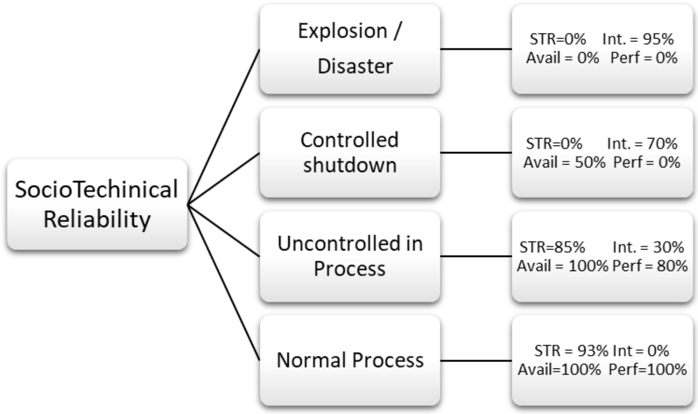

Figure 5 – Modes of Operation

Normal operation has an estimated socio-technical reliability above 93%, performance in this case is 100%, in other words, the plant operates at 100% production load, and 0% intensity as there is no severity of failures during operation. normal operation.

In the emergency with the correct operational control, in time and well done the reliability drops to values between 85% to 93%, that is, the case study of this article, which estimates a socio-technical reliability of 89.5%, is in uncontrolled process also has a fault intensity of 30%. In this case it is still possible to achieve non-stop recovery by only decreasing throughput (80% performance).

For the process to return to normal operation, management decisions must be made based on the cause of the failures. For this case study, management decisions will be exposed in the decision diagram (figure 6). In addition, other risk containment barriers should be used, such as preventive equipment maintenance, staff training, procedural review and operational discipline program.

The third case the operational control fails due to human factors (forgetfulness, lack of competence, incorrect maintenance) the action that would safeguard the plant did not happen and the shutdown will occur to not happen the accident or disaster, in this 3 stage there is a redundancy that is the plant shutdown.

Considering the case studied, an analysis is made for the failure of the hydroprocessing unit. When the quality of the raw material used changes from light, low sulphur oil to higher sulphur, recirculation should increase, so the hydrotreating inlet flow should decrease.

If a decision error occurs, the input stream for a single process can be maintained and an overload can be generated. Increasing the material level in the equipment and consequently the risks of leakage, equipment failure, deteriorated process quality. In order to avoid a decrease in product delivery, spare equipment must be put into operation. If this decision does not occur, the plant may become unbalanced and a forced decrease may occur through the decision.

Another possibility is the decision not to be made, equipment to overload and alarms or meters to fail. In this case, communication between panel and area operators can identify the problem and the management decision to stop the reality restoration operation being made.

If, in addition to overloading and alarm failure, human communication failure occurs between operators in the same class or in shift crossings. The case may not be perceived, thus continuing with the system overload, leading to collapse, a leak accompanied by spark that leads to an explosion, leaving the plant completely unavailable.

3.5 Decision Tree

The decision diagram was designed as a way to keep management safe to take the necessary stances to contain hazards or re-establish order through planned shutdown.

With the reliability diagram, fault tree and knowledge of operating modes, it was possible to construct a decision diagram that should be used by plant leaders to avoid critical situations and explosions. This tree was made based on hydroprocessing failure.

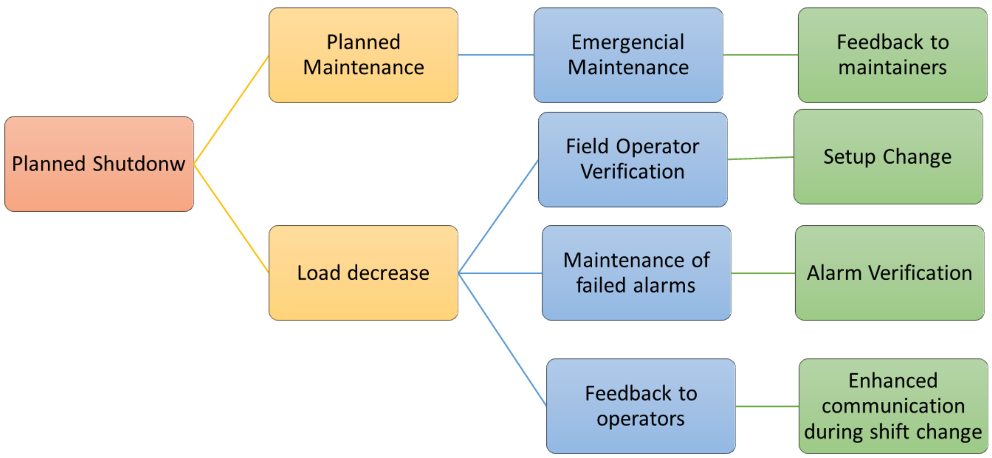

Figure 6 – Diagram Decision

4 Conclusion

This article aims at operational resilience of the plant, assisting managers in decision making intending to avoid the loss state or to return to normal operation. For this it is necessary to go through several steps followed in the methodology.

First, we need to know the operational context, the technology, analyse the risks, the human factors. So that you can calculate the reliability and see the critical areas and functions where the biggest causes of loss are. From then on, decide what are the best actions to take to maintain operational resilience and move to execution with the resources and expertise required to avoid rework.

The article followed the steps until the decision. It is important to know that the data were analysed based on knowledge of experts and literature on the subject, it is expected an approximation consistent with reality.

For this reason, the article demonstrates the need for the approximation between the university and the Brazilian refining industry, which has a great opportunity to improve reliability. With the decision making and the assertive analysis of the current reliability, it would be possible to increase the profit level of the industries and increase the effectiveness of the containment barriers through the execution of the presented points.

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