الجمهورية الجزائرية الديمقراطية الشعبية
People's Democratic Republic of Algeria
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Electromechanical Department

MEMORY

Presented with a view to obtaining a Master's degree

Option: Electromechanical

Risk classifications of failures by fuzzy logic

by

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Promotion 2023-2023

بسم الله الرحمن الرحيم

Achknowledgments

We would like first to thank allah for giving us strength to finish this

work and to overcome the all the difficulties

We would like to express our sincare gratitude to our supervisor

Dr . Zoubir aoullmi

For the constant support and guidance throughout this dissertation without his assistance this reaserch would not have been come to light

Special thanks to the members of the board of examiners. Mr Zoubir aoulmi mr. Redouane Moghrani and mr. louafi messaoud

Examin and impove this work

DEDICATION

To our famillies and friends

To Nasser and chriff

To our classmates

We dedicate this work

...

Nour el islem and ahmed el seddik

ملخص

تحلل الدراسة معلومات فشل آلة تحطيم المادة الخام خلال فترة عامين. أولاً ، نقوم بدمج مؤشرات المخاطر: حدوث (ح) ، وشدة (ش) ، واكتشاف العطل (ك) لوضع الفشل الذي تم تحديده من قبل الخبراء. ثانيًا، يتم استخدام كل من FMEA و المنطق الضبابي لإجراء تحليل وقت التوقف عن العمل. يمكن تحديد غالبية المخاطر باستخدام أي طريقة ، على الرغم من وجود اختلافات كبيرة بينها. لتقليل وقت تعطل سير النقل ، نقترح ضرورة زيادة اعتمادية المكونات الحاسمة. في آلة كسارة المواد الخام في شركة الأسمنت ، تم التحليل باستخدام FMEA الضبابي ، الذي يحدد أولوية المخاطر الكبيرة ، بدقة. و تعيين المكونات التي تتطلب التحسين باستخدام العملية المذكورة أعلاه، وتم تقديم اقتراحات للتحسين وسيتم وضعها موضع التنفيذ حسب الضرورة.

الكلمات المفتاحية: صيانة؛ مخاطر RNP ؛ المنطق الضبابي؛ FMEA. كسارة الخام.

Abstract

The study analyzes failure information for the raw crusher machine during a two-year period. First, we incorporate the risk indicators: occurrence (O), severity (S), and detection (D) of a failures mode that have been determined by experts. Second, both a fuzzy FMEA and an FMEA are used to perform downtime analysis. The majority of RNP dangers may be identified using any method, although there are significant differences between them. To cut down on conveyor belt downtime, we propose that crucial component dependability needs to be increased. On the raw crusher machine in the cement company, the use of fuzzy FMEA, determining the priority of significant risks, has never been thoroughly examined. The components that require improvement have been identified using the aforementioned process, and suggestions for improvement have been made and will be put into practice as necessary.

Keywords : Maintenance; RNP risks;fuzzy logic; FMEA; raw crusher machine.

Résumé

L'étude analyse les informations sur les défaillances de la machine de broyage de matières premières au cours d'une période de deux ans. Dans un premier temps, nous intégrons les indicateurs de risque : occurrence (O), gravité (S) et détection (D) d'un mode de défaillance qui ont été déterminés par des experts. Deuxièmement, une AMDEC floue et une AMDEC sont utilisées pour effectuer une analyse des temps d'arrêt. La majorité des risques peuvent être identifiés à l'aide de n'importe quelle méthode, bien qu'il existe des différences significatives entre elles. Pour réduire les temps d'arrêt de la bande transporteuse, nous proposons d'augmenter la fiabilité des composants cruciaux. Sur le concasseur à cru de la cimenterie, l'utilisation de l'AMDE floue, déterminant la priorité des risques significatifs. Les composants qui nécessitent des améliorations ont été identifiés à l'aide du processus susmentionné, et des suggestions d'amélioration ont été faites et seront mises en pratique si nécessaire.

Mots clés : Maintenance ; Risques RNP ; logique floue ; AMDEC ; broyeur cru.

SUMMARY

Chapter I GENERALY ABOUT MAINTENANCE

Chapter II. Presentation of FMECA method

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Chapter IV

General Introduction

General Introduction

Currently, cement is a rare and highly sought-after material. An important loss of production arises from an unintentional shutdown that lasts a few minutes. Because of this, manufacturers' top priority has always been the control of their manufacturing systems. Undoubtedly, this calls for technical expertise.

As a result, the cement plant's Maintenance department sought to improve this method of planning the maintenance of its machine park, as it was sometimes non-rational, more intuitive, and/or guided by learning phenomena. One option was to have a solid, quality tool that would allow us to view the device to ensure it was kept in the best possible condition. FMEA of criticality is one of the most used methods.

Determining the degree of criticality of the equipment of the subsets of the machine park will therefore be the initial objective of this study. Then, in order to create the appropriate preventive and sometimes even curative activities, we will prioritize them. The main objective of this thesis is to present a general view on maintenance. We insist, in the first place, on these methodological and technical bases, on the one hand. And on the other hand, we use FMECA and fuzzy logic as a global solution, which identifies fairly well the operating problems of Grinder machine in company of cement.

This approach is interesting for technicians and engineers since it naturally leads to selecting the most critical failures and finding reliable solutions.

This work is presented in four chapters. In a first chapter we talk about genera maintenance. In the second chapter, we expose a generality on the FMEA method. The third chapter is devoted to the application of fuzzy logic. In the fourth chapter we are interested in the application of the fuzzy logic method on the raw crusher machine.

Our work ends with a conclusion, which summarizes all the chapters.

CHAPTER I. Generality about maintenance

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I.1 Introduction:

Maintenance is a fundamental process that encompasses a range of activities aimed at ensuring the proper functioning and longevity of systems, equipment, and infrastructure. It is a vital function across various industries and sectors, including manufacturing, transportation, energy, facilities management, and information technology.

The primary objective of maintenance is to prevent or minimize equipment failures, malfunctions, and breakdowns. By conducting regular inspections, servicing, and repairs, maintenance activities identify and address potential issues before they escalate, reducing the risk of unplanned downtime, production losses, and safety hazards.

The importance of maintenance cannot be overstated. Well-maintained systems and equipment are essential for achieving operational efficiency, meeting production targets, and ensuring workplace safety. Effective maintenance practices can result in increased asset lifespan, reduced maintenance costs, improved product quality, and enhanced customer satisfaction.

Maintenance management plays a vital role in organizing and executing maintenance activities. It involves planning maintenance schedules, allocating resources, managing spare parts inventory, and documenting maintenance activities. Computerized maintenance management systems (CMMS) are commonly used to streamline maintenance processes, track maintenance history, and generate reports for analysis and decision-making.

The field of maintenance is constantly evolving, driven by technological advancements and industry best practices. Concepts such as reliability-centered maintenance, condition-based maintenance, and predictive analytics are gaining prominence, enabling organizations to adopt proactive and data-driven maintenance strategies.

I.2. History of maintenance:

For most of our industrial history, maintenance was simple. When it broke, you fixed it .The history of maintenance is as old as that of industry, but it only became a major activity during the 1980s. Even today, many industrial managers do not measure the positive impact of good industrial maintenance management on the activity of their company. Today it is an important performance factor and a source of rapid profits within the company: both in terms of productivity and technology, good management of your maintenance can only have positive consequences for your company and the product you make. **[1]**

I.3. General Definition:

Maintenance is defined as the set of actions that make it possible to maintain or restore an asset to a specified state or able to provide a specific service. Maintaining, therefore, means carrying out operations that make it possible to preserve the potential of the equipment to ensure continuity and the quality of production. **[2]**

I.4. Evolution of maintenance

Like other functions in the company, maintenance is influenced by the company's internal environment, but also and above all external (technological, economic, social, ecological, etc.). [3]

FIGURE I.1. Main environments affecting maintenance

There have been 4 “industrial revolutions” (so far!). Although there were many influences and factors, each revolution had a major technological shift.

The **first Industrial Revolution** occurred in approximately 1784. The main technology shift was related to mechanization. Up until that point, we had to use human or “beast of burden” power to get any manufacturing done. This revolution occurred when some bright innovators figured out how to harness steam or waterpower to do the back-breaking work humans were doing beforehand. Mechanization, aided by waterpower and steam would move to a factorial increase over human powered

The **second Industrial Revolution** started around 1870 when we added electricity to the mix – amazing, nearly unlimited amounts of power. Combined with mass production, manufacturing could now occur at a much higher scale. Henry Ford is the poster child for assembly-line/mass production, but that was closer to 1913. Once the investment was made, factories could churn out exponentially more products due to these innovations.

The **third Industrial Revolution** was in the more recent late 1960s. Robots, computers, and other similar automation were at their more primitive dawn, highlighting a profound technology shift. In the following decades, we have watched these technologies completely modernize factories – with faster outputs and safer working environments.

The current **fourth Industrial Revolution** (estimated to start in 2010) combines all the previous progress, while also employing smart technology to intelligently connect everything: machine-to-machine, people-to-machine, etc. The Internet is a key part of this revolution, but there are numerous other "exponential technologies" (artificial intelligence/machine learning, additive manufacturing, augmented/virtual reality, and much more). The goal is to enable autonomous decision-making processes, and monitor assets and processes in real-time – all connecting back to the business enterprise in real-time. We are just starting this revolution.

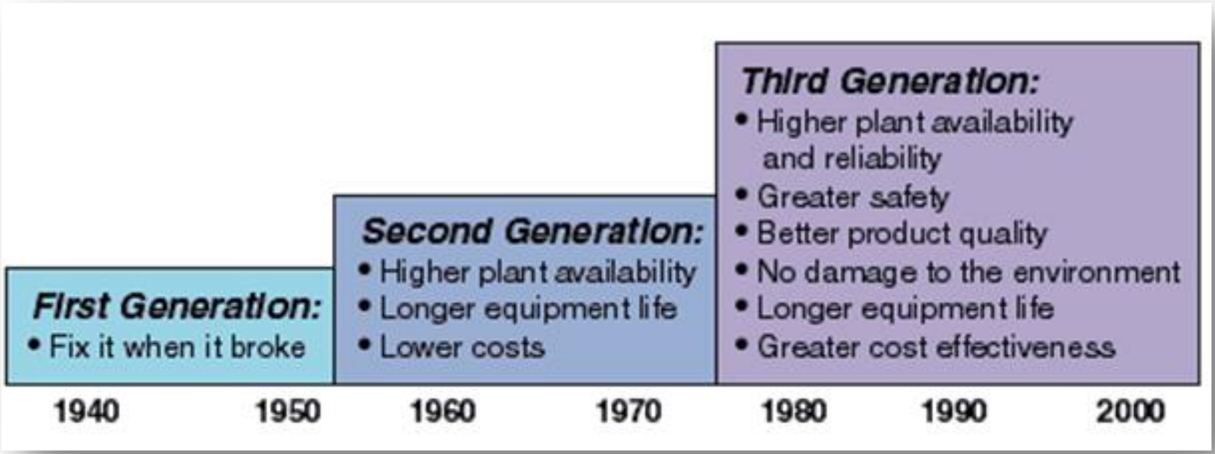

Figure I.2. Evolution maintenance

I.5. FACTORS DETERMINING MAINTENANCE DEVELOPMENT: [4]

1) Technological factors
2) Economic factors
3) Factors related to human behaviour

I.5.1 Technological factors:

Ensuring a dynamic development of industrial enterprises required a basic requirement of introducing technical progress in all areas of their activity. Increasing the competitiveness of industrial enterprises could be achieved only by scientific research and technological development. The rise of the technical level and quality of work of industrial enterprises was achieved by introducing new technologies, based on recent developments in computer science and microelectronics. Electronics and informatics broke into works honing production facilities: the machines are equipped with numerical control, industrial robots have been expanded, flexible manufacturing workshops are developing and automation is present everywhere. There are numerous processes in which the assembly line is programmed by a computer using software archive of the manufacturing sector, thus achieving aided manufacturing.

I.5.2. Economic factors:

The importance of maintenance activity is determined by the major influences that have on the most important economic indicators characterizing an industrial activity, regarding its profitability. The amount of expenses needed for the maintenance and repair of the equipment is influenced by two factors: the number of repairs performed and the volume of the prophylactic maintenance during operation. To obtain reducing overall equipment maintenance and repair costs, we have to act on the two factors.

I.5.3 Behavioural factors:

An important factor in ensuring the efficiency of maintenance and repair is the maintenance staff and the exploiting staff and also the nature of the relationship between them. In the field of human relations, the organization of maintenance work involves preparing forecasts of labour requirements the level of qualification, selection of resources, clearly defining workstations and accurate evaluation of the results of the activity, the formation of a training program, the application of participatory methods, the stimulation of voluntary employment of production operators to maintenance activities, improved working conditions, etc.

I.6. Different types of maintenance: [5]

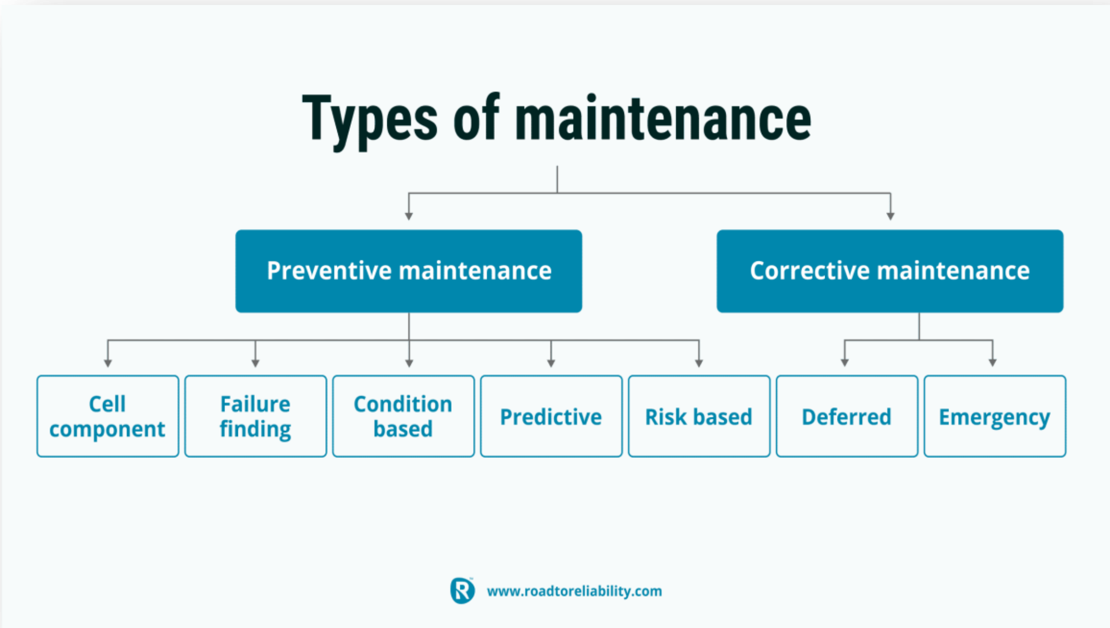

Figure I.3. Types of maintenance

There are 9 types of maintenance split between Preventive Maintenance and Corrective Maintenance.

a) **Preventive Maintenance:**

Is done before a failure occurs and consists of maintenance types like Time-Based Maintenance, Failure Finding Maintenance, Risk Based Maintenance, Condition Based Maintenance and Predictive Maintenance.

b) **Corrective maintenance:**

is done after a failure has occurred either as Deferred Corrective Maintenance or as Emergency Maintenance. In the rest of this article, I will discuss each of these different types of maintenance in detail

I.6.1 Preventive Maintenance (PM):

A. Time Based Maintenance (TBM)
B. Failure Finding Maintenance (FFM)
C. Risk-Based Maintenance (RBM)
D. Condition Based Maintenance (CBM)
E. Predictive Maintenance (PDM)

We will explore each of these types of maintenance in more detail including when you should consider using them.

I.6.1.a Time-Based Maintenance (TBM) :

When people talk about preventive maintenance (or preventative maintenance) they usually refer to what is better described as Time Based Maintenance (TBM). Time-Based Maintenance is a type of maintenance that is done at regular intervals while the equipment is still functioning to prevent failure or reduce the likelihood of failure.

I.6.1.b Risk-Based Maintenance (RBM) :

RBM uses a risk assessment methodology to assign your scarce maintenance resources to those assets that carry the most risk in case of a failure (remembering that risk = likelihood x consequence). As a result, equipment that has a higher risk and a very high consequence of failure would be subject to more frequent maintenance and inspection. Low-risk equipment may be maintained at a much lower frequency and possibly with a much smaller scope of work.

When you implement a Risk-Based Maintenance process effectively you should have reduced the total risk of failure across your plant in the most economical way.

Risk-Based Maintenance is essentially preventive maintenance where the frequency and scope of the maintenance activities are continuously optimized based on the findings from testing or inspection and a thorough risk assessment. Examples of Risk-Based Maintenance would be Risk-Based Inspection as applied to static equipment like vessels and piping or even pressure relief valves.

I.6.1.c Failure Finding Maintenance (FFM):

Failure Finding Maintenance tasks are aimed at detecting hidden failures typically associated with protective functions. Think pressure safety valves, trips transmit ,e, r, and the like. This type of equipment won't be required to function until something else has failed.

That means that under normal operating conditions, you will not know whether this equipment is still functional i.e. the failure modes are hidden. And since these failures are hidden, you'll need to find them before you are relying on that equipment to protect you Simple really.

It's important to realize that failure-finding maintenance tasks do not prevent failure but simply detect it. And once detected you'll have to repair the failure you found. Failure Finding Maintenance is conducted at fixed time intervals typically derived from legislation or risk-based approaches.

I.6.1.d Condition Based Maintenance (CBM):

Most failure modes are not age-related. However, most failure modes do give some sort of warning that they are in the process of occurring or are about to occur. If evidence can be found that something is in the early stages of failure, it may be possible to take action to prevent it from failing and/or to avoid the consequences of failure.

Condition Based Maintenance as a strategy, therefore, looks for physical evidence that a failure is occurring gut to occur. Thinking of CBM in this way shows its broader applications outside condition monitoring techniques often only associated with rotating equipment.

An important concept within Condition Based Maintenance is the P-F curve shown in the figure below:

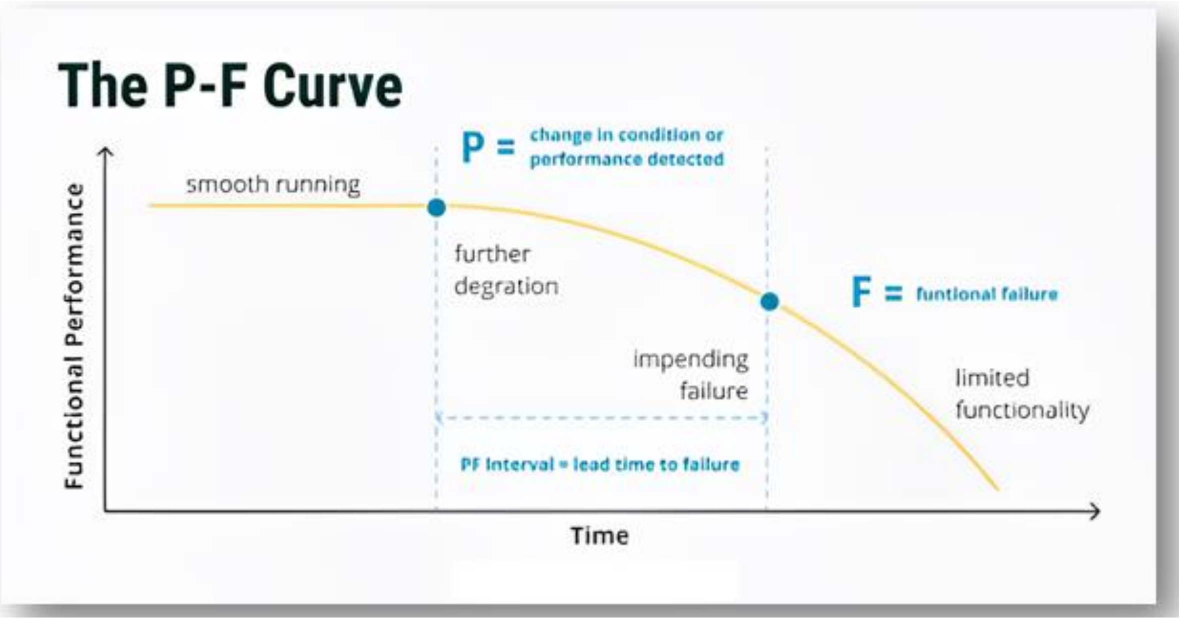

Figure I.4. The P-F curve

The curve shows that as a failure starts manifesting, the equipment deteriorates to the point at which it can be detected (point “P”). If the failure is not detected and mitigated, it continues until a functional failure occurs (point “F”).

It is important to realize as a maintenance strategy does not reduce the likelihood of a failure occurring through life-renewal, but instead is aimed at intervening before the failure occurs, on the premise that this is more economical and should have less of an impact on availability.

I.6.1.e Predictive Maintenance (PDM) :

Up until recently when people spoke about Predictive Maintenance (PDM) this was essentially a synonym for Condition Based Maintenance. But with the advent of Artificial Intelligence, much lower costs of equipment sensors , and machine learning there is a difference appearing between Predictive Maintenance (PDM) and Condition Based Maintenance (CBM), at least in my view.

I see Predictive Maintenance as an extension, a more advanced approach to CBM where we use potentially many process parameters gained from online sensors to determine if our equipment is moving away from stable operating conditions and is heading towards failure. The central idea here is to predict when the failure is going to occur and then determine the appropriate time for maintenance intervention.

There are a lot of (very large) companies actively moving into this space and it is certainly a fast-moving and exciting part of our discipline as Maintenance & Reliability professionals. However, I do still believe that even the most advanced Predictive Maintenance approaches need to be underpinned by sound reliability principles and understanding. And I also believe that the use of Predictive Maintenance

I.6.2 Corrective Maintenance (CM):

A Run to Failure or Corrective Maintenance strategy only restores the function of an item after it has been allowed to fail. It is based on the assumption that the failure is acceptable (i.e. no significant impact on safety or the environment) and preventing failure is either not economical or not possible.

Apart from being the outcome of a deliberate Run to Failure strategy Corrective Maintenance is also the result of unplanned failures which were not avoided through preventive maintenance.

A run-to-failure strategy can effectively be used for general area lighting, smart process instrumentation (without trip functionality), etc. where the consequence of failure is limited and would not necessitate a need for an urgent repair.

I.6.2.a Deferred Corrective Maintenance :

Deferred Corrective Maintenance is a practice where the repair or resolution of a known equipment or system failure is intentionally postponed or delayed to a later time. It occurs when the immediate corrective actions are not taken due to factors such as resource constraints, operational priorities, or scheduling considerations. The decision to defer the maintenance is made with the understanding that the failure does not pose an immediate risk or hinder the overall functioning of the equipment or system. However, it is important to note that deferred corrective maintenance should be managed and scheduled appropriately to avoid potential risks or further deterioration of the asset.

I.6.2.b Emergency Maintenance (EM) :

Emergency Maintenance is corrective maintenance that is so urgent that it breaks into your Frozen Weekly Schedule

It upsets your plans and schedules and typically throws everything into disarray. Some people thrive in this type of environment and often get heralded as heroes when they've worked 16 hrs non-stop to get production back online. But when it comes to the Road to Reliability it is a dead end. So Emergency Maintenance is the only maintenance type that we want to avoid as much as possible

I-7 Maintenance Types: a comparison : [6]

The table below shows a brief summary of:

- The different maintenance types.
- What type of tasks are involved.
- The objective of the task.
- and How the interval between the tasks is determined.

Maintenance type	Preventive Maintenance					Corrective Maintenance	
	Time based	Failure finding	Risk based	Condition based	Predictive	Deferred	Emergency
Task type	Scheduled Overhaul / Replacement	Functional Test	Measurement of condition	Calculation and extrapolation of parameters	Inspection or Test	Repair/ Replace	Repair/ Replace
Objective	Restore or replace regardless of condition	Determine if hidden failure has occurred	Restore or replace based on a measured condition compared to a defined standard	Determine if failure is imminent and intervention is required	Determine condition and conduct risk assessment to determine when next inspection, test or intervention is required.	Restore or replace following failure. Result of a Run to Failure Strategy or an unplanned failure.	Restore or replace following unplanned failure.
Interval	Fixed time or usage interval e.g. 1 month, 1,000hrs or 10,000 km	Fixed time interval (can be set based on risk assessment e.g. SIL)	Fixed time interval for condition measurements/ inspections	Continuous online monitoring of parameters, intervention as required	Time based interval between tasks and scope of task is based on risk assessment	Not applicable, but intervention is deferred to allow for proper planning & scheduling.	Immediate intervention required.

Table I.5: comparison of maintenance types

I.8 Setting maintenance objectives and indicators : [7]

Objectives express in common language what we want. A set of objectives for maintenance could include:

- **a.** Maintenance management: unaccomplished; good accomplished
- **b.** Energy control and optimization
- **c.** Effective preventive maintenance, minimum failures, and quick repairs
- **d.** Efforts to improve maintenance for better maintainability and energy efficiency
- **e.** Optimized operating costs
- **f.** Good image

We will explore each of these objectives

I.8.a Maintenance according to good practices Indeed:

A broad scope objective.

Good maintenance practice understood as the basic set of rules required to manage it properly involves:

- Maintenance items characterization and preventive maintenance planning
- Maintenance spares and materials characterization and logistics
- Work planning and management of work orders
- Maintenance costing
- Maintenance history build-up
- Maintenance analysis and indicator computation

I.8.B Energy control and optimization:

We must remember that energy consumption does not depend only on the performance and efficiency of the equipment. It depends on a great number of factors most of which are not under the direct responsibility of the maintenance department but they can, in most cases, be identified by the maintenance people that should develop a pro-active attitude towards identifying them. Let us enumerate several possibilities:

- Drive motor upgrades introducing more economical prime movers
- Checking/calibrating to avoid wrong data inputs
- Improvements in insulation, design, and equipment to avoid heat losses

I.8.c Effective preventive maintenance / minimum failures :

Maintenance effectiveness indicators are well served by standardized maintenance indicators.

$$T17 = \frac{\text{TOTAL OPERATION TIME}}{\text{NUMBER OF FALURES}}$$

$$T21 = \frac{\text{TOTAL RESTORATION TIME}}{\text{NUMBER OF FAILURES}}$$

Where:

Operating time = time during which an item is performing its required function;

– Restoration time = time interval during which an item is in downstate due to a failure

(including administrative and logistic delays) Several failures.

I.8.D. Effort on improvement:

Let us assume that the necessity of improvements had been diagnosed and we wanted some metrics to express effort in this area. Improvement maintenance is frequently identified as an ever-present objective in buildings (introduction of energy-saving equipment, improving accesses for maintenance, monitoring equipment, and the like). A suitable indicator for this could also be selected from the standard referenced above:

$$E19 = \frac{\text{COST OF IMPROVEMENT MAINTENANCE}}{\text{TOTAL MAINTENANCE COST}} \times 100\%$$

Where

Total maintenance cost = wages + social taxes + extra time of personnel + external personnel– + materials and spares + contractors + departmental costs (energy, machine tools, depreciation, etc.). It excludes downtime costs.

Cost of improvement maintenance is part of the maintenance costs dedicated to the improvement type of work

I.8.E Optimized operating costs:

Operating costs fall in the domain of operational management. So let the production establish their indicators. Maintenance should take good note of those indicators as they are bound to be closely linked to their own, as the major cost issues in a facility, are connected with maintenance and energy issues.

I.8.F Good image:

Image is also in the domain of operational management. Operational management makes their indicators and you should try to use or create one or more indicators for maintenance that somehow express what they want.

Of course maintenance performance is a great contributor to the overall image of a facility and everybody in the department should be fully aware of that. Many critical eyes are looking around –safety-related matters, hygiene, condition of visible maintenance items among many others.

I.9. The 5 levels of maintenance: [8]

The concept of maintenance levels is intended to keep an industrial machine park as valuable as possible, both in terms of equipment value and in terms of performance and safety. A good practical application of the different maintenance levels allows us to achieve optimal maintenance.

Therefore, the French Standardization Association has defined, in the X 60-010 (1994) standard, then in the NF X 60-000 (2016) standard, 5 levels of maintenance. Each level corresponds to a degree of complexity of the corresponding maintenance interventions.

Thanks to this classification, it is possible to determine the level of expertise required and the methods that will have to be used to carry out an operation. It also allows to us evaluate if an intervention can be done internally or if it is necessary to call upon qualified external providers.

I.9.a. Level 1:

The 1st level of maintenance corresponds to the simple interventions, necessary and realized on easily accessible elements. These operations do not require the dismantling or opening of the equipment and can be carried out by the operator himself or by a non-specialized operator.

Only a few spare parts or consumables are used for these operations. There is no particular safety risk if the essential instructions are available, e.g. on manual or visual instructions.

I.9.b. Level 2:

Level 2 maintenance corresponds to the less complex interventions, whose procedures are simple to follow. Moreover, the replacement of parts during these operations does not require the global dismantling of the equipment concerned. hese tasks must be performed by a qualified technician with safety and hazard training. Therefore, they are usually performed by a technician of average qualification**.**

I.9.c. Level 3:

Level 3 maintenance corresponds to interventions considered complex. These interventions must therefore be preceded by a diagnosis and identification. They can be carried out on-site or in a maintenance workshop and must take into account the equipment as a whole because the modification of an element can have consequences on its general operation. Level 3 maintenance operations must be performed by specialized technicians using the tools indicated in the machine’s maintenance instructions.

I.9.d Level 4:

Level 4 maintenance operations are complex and of great importance, requiring special technical expertise. They must therefore be carried out by a technician or a team of specialized technicians with a specific qualification, and supervised by a specialized manager.

These interventions are carried out in workshops providing adapted tools, documentation, and measurement benches.

I.9.e Level 5 :

Level 5 maintenance includes complex actions performed by the equipment manufacturer or by a company approved by him. The actions to be performed are similar to manufacturing actions.

Examples of level 5 maintenance interventions include rebuilding or repairing equipment or bringing equipment into compliance with new regulations.

I.10Root Cause Analysis Explained : [9]

The easiest way to understand root cause analysis is to think about common problems. If we're sick and throwing up, at work, we'll go to a doctor and ask them to find the root cause of our sickness. If our car stops working, we'll ask a mechanic to find the root cause of the problem. If our business is underperforming (or overperforming) in a certain area, we'll try to find out why. For each of these examples, we could just find a simple remedy for each symptom. To stop throwing up at work, we might stay home with a bucket. To get around without a car, we might take the bus and leave our broken car at home. But these solutions only consider the symptoms and do not consider the underlying causes of those symptoms—causes like a stomach infection that requires medicine or a busted car alternator that needs to be repaired. To solve or analyze a problem, we'll need to perform a root cause analysis and find out exactly what the cause is and how to fix it here's how root cause analysis works:

1. Define the Problem: Clearly define the problem or incident that needs to be investigated. This could be a failure, error, accident, or any other undesired outcome.

2. Gather Data: Collect relevant data and information related to the problem. This may include incident reports, observations, interviews, records, and any other available sources of information.

3. Ask "Why?" Multiple Times: Start by asking "Why did the problem occur?" and identify the immediate cause. Then, ask "Why did that cause happen?" and continue to ask "Why?" at least five times to peel back the layers and uncover deeper causes. This helps to identify the root cause, which is the fundamental reason behind the problem.

4. Analyze Contributing Factors: Alongside identifying the root cause, analyze and identify other contributing factors that influenced or worsened the situation. These factors could be related to people, processes, equipment, environment, or any other relevant aspects.

5. Develop Corrective Actions: Based on the identified root cause and contributing factors, develop appropriate corrective actions to address the problem. These actions should be focused on preventing the recurrence of the problem and mitigating the identified factors.

6. Implement and Monitor: Implement the corrective actions and monitor their effectiveness over time. Regularly assess and review the results to ensure that the problem has been resolved and the identified root cause has been adequately addressed.

I.10.1 Core principles :

- Focus on correcting and remedying root causes rather than just symptoms.
- Don’t ignore the importance of treating symptoms for short-term relief.
- Realize there can be, and often are, multiple root causes.
- Focus on HOW and WHY something happened, not WHO was responsible.
- Be methodical and find concrete cause-effect evidence to back up root cause claims.
- Provide enough information to inform a corrective course of action.
- Consider how a root cause can be prevented (or replicated) in the future.

As the above principles illustrate: when we analyze deep issues and causes, it’s important to take a comprehensive and holistic approach. In addition to discovering the root cause, we should strive to provide context and information that will result in an action or a decision. Remember: good analysis is actionable analysis.

I.10.2 Benefits and Goals of root cause Analysis :

The first goal of root cause analysis is to discover the root cause of a problem or event.

The second goal is to fully understand how to fix, compensate, or learn from any underlying issues within the root cause.

The third goal is to apply what we learn from this analysis to systematically prevent future issues or to repeat successes. The analysis is only as good as what we do with that analysis, so the third goal of RCA is important. We can use RCA to also modify core processes and system issues in a way that prevents future problems. Instead of just treating the symptoms of a football player’s concussion, for example, root cause analysis might suggest wearing a helmet to reduce the risk of future concussions. Treating the individual symptoms may feel productive. Solving a large number of problems looks like something is getting done. But if we don’t diagnose the real root cause of a problem we’ll likely have the same problem over and over. Instead of a news editor just fixing every single omitted Oxford comma, she will prevent further issues by training her writers to use commas properly in all future assignments

I .11 Reliability Centered Maintenance : [10]

Reliability-Centered Maintenance (RCM) is a corporate-level maintenance strategy designed to optimize maintenance programs by establishing safe minimum levels of equipment upkeep. RCM emphasizes matching individual assets with the maintenance techniques most likely to deliver cost-effective outcomes. The successful implementation of an RCM process enhances reliability, equipment uptime, and company savings.

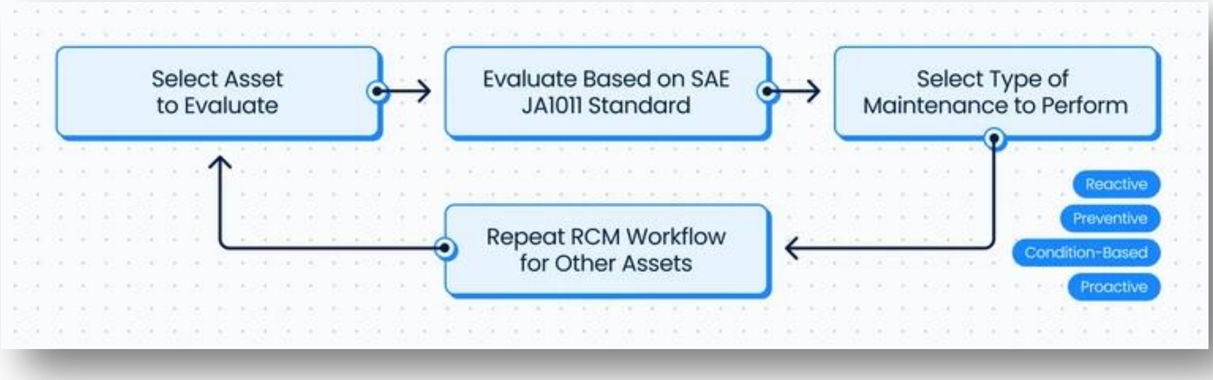

Figure I.6 Reliability Centered Maintenance

Reliability-Centered Maintenance (RCM) is a complete framework that always attempts to extend equipment lifespans and decrease downtime, in *the most cost-efficient way* possible. The primary objective of RCM is best understood by analyzing its root words:

I .11.aReliability: The quality of performing consistently well.

I .11.b Maintenance: Ensuring assets continue to function as desired.

Essentially, Reliability-Centered Maintenance (RCM) provides a roadmap to analyze and act upon the root causes of equipment failures—technology, culture, design, and maintenance strategy inefficiencies—in pursuit of affordable asset reliability.

Of course, downtime is inevitable when working with complex pieces of machinery. However, top-tier organizations use RCM to prevent sudden breakdowns that require laborious maintenance, costly outsourcing, and lost production time.

I.11.1T he Principles of Reliability-Centered Maintenance :

The RCM paradigm argues that the less maintenance you perform on an asset, the better. Only perform maintenance when absolutely necessary or when the benefits outweigh the risks and costs. RCM is based on four key objectives:

- Preserve system functions.
- Identify failure modes that can affect system functions.
- Prioritize identified failure modes according to risk and cost projections.
- Select the most effective tasks to control failure modes.

I.11.2The Requirements of Reliability-Centered Maintenance :

Organizational leaders should outline their RCM goals by considering management availability, accessible technologies, and budgetary resources. This somewhat timeconsuming process carefully analyzes individual asset management scenarios before assigning corresponding maintenance tasks.

I.11.3Advantages and Disadvantages of Reliability-Centered Maintenance :

Successfully implementing RCM benefits organizations that can afford it. The framework takes the guesswork out of maintenance prioritization and helps organizations maintain assets in a consistent, structured, and cost-effective manner.

Because RCM heavily relies on predictive maintenance (PdM) technologies, its program advantages and disadvantages mirror those of it. However, RCM allows facilities to match resources to equipment needs more closely while improving reliability and decreasing cost—more than any singular PdM strategy.

I.11.4 Advantages :

The advantages of reliability-centered maintenance include:

- **Cost Effectiveness.** RCM helps reduce costs by minimizing unnecessary routine maintenance tasks. When combined with preventive maintenance, RCM has been shown to reduce workloads by 70 percent.

- **Better Teamwork.** RCM takes a group approach to maintenance tasks. Communication and cooperation among departments and teams improve when everyone is involved in problem analysis and decision making.

- **Improved Asset Performance.** It also eliminates unnecessary overhauls and, therefore, reduces shutdowns. RCM also helps to diagnose failure more quickly.

- **Improved Employee Motivation.** When employees are involved in the application of RCM, they get a better understanding of the assets in their operating contexts. This motivates them to take ownership of maintenance problems and solutions.

- **Better Safety and Environmental Integrity.** RCM seeks to understand the implications of every failure mode and takes proactive steps to prevent them. Besides limiting failures, the maintenance prioritization process promotes the availability of necessary protective devices

I.11.5 Disadvantages :

RCM also has its drawbacks. The initial costs of implementing RCM are high. Performing RCM analysis requires teams to invest significant time, finances, and resources to get started. ROI may be slower than executives prefer.

The second major disadvantage of RCM is that it simultaneously incorporates all of the other types of maintenance strategies, including some of their drawbacks.

For instance, say you choose a run-to-failure approach for a given asset. You simultaneously run the risk of an unplanned failure. For this reason, RCM is sometimes seen as expensive compared to running predictive or preventive maintenance programs alone. However, most experts agree that RCM is more cost-effective in the long run.

I.12total productive maintenance : [11]

Total productive maintenance (TPM) is a strategy that operates according to the idea that everyone in a facility should participate in maintenance, rather than just the maintenance team. This approach uses the skills of all employees and seeks to incorporate maintenance into the everyday performance of a facility.

I.12.1Understanding the foundation of TPM :

TPM is built on a “5S” foundation, with eight pillars supporting it. The beginning of a TPM program will focus on establishing the 5S foundation and developing an autonomous maintenance plan. This frees up the maintenance staff to begin larger projects and perform more planned maintenance

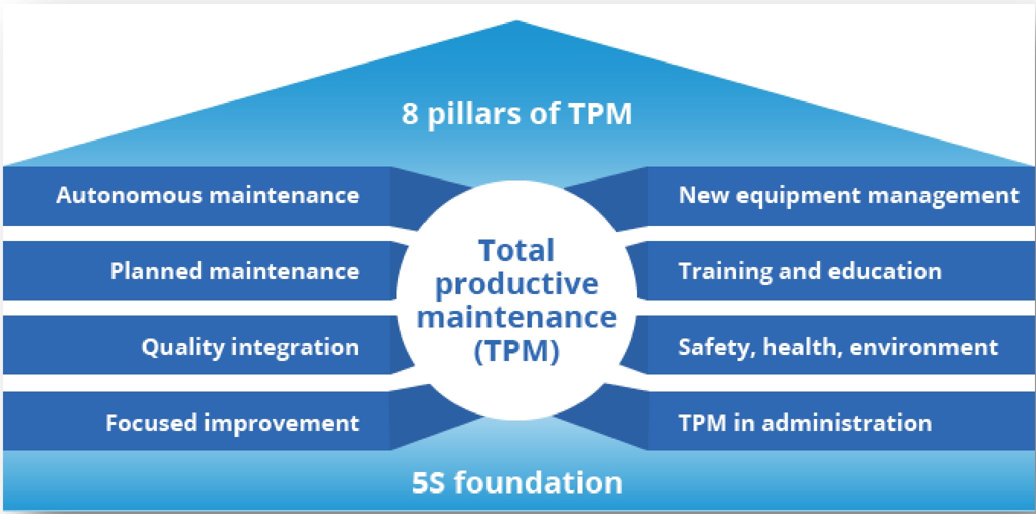

Figure I.7 The 8 pillars of TPM

I.12.aAdvantages of TPM :

When everyone in a facility is thinking about and contributing to maintenance, many aspects of the facility will change for the better. Teams employing a TPM strategy often experience the following:

I.12.bFewer breakdowns :

When machine operators keep an eye out for changes with their equipment, big issues are more likely to be spotted early, before a breakdown occurs. This lets the maintenance team get on top of their PM maintenance schedule, rather than always reacting to emergency breakdowns.

I.12.c Safer workplace :

Technicians are much more likely to take risks when rushing to fix a breakdown, so fewer breakdowns generally mean a safer workplace. On top of that, when everyone keeps maintenance in mind, problems can be spotted and dealt with well before they become potentially dangerous situations.

I.12.2 Better overall performance :

If everyone in a facility is keeping an eye on maintenance, small fixes will stop going undetected, which helps you move away from reactive maintenance and get backlog under control. It takes the pressure of small jobs off the maintenance team so they can concentrate on the bigger jobs, which increases the overall performance of your facility.

I.13 Maintenance management : [12]

Maintenance management is the process of maintaining your assets and resources efficiently. The main objective is to reduce the costs, time, and resources associated with your maintenance processes while ensuring that everything flows as intended. When done well, your maintenance management program will help you avoid wasted resources and downtime due to broken equipment. Instead of being surprised by unexpected events that hamper your workflow, you'll be able to control all maintenance processes without unwelcome failures.

Maintenance management used to be a chaotic process involving handwritten notes. Now, you can combine CMMS software, best practices, and trained personnel to keep your assets in working condition. Importantly, there is no one-size-fits-all solution. Instead, your maintenance management program should be highly customized to suit the maintenance employed at your plant, whether you use a time-based maintenance strategy like preventive maintenance or a condition-based strategy like predictive maintenance.

I.13.1the importance of management maintenance :

The efficiency of your maintenance has a big part to play in the success of your business. By properly maintaining your assets and equipment, you can keep production stable, reduce the likelihood of unplanned downtime, improve reliability and availability, and maximize your product quality.

Failing to get to grips with your maintenance management can lead to a spike in the cost of repairs, complete breakdowns of machines, delayed customer shipments, and lost revenue. It can also harm workplace safety and productivity.

I.13.2the purpose of maintenance management :

The main objectives of maintenance management are the same regardless of the type of facility you manage. They include:

- Extending the life of your assets

- Reducing the risk of asset failures and downtime
- Scheduling maintenance and allocating your resources more efficiently
- Controlling your costs
- Complying with regulations in your industry
- Ensuring the safety of your workers
- Implementing better policies and procedures

Looking more closely at your historical maintenance data in your CMMS software can also give you a better understanding of maintenance trends. For example, it can help you cover details such as why an asset is underperforming or whether it has been maintained at the correct intervals.

I-14 Conclusion:

Maintenance is a critical function that ensures the smooth operation, reliability, and longevity of assets. By implementing effective maintenance practices, organizations can minimize downtime, improve productivity, and optimize costs. As technology continues to advance, maintenance professionals need to stay updated with emerging trends and embrace innovative approaches to keep pace with the evolving needs of modern industries.

Chapter II. Presentation of FMECA method

Chapter II. Presentation of FMECA method

II.1 INTRODUCTION:

FMECA stands for Failure Modes, Effects, and Criticality Analysis. It is a systematic and structured method used to assess and prioritize potential failures within a system, process, or product. FMECA is commonly employed in engineering, reliability analysis, risk management, and quality control to identify and mitigate potential failures before they occur.

FMECA is a proactive approach that allows organizations to identify and address potential failures before they occur, thereby enhancing system reliability, safety, and performance. It helps in making informed decisions and allocating resources efficiently to manage risks associated with failures.

II.2 What is FMECA ?[13]

Failure modes, effects, and criticality analysis (FMECA) is a technique used to identify potential failures in systems and equipment. Once you have identified the failure modes, you can determine their effects and prioritize them based on how critical they are.

The goal of FMECA is to determine which failure modes pose the highest risk to your system or asset so that you can improve safety measures for all involved. It’s important to keep in mind that this process does not guarantee flawless results: no what you do or how well-informed your decisions are, mistakes will happen sometimes. However, by performing the proper risk assessments and taking preventive measures when appropriate, we can help mitigate these risks before they occur.

II.2.1 Where Does this method come from

Created in 1966 in the United States by the company Mc DONNEL DOUGLASS; The method was developed by NASA and the armament industry to assess the effectiveness of their system. The method has proven itself in the industrial sector, a sector in which the reliability and safety of the product or processes or processes are essential.

II.2.2What are the objectives of FMECA?

The objective of an FMECA is to look for all of the potential ways a process or product can fail. A product failure occurs when the product does not function as it should or when it malfunctions in some way. A process failure occurs when the process does not deliver the intended outcome. Even the simplest processes and products have many opportunities for failure.

Failures are not limited to problems with the asset or product because failures also can occur when the operator or user makes a mistake, a failure which should also be included in the FMECA. Ways in which a product or process can fail are called failure modes. Each failure mode has a potential effect, and some effects are more likely to occur than others. The FMECA process is a way to identify the failures, effects and risks within a process or product, and then eliminate or reduce them.

II.3 What do we mean by failure?[14]

It is a product or set that:

- Does not work
- Doesn't run on startup, or when expected, or doesn't stop when expected
- Does not meet required specifications

Or that the expected performance is not obtained.

II.4The different types of FMEA [15]

Without going in-depth into each of its concepts, it should just be noted that there are several types of FMECA, including the following:

1) Process

Failures in the manufacturing process are identified, the effects of which act directly on the quality of the manufactured product (breakdowns are not taken into account).

2) Medium

We identify the failures of the means of production whose effects act directly on the productivity of the company.

It is therefore about the analysis of breakdowns and the optimization of maintenance.

3) Security

This type aims to reduce the risks associated with the use of a means of production.

4) Design

It is carried out during the design of a production tool.

5) Product

It analyzes the impact of product failures on a customer's use of it.

6) Organization

It applies to the different levels of a system. It encompasses the management system, the information system, the production system, marketing, HR, finance and all levels of the organization.

II.4.1What is the benefit for the company of adopting this method?

Within a company, the use of FMECA results in:

- Optimized production, the right product the first time
- A permanent improvement of the means of production to limit failures
- Constant improvement of the organization
- The setting of a quality threshold to be obtained, and the implementation of the means to achieve it
- An analysis of each of the production defects
- Drafting recommendations in the event of failures

II.5 FMECA meets the requirements of the ISO standard :[16]

As we have just seen, FMECA is a prevention method that should be adopted by all companies seeking efficiency. But this is not always the case. And this is reflected in the 2008 version of the ISO 9001 standard; the preventive approach was very little used. During the audits, it was rather the implementation of curative and corrective actions that were more understood by the company.

II.5.1 the ISO 9001:

In 2015 standard requires the commitment to a systematic approach to risks so that they are identified, taken into account, and controlled throughout the implementation of the QMS and the design and production processes. It is an approach that must be proactive.

The ISO 9001 version 2008 standard was more in a reactive approach and less in the early detection and prevention of adverse effects.

Approaches such as quality assurance and statistical process controls have shown their limits in solving, preventing, and avoiding the appearance of problems in business processes.

For example, we always wonder about the reliability of a machine, and what problems we encountered in a machine, or a process.

The solution is to implement maintenance methods. One of these methods is FMEA.

This is perfectly justified when no installation history is available (especially for new or newly designed machines).

It is then necessary to be able to predict the breakdowns likely to affect the operation of the machine.

FMECA is therefore essentially an "inductive method which allows a qualitative and quantitative analysis of the reliability or security of a system" according to the French Association for Standardization ".

II.6 The principle: [17]

The FMECA analysis method applies equally well to the design of a new product, to the development of a manufacturing process, or even a process to identify the points of failure likely to penalize performance.

This method is preventive. It is a valuable tool for ensuring the feasibility of specifications in compliance with customer specifications and regulatory requirements.

The process is complete, it proposes to list and then organize the foreseeable failure modes and the consequences during the design of a product or the implementation of a process. It is an essential tool for study work, but not only. It is not only used a priori.

As the product is produced or the process is implemented, taking advantage of the knowledge acquired, the analysis turns out to be finer, and more relevant. Note, FMECA supplements the first version of the approach entitled: "FMECA" which does not include the notion of Criticality, hence the final letter "C" of the acronym. Criticality is an essential parameter to complete the scope of the risk analysis and thus obtain a real decision-making aid instrument.

FMEA analysis preparation is a delicate study to say the least. The method is not the most obvious. The identification of failure modes, as well as the evaluation of the effects and the formalization of the causal links, requires particularly in-depth study work. The Criticality estimate is even more random.

However, it is the latter which essentially carries the overall value of the analysis. This means that it deserves special attention and participation from all

II.6.1 steps to implementing the FMECA method :

The method has two aspects: a qualitative side and a quantitative side.

- ***for the qualitative side***

It is a matter of gathering potential failures of processes, researching and identifying the causes, and knowing the potential consequences for the customer and the user as well as for the environment.

- ***quantitative side***

It consists in measuring the risks associated with this failure.

- The goal is to classify failure.

This will make it possible to know the level of seriousness and the impact that this can have on the client or user or the internal or external environment.

This is also intended to determine the measures to be measured about the potential impact of failure.

II.7 Team effort The FMECA :[18]

FMECA should be a catalyst to stimulate ideas between the design engineer, operations manager, maintenance manager, and a representative of the maintenance personnel (technician).

The team members should have a thorough understanding of the systems operations and the mission's requirements. A team leader should be selected that has FMECA experience. If the leader does not have experience, then an FMECA facilitator should be sought. If the original group of team members discovers that they do not have expertise in a particular area during the FMECA then they should consult an individual who has the knowledge in the required area before moving on to the next phase. The earlier a problem in the design process is resolved, the less costly it is to correct it.

II.8 FMECA characteristics The FMECA :[19]

FMECA should be scheduled and completed concurrently as an integral part of the design process. Ideally this analysis should begin early in the conceptual phase of a design, when the design criteria, mission requirements and performance parameters are being developed. To be effective, the final design should reflect and incorporate the analysis results and recommendations. However, it is not uncommon to initiate a FMECA after the system is built in order to assess existing risks using this systematic approach. Figure 1-1 depicts how the FMECA process should coincide with a facility development process.

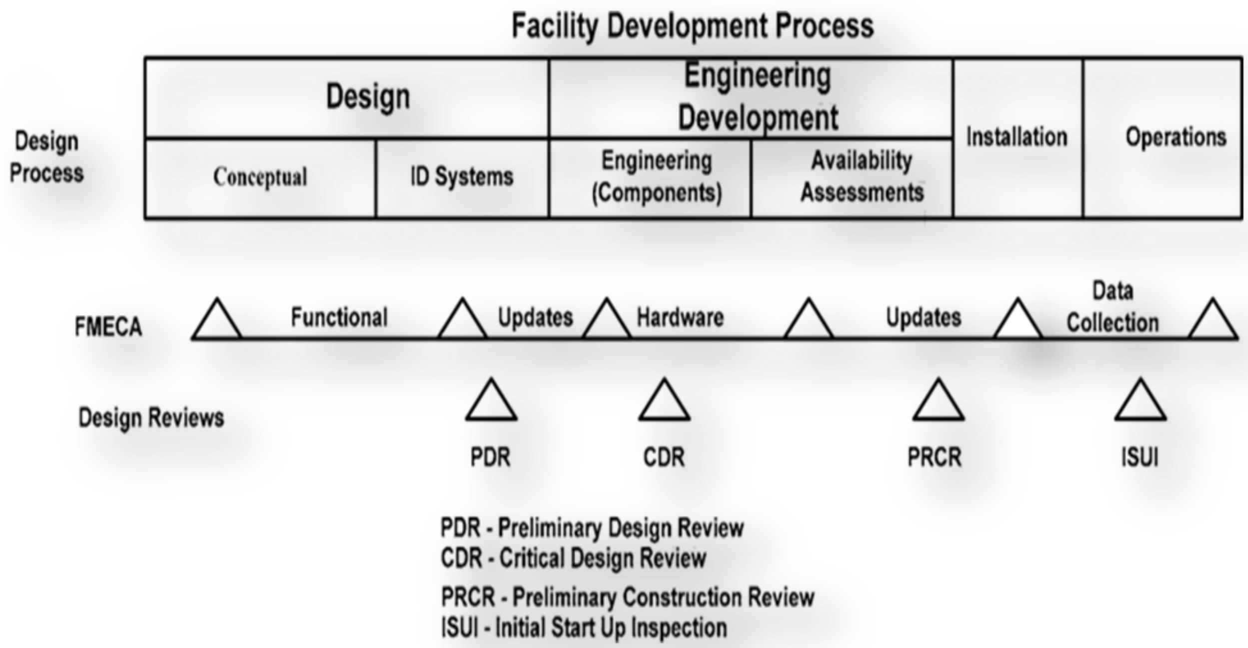

Figure II.1 : Facility development process

Since the FMECA is used to support maintainability, safety and logistics analyses, it is important to coordinate the analysis to prevent duplication of effort within the same program. The FMECA is an iterative process. As the design becomes mature, the FMECA must reflect the additional detail. When changes are made to the design, the FMECA must be performed on the redesigned sections. This ensures that the potential failure modes of the revised components will be addressed. The FMECA then becomes an important continuous improvement tool for making program decisions regarding trade-offs affecting design integrity.

II.8.1 Let us see below the stages of implementation of the FMEA method:

- Create a working group
- Perform a functional analysis of the process (or device)
- Possible failure analysis
- Evaluate these failures and determine their criticality
- Define and plan actions

II.8.2 Set up a working group :

Since the FMEA method is predictive, it relies heavily on experience.

It is therefore necessary to call on experiences from various backgrounds to neutralize the subjective aspect of the analyses.

This group is made up of 4 to 8 individuals from various departments of the company:

- production service

- maintenance department
- quality department
- service methods

One of the criteria for the formation of the group is significant experience.

In addition, one of the people in the group acts as a facilitator.

Its role is to lead and direct the debates, to ensure that the limits of the subject are respected, to designate the person who must decide in the event of a dispute, to draft the FMECA, and to plan the meetings.

This person does not necessarily know the object of the analysis and it is even preferable that he does not know it to introduce a certain objectivity into the process – and he is often outside the company (consultant).

Even if FMECA looks like a discussion where different points of view are opposed, it is nonetheless a method imbued with a certain rigor that should lead to very concrete actions.

Among the effectiveness criteria of the method:

- A meaningful experience
- Discipline: presence effort
- Efficiency

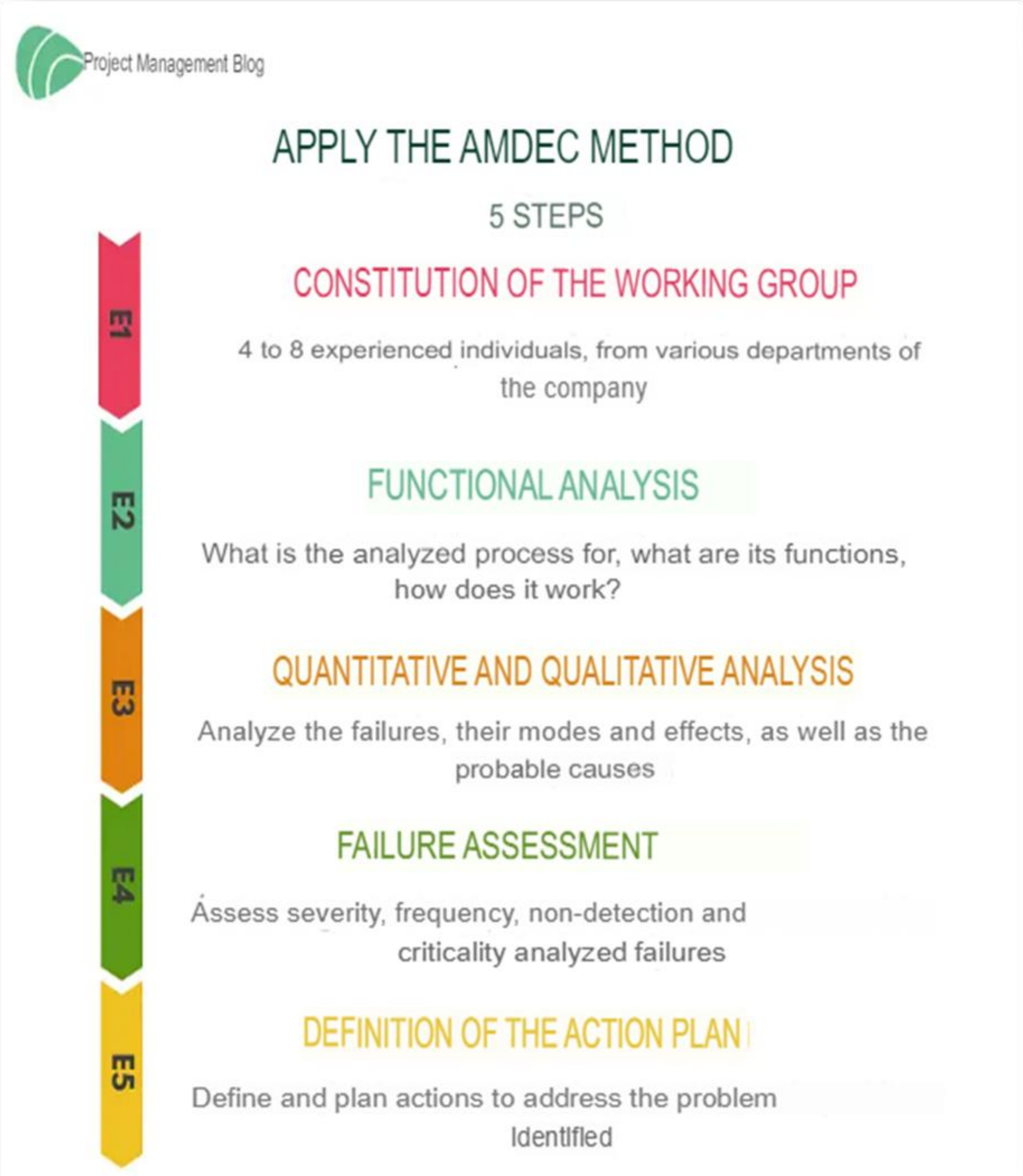

Figure II.2. Apply of FMECA method

II.9 Do a functional analysis of the process: [20]

The system whose failures are being studied must first be "dissected":

*****What is it used for? : Each function answers this question: Ex: an airplane flies

*What functions should it perform?

How does it work?

The functional analysis must answer these questions rigorously.

The system should be analyzed under the following aspects:

- **External**: relations with the external environment (what goes in, what goes out)
- **Internal**: analysis of flows and activities within the process or machine

Various functional analysis techniques are cited.

II.9.1 Which functional analysis tools :

Top-down analysis: Any problem can be broken down into simpler sub-problems: we solve several

small problems rather than one big problem. Here is a diagram to illustrate this:

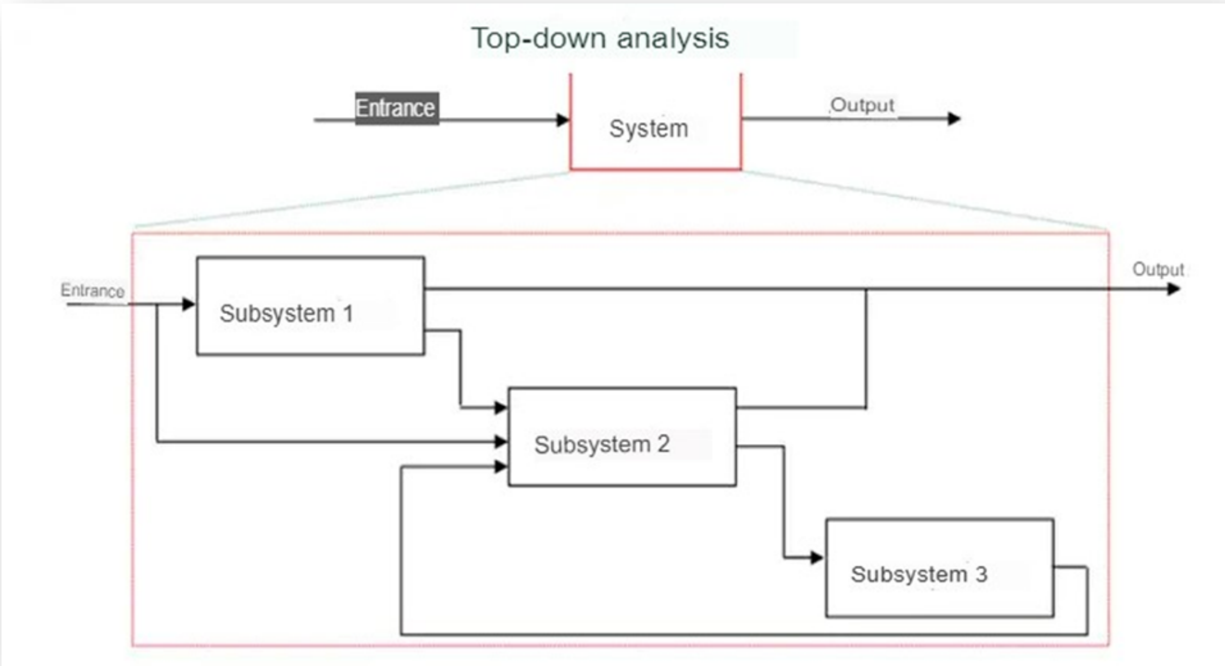

Figure II. 3 : top – down

***the octopus method .**

***Flow charts.**

***the tree structure**

II.9.2 the process diagram:

This method is used to describe the sequential structure of a process. Here is a diagram to illustrate it:

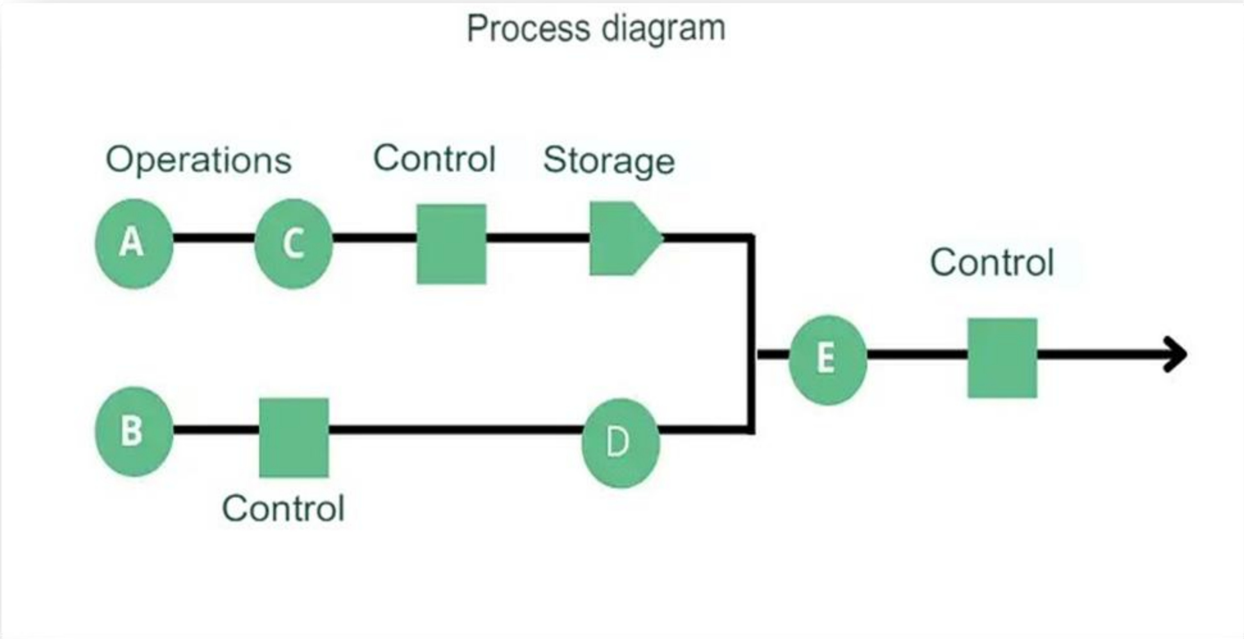

Figure II.4 : process diagram

- The influence of the environment on the process.

II.9.3 Analyze potential failures :

This analysis is done on two levels:

- Qualitative analysis
- and quantitative analysis

II.9.4 Qualitative analysis :

This consists of identifying all the possible failures, determining the modes of failure, identifying the effects of each failure, and analyzing and finding the possible causes and the probable causes of the potential failures. To achieve this objective, we rely on functional analysis. From the defined functions, we look directly for potential failures. Thus, functional analysis helps to find the upstream and downstream causes and the effects of each failure mode.

II.9.5 Quantitative analysis :

This is an estimate of the severity index of the "Cause - mode - effect" trio of the potential failure studied according to certain criteria. Several criteria can be used to determine this index.

Often, in practice, a failure is considered to be all the more important if:

- Its consequences are serious
- It often occurs
- It happens and we risk not detecting it

This analysis is about function. It expresses how this function no longer does what it was supposed to do.

The functional analysis identifies the functions, and the FMECA considers for each of them its way (or its ways, because there may be several) of no longer behaving correctly.

A. The case

- It is the anomaly that leads to the failure mode
- Failure is a deviation from the standard of operation
- The causes find their sources in five large families. We make an inventory of them in diagrams called "cause and effect diagrams", of which there is the diagram:

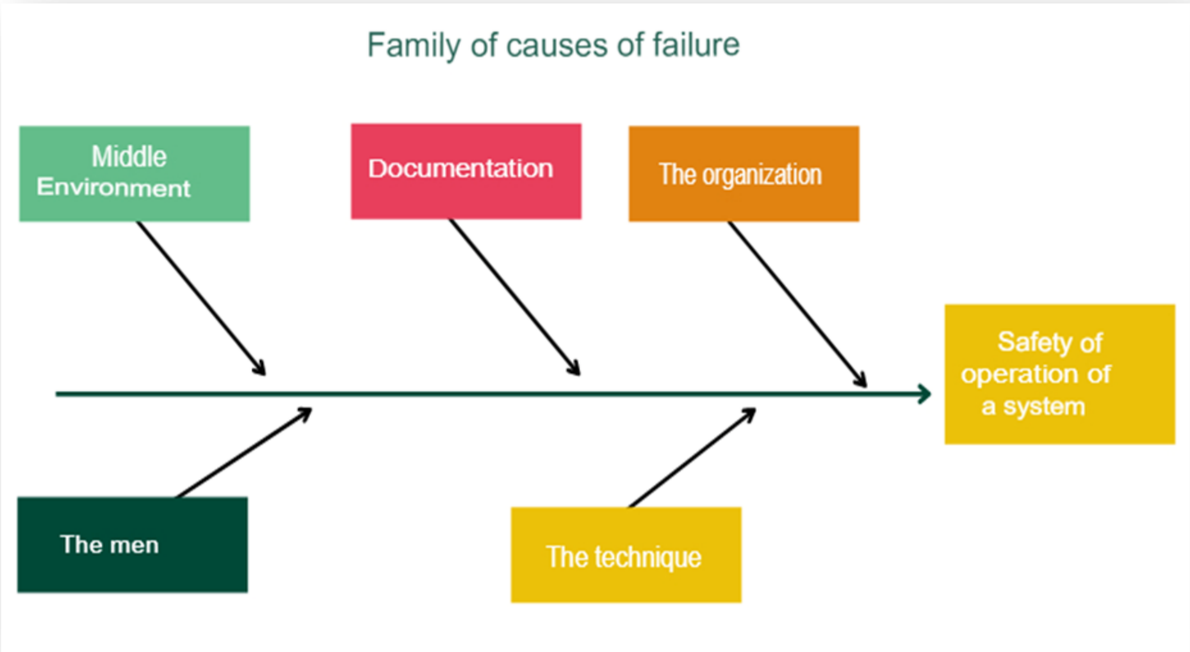

Figure II.5. Family of causes of failure

- Each family can in turn be broken down into sub-family
- A failure mode can result from the combination of several causes. A cause can be the origin of several failure modes.

II.9.6 The effect :

The effect materializes the consequence of the failure mode. It depends on the FMECA point of view that we adopt:

- Effects on product (process) quality
- Effects on productivity (machine)
- Effects on safety (safety)

An effect can itself become the cause of another failure mode.

II.10 Assess these failures and determine their criticality:[21]

The evaluation is done according to 3 main criteria:

- gravity
- Frequency
- non-detection
- criticality

These criteria are not restrictive, the working group can define others that are more appropriate for the problem in question.

Each criterion is evaluated within a score range. This range is determined by the working group.

II.10.1 Gravity :

It expresses the importance of the effect on the quality of the product (process) or productivity (machine) or safety (safety).

The group must decide how to measure the effect.

Example :

Effect on the dimension of a product:

- ✓ Note 1: difference less than 0.5%
- ✓ Note 2: difference less than 1%
- ✓ Note 3: difference less than 5%
- ✓ Note 1: difference above t%

Effect on production downtime:

- ✓ Note 1: less than 4 hours
- ✓ Note 2: less than 24 hours
- ✓ Note 3: less than a week

- ✓ Note 1: more than one week

II.10.2 Frequency :

The period during which the failure is likely to recur is estimated.

Example :

- ✓ Note 1: less than once a year
- ✓ Note 2: less than once a month
- ✓ Note 3: less than once a week
- ✓ Note 1: more than once a week

II.10.3 Non-detection :

It expresses the efficiency of the system in detecting the problem.

- ✓ Note 1: effective detection allowing preventive action
- ✓ Note 2: system presenting risks of non-detection in certain cases
- ✓ Note 3: unreliable detection system
- ✓ Note 1: no detection

II.10.4 Criticality :

When the 3 criteria have been evaluated in one line of the FMECA synthesis, the product of the 3 scores obtained is calculated to calculate the criticality:

C=G*F*N

C = criticality

G = gravity

F = frequency

N = Non-detection

The working group must then decide on a criticality threshold.

Beyond this threshold, the effect of the failure is not bearable. Action is needed.

II.11 Define and plan actions :[22]

The purpose of the FMECA analysis, after highlighting the critical failures, is to define actions likely to deal with the problem identified.

Actions are of 3 types:

- **Preventive actions:** action is taken to prevent failure before it occurs, to prevent it from occurring. These actions are planned. The period of application of an action results from the evaluation of the frequency
- **Corrective actions:** when the problem is not considered critical, action is taken when it arises. The action must then be as short as possible for a rapid upgrading

- **Improvement actions:** these are generally process modifications or technological modifications to the means of production intended to eliminate the problem. The cost of this type of action is not negligible and it is treated as an investment

Actions, to be effective, must be monitored:

II.11.1 action plan:

- Appointment of a person responsible for the action

- Determination of a deadline

- Determining a budget

- Review of the evaluation after implementation of the action and feedback on the results.

II.11.2 FMECA limits:

The AMDEC method can be long and complex. It requires good organization and involvement of the working group and remaining precise in the approach and the research.

II.11.3 Synthetic:

FMECA aims to satisfy the customer by preventing failures at all levels of design, thus contributing to improving the quality and reliability of the subject addressed. It is a useful method to make a preliminary analysis of the risks of a product, to permanently improve the organization of a company.

II.12 Conclusion :

FMECA is a prevention method applicable to any system. This method must be part of a global approach and it is a way to guard against certain failures and to study the causes and consequences. It is a tool that can help with the implementation of certain standards, including ISO 9001 version 2015 in the "Design Control" section. Feel free to share your opinions and questions in the comments. The objective is preventive. This method of continuous improvement leads to a hierarchical list of weak points that characterizes production (or other) equipment. FMECA does not content itself with diagnosing existing systems; it is applicable from their design stage to anticipate probable failures. The idea is to be able to make adjustments very early on before the device is finalized. The applications of the method are not limited to technical equipment, processes, and processes but also benefit from its virtues.

The methodology requires knowledge of the system in question, other tools such as functional analysis then come into play. It will be possible to study the effects of the failure modes and prioritize them in a second step. This tool is central to many quality initiatives.

Chapter III. Fuzzy logic

Chapter III. Fuzzy logic

III.1. Introduction:

Fuzzy logic is a technique used in artificial intelligence. It was formalized by Lotfi Zadeh in 1965 and used in fields as varied as automation (ABS brakes), robotics (shape recognition), road traffic management (red lights), air traffic control, environment (meteorology, climatology, seismology, life cycle analysis), medicine (diagnostic assistance), insurance (risk selection and prevention) and many others.

It is based on the mathematical theory of fuzzy sets. This theory, introduced by Zadeh, is an extension of classical set theory to take into account imprecisely defined sets. It is a formal and mathematical theory in the sense that Zadeh, starting from the concept of membership function to model the definition of a subset of a given universe, has developed a complete model of properties and formal definitions. He also showed that this theory of fuzzy subsets effectively reduces to the theory of classical subsets in the case where the membership functions considered take binary values ({0,1}).

It also has the advantage of being easier and cheaper to implement than probabilistic logic, although the latter alone is strictly sensu coherent (see Cox-Jaynes theorem). For example, the Ev(p) curve can be replaced by three straight line segments without excessive loss of precision for many of the applications considered above.

III.2. Principe: [23]

Unlike Boolean logic, fuzzy logic allows a condition to be in a state other than true or false. There are degrees in the verification of a condition.

Consider for example the speed of a vehicle on a French national road. The normal speed is 90 km/h. A speed can be considered high above 100 km/h, and not at all high below 80 km/h.

Boolean logic would look at things like this (see Fig. 1):

*The speed is considered 100% high from 100 km/h, and 0% below.

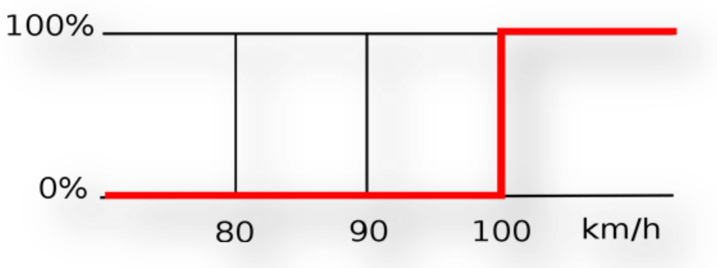

Figure III.1. Increasing speed type 1

Fuzzy logic, on the other hand, allows degrees of verification of the condition "Is the speed high?" (see Fig. III.2):

- The speed is considered not at all high below 80 km/h. We can therefore say that below 80 km/h, the speed is raised to 0%.

- The speed is considered high above 100 km/h. The speed is therefore increased to 100% above 100 km/h.
- The speed is therefore increased to 50% at 90 km/h, and 25% at 85 km/h

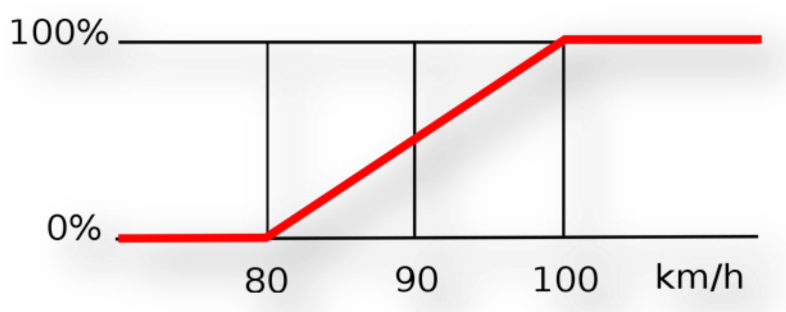

Figure III.2. Increasing speed type 2

Similarly, the "Is the speed low?" will be evaluated as follows:

- The speed is considered low below 80 km/h. It is therefore low at 100%.
- The speed is considered not at all low above 100 km/h. It is therefore low at 0%.
- The speed is therefore low at 50% at 90 km/h and 25% at 95 km/h.

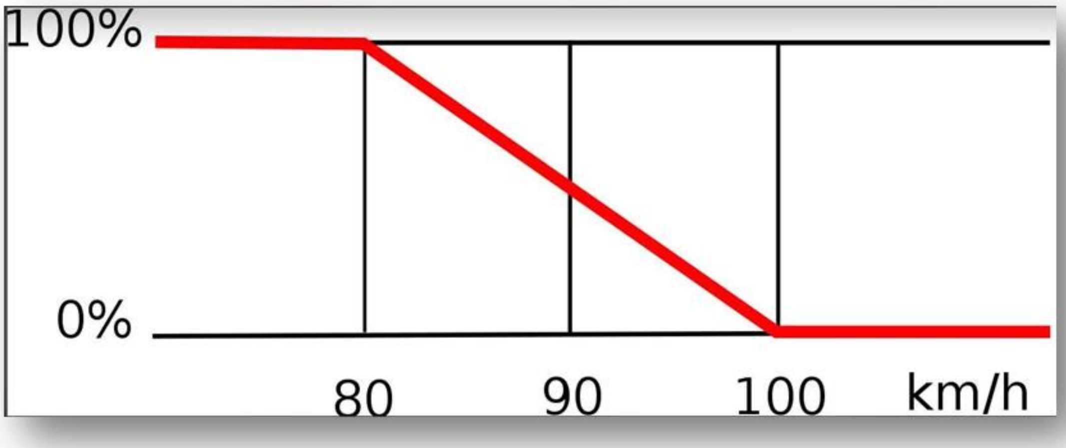

Figure III.3. Decreased speed

You can also define a function "Is the speed average?" (**see Fig. III.4):**

- The average speed is 90 km/h. At this pace, the speed is average at 100%.

- The speed is not at all average below 80 km/h and above 100 km/h. The speed is average at 0% outside this interval.
- The speed is therefore average at 50% at 85 km/h and 95 km/h.

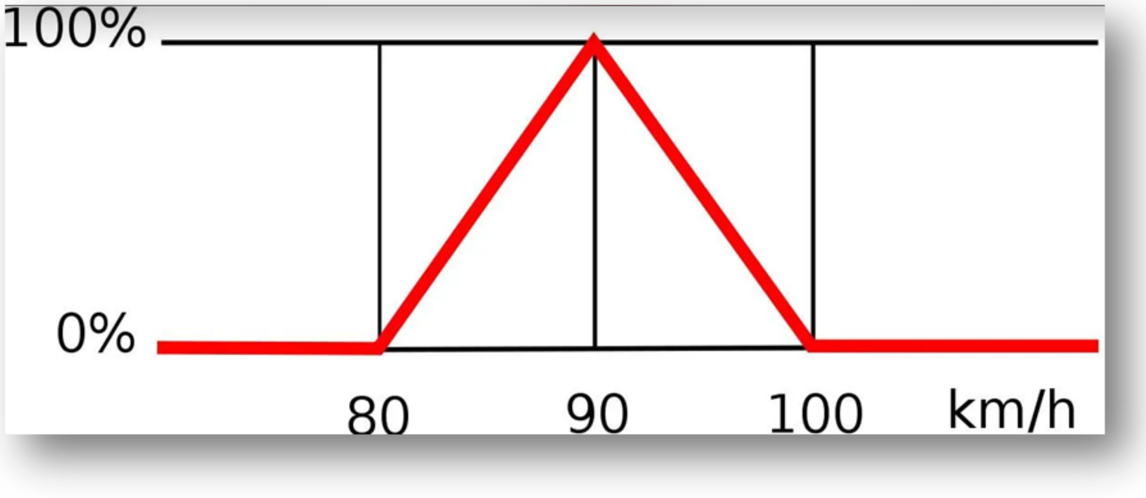

Figure III.4. Therefore average speed

The transition does not have to be linear. Hyperbolic transitions (like a sigmoid or a hyperbolic tangent), exponential, Gaussian (in the case of an average state), or any other kind can be used

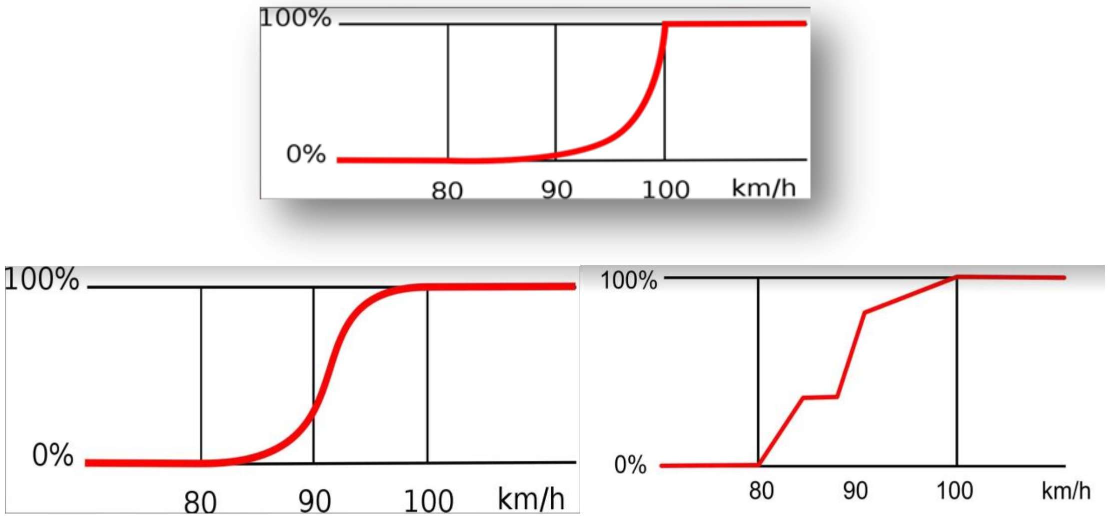

Figure III.5. Case of an average state speed

III.3. Fuzzification: [24]

This first step consists in transforming the variables (input and output) into variables linguistics:

- For each variable, we first define the universe of discourse (i.e. the range of

values that the variable can take).

- The variable is then divided into categories called linguistic variables
- A function (going from 0% to 100%) allows defining each variable and its percentage of veracity to the statement: "the observation is in such a category" is affected to each category.

This step is mainly carried out based on statistical observations (or by learning, supervised or not, to group the values of a variable into homogeneous categories) or to say expert. The graphs below are drawn taking the example of the size

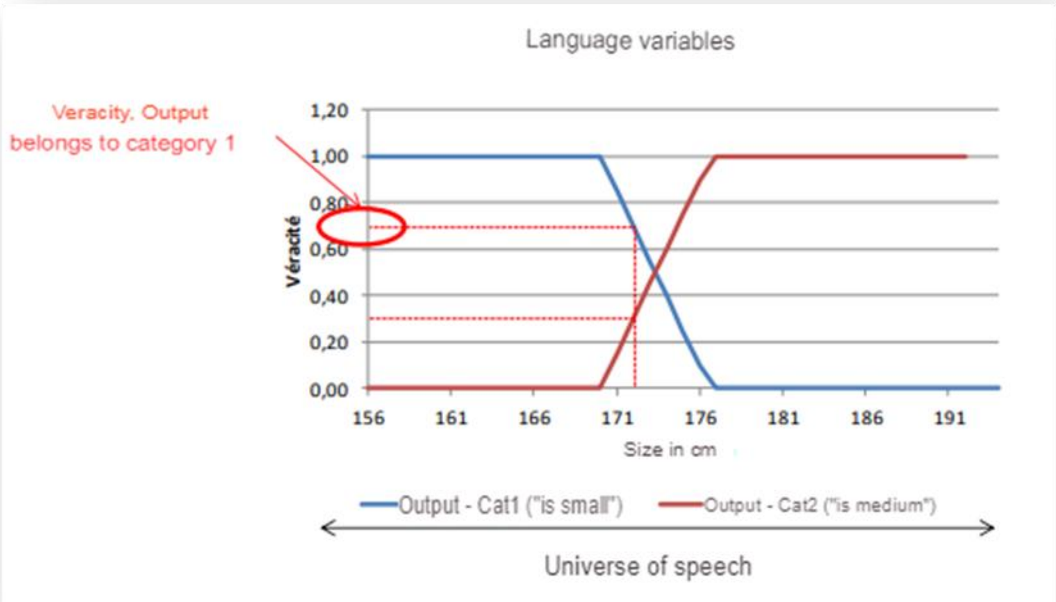

Figure III.6. Veracity function

Thus, saying that the output is in category 1 if the output variable is 75% has a veracity of 70% and a veracity of 30% for category 2.

Universe of speech: height in cm between 156cm and 194cm

Linguistic variable: name of the output variable (for example the size)

Linguistic values: "Cat1" (small), "Cat2" (medium).

III.3.2. Fuzzy inference: [25]

a. Building a Rule Set :

Based on the previously realized categories, a set of rules is constructed. By example: "Variable 1 Category 1 and Variable 2 Category 1".

The veracity of each of the rules is then calculated. The construction of these rules, mainly based on "AND", "OR" and "NOT", is mathematically translated as such.

b. Decision Matrix :

Each rule is assigned an answer through a decision matrix

Output	Var 2 Cat 1	Var 2 Cat 2
Var 1 Cat1	Cat1	Cat 2
Var 1 Cat2	Cat 2	Cat 1

Table III.1. Decision matrix

This can be rewritten:

Rule (i)	Description (R;)	Exit rule (Conclusion),)
1	Var 1 Cat 1 and Var 2 Cat 1	Cat1 Output
2	Var 1 Cat 1 and Var 2 Cat 2	Cat2 Output
3	Var 1 Cat 2 and Var 2 Cat 1	Cat2 Output
4	Var 1 Cat 2 and Var 2 Cat 2	Cat1 Output

Table III.2. Decision matrix exploded view

At this stage, an observation, therefore, follows the following path:

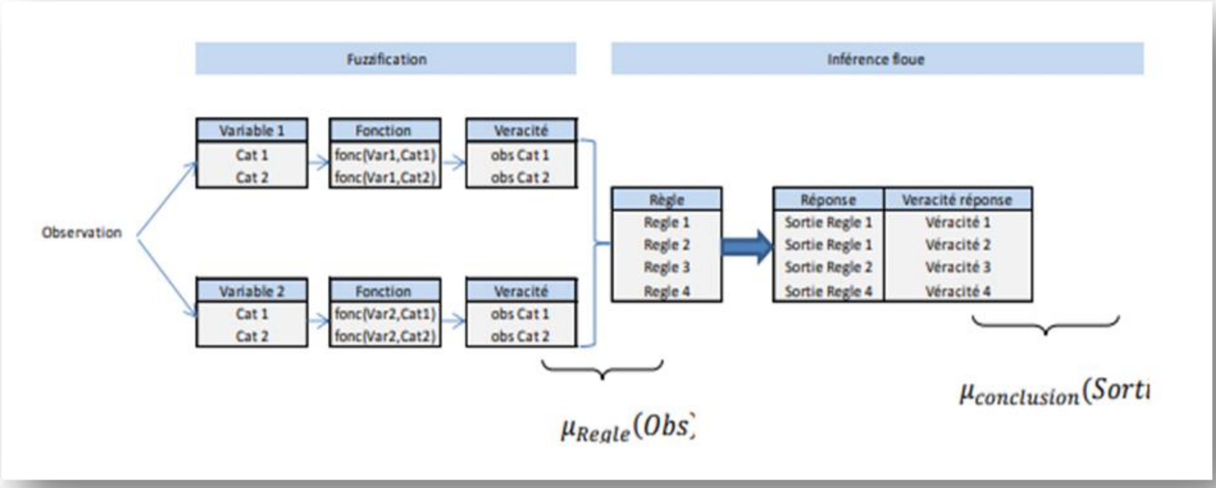

Table III.3. Observation follows the following path

c . Implication:

It is the calculation of the activation rules. It remains to define an activation rule to obtain a single response. This step is called involvement.

It can be done through two rules:

Notions$x0$ = ($Variable1$, $Variable2$)be the characteristics of the individual.

Larsen :$\mu_{conclusion'_{R_i}}: y \mapsto \mu_{R_i}(x_0) \times \mu_{conclusion_{R_i}}(y)$

Mamdani :$\mu_{conclusion'_{R_i}}: y \mapsto MIN_y(\mu_{R_i}(x_0), \mu_{conclusion_{R_i}}(y))$

With :

*($x0$) the degree of activation of the rule;

*$\mu_{Conclusio}(y)$the membership function of the output fuzzy set according to the rule

of decision. It should be kept in mind that$\mu_{Conclusion_{ri}}$ is a function.

Also, calculating the activation rule amounts to crossing the probability of the rule and the probability of the output associated with the rule. It is possible to pursue the analogy with the Bayesian methods of the classic probabilistic framework: the probability of the rule can be likened to an a priori probability and the probability of the exit to a posterior probability.

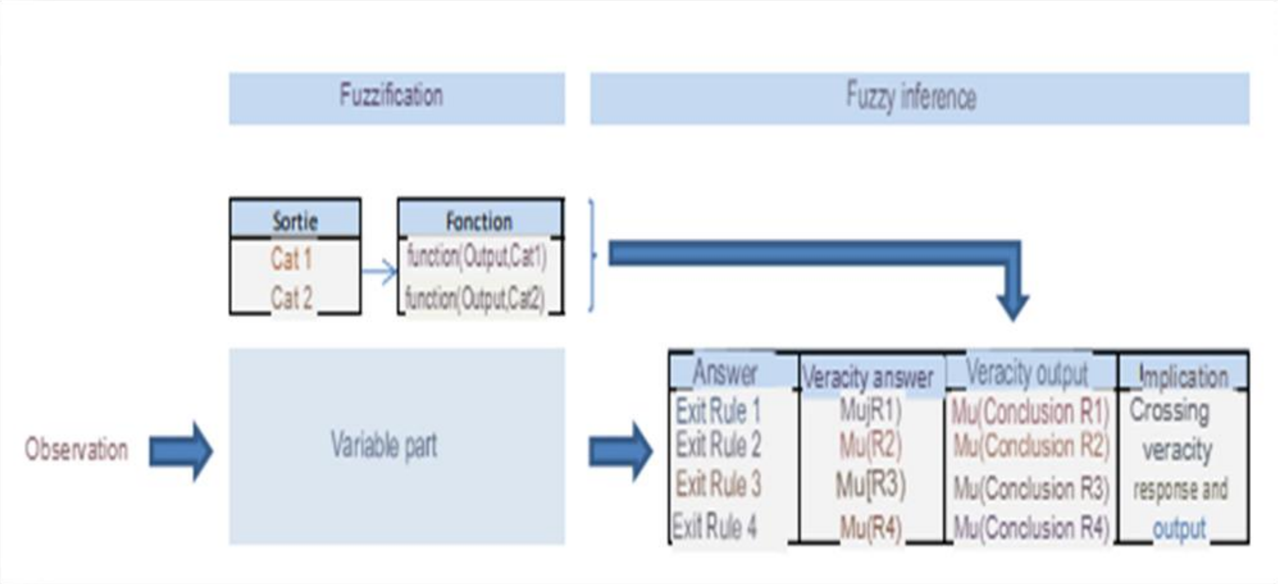

Table III.4. Output rule

By taking the Larsen rule and taking the graph associated with the exit rule and assuming:

Veracity answer	Veracity value
Veracity 1	70%
Veracity 2	0%
Veracity 3	40%
Veracity 4	0%

Table III. 5 : rules of outputs

We obtain:

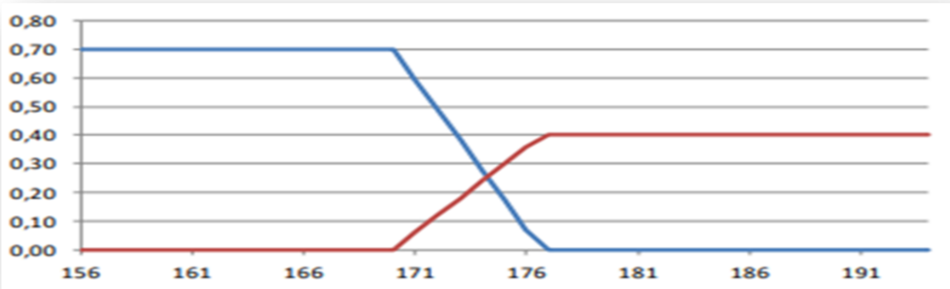

Figure III. 8 : activation rule

Note: The implication gives rise to a curve in the sense that:

The input variable gives rise to truths (by going through the different rules)

The output variable (associated with each rule) is also a veracity function for each modality.

d. Aggregation

This fourth step of inference consists of grouping all the rules. This grouping is therefore carried out based on logical "Or", which translates (cf. Table 1) by "Max". By taking thechart

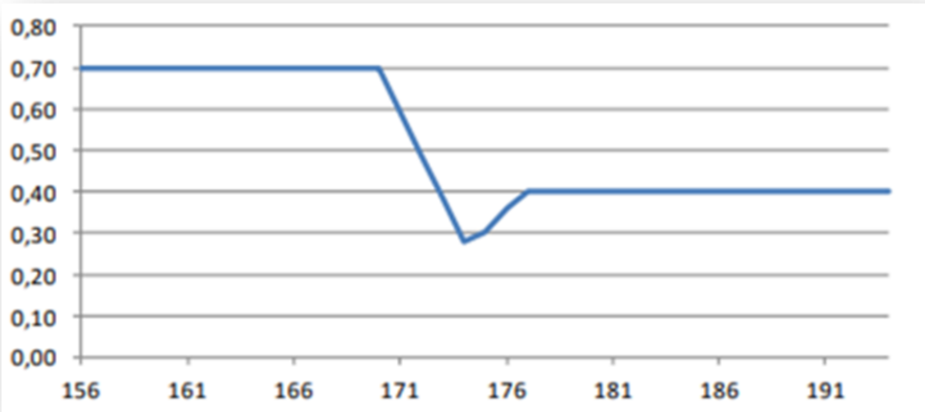

Figure III. 9. Finale activation

III. 3.3. Defuzzification :[26]

The last step of the fuzzy logic aims to transform the final activation curve obtained during the aggregation step into a real value.

Two methods are then applied to obtain the retained value of the variable to be predicted:

- The method of the average of the maxima: corresponds to the average of the output values more likely.
- The method of centers of gravity: abscissa of the center of gravity of the surface of the curveof results.

III.4. Characteristics of Fuzzy Logic: [27]

Here, are some important characteristics of fuzzy logic:

- Flexible and easy easy-to-implementing learning technique
- Helps you to mimic the logic of human thought
- Logic may have two values that represent two possible solutions
- Highly suitable method for uncertain or approximate reasoning
- Fuzzy logic views inference as a process of propagating elastic constraints
- Fuzzy logic allows you to build nonlinear functions of arbitrary complexity.
- Fuzzy logic should be built with the complete guidance of experts

III.5.Fuzzy Logic Architecture:

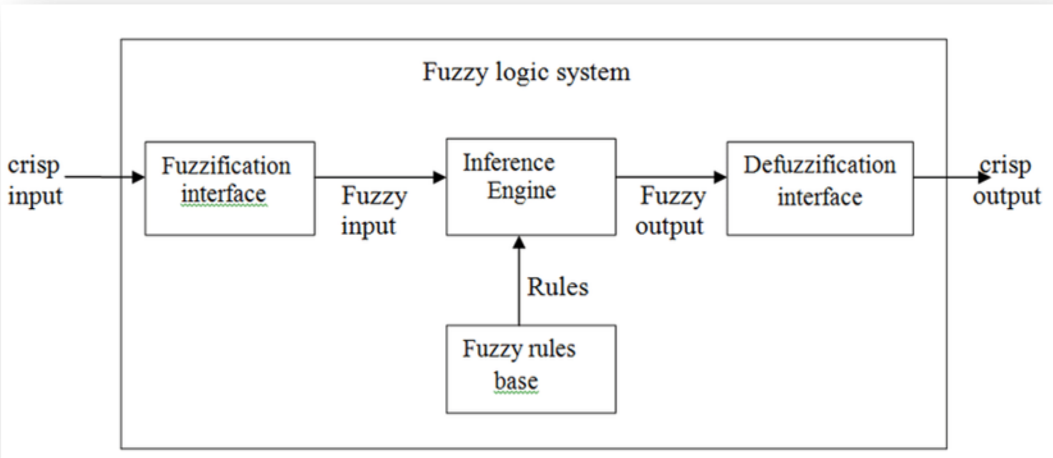

Figure III. 8. Fuzzy Logic Architecture

III.6. The difference between fuzzy logic and boolean logic:

The distinction between fuzzy logic and Boolean logic is that fuzzy logic is based on possibility theory, while Boolean logic is based on probability theory. In this way, fuzzy logic is a measure of a soil's similarity to a class, rather than its chance of belonging to it (Zhu, 2006).

See the below-given diagram. It shows that in a Fuzzy system, the values are denoted by a 0 to 1 number. In this example, 1.0 means absolute truth and 0.0 means absolute falseness.

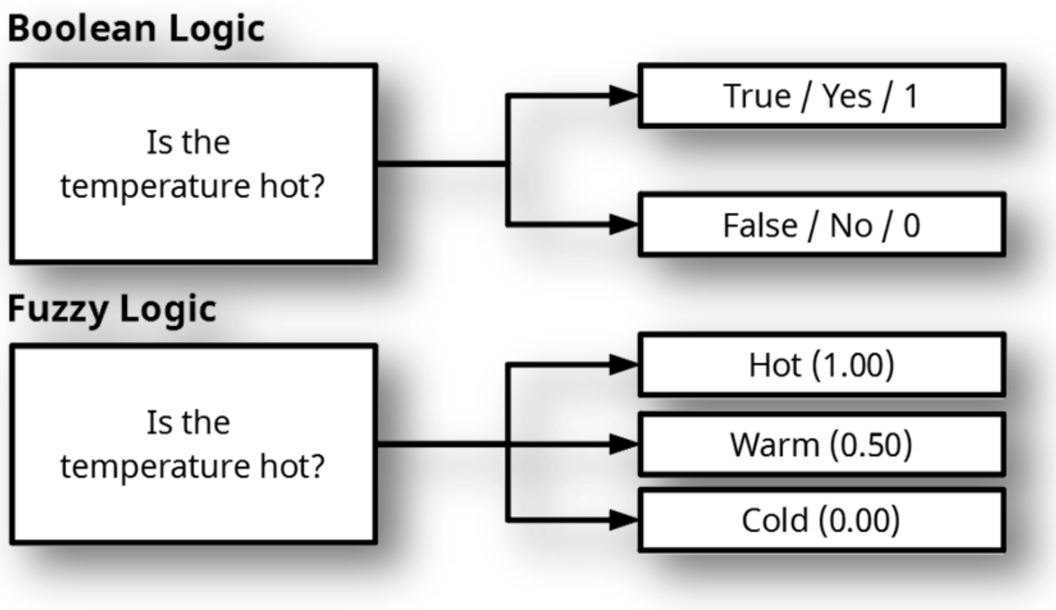

Figure III.9. The difference between fuzzy and boolean logic

III.7.Application Areas of Fuzzy Logic :

The Blow given table shows the application of Fuzzy logic by famous companies in their products.

PRODUCT	COMPANY	FUZZY LOGIQUE
Anti-lock brakes	Nissan	Use fuzzy logic to control brakes in hazardous cases ddependingoncar speed, acceleration, wheel speed, and acceleration
Auto transmission	NOK/Nissan	Fuzzy logic is used to control the fuel injection and ignition based on throttle setting, cooling water temperature, RPM, etc.
Auto engine	Honda, Nissan	Use to select geat based on engine load, driving style, and road conditions.
Copy machine	Canon	Using for adjusting drum voltage based on picture density, humidity, and temperature.
Cruise control	Nissan, Isuzu, Mitsubishi	Use it to adjust the throttleset car speed and acceleration
Elevator control	Fujitec, Mitsubishi Electric, Toshiba	Use it to reduce waiting for time-based on passenger traffic

III. 8 Advantage of Fuzzy Logic Systems :

- Fuzzy logic in Data Mining helps you to deal with the uncertainty in engineering
- Mostly robust as no precise inputs are required

- It can be programmed in the situation when the feedback sensor stops working
- It can easily be modified to improve or alter system performance
- inexpensive sensors can be used which helps you to keep the overall system cost and complexity low
- It provides themwith the most effective solution to complex issues

III.9. Disadvantages of Fuzzy Logic Systems :

- Fuzzy logic is not always accurate, so The results are perceived based on assumption, so it may not be widely accepted.
- Fuzzy systems don't have the capability of machine learning as well as neural network-type pattern recognition

III.10. Conclusion :

In conclusion, fuzzy logic offers several advantages in various domains, including control systems, artificial intelligence, decision-making, and pattern recognition. By incorporating degrees of truth and allowing for approximate reasoning, it provides a more flexible and nuanced approach to problem-solving. Fuzzy logic has been successfully applied in numerous real-world applications, such as automatic control systems, expert systems, and industrial processes.

Despite its effectiveness, fuzzy logic is not without limitations. The design and tuning of fuzzy systems can be complex and require domain expertise. Interpreting fuzzy rules and managing the computational complexity can also be challenging. Additionally, fuzzy logic may not be suitable for situations that require precise and deterministic decision-making. Overall, fuzzy logic has proven to be a valuable tool for dealing with uncertainty and imprecision, and it continues to be an active area of research and application in various fields. Its ability to handle vagueness and approximate reasoning makes it a valuable addition to the toolkit of decision-making and problem-solving methodologies.

Chapter IV. Risk ranking using Fuzzy FMEA (Case Study: raw crusher machine in cement company of Tebessa, Algeria)

Chapter IV. Risk ranking using Fuzzy FMEA (Case Study: raw crusher machine in cement company of Tebessa, Algeria)

IV.1 INTRODUCTION :

Cement has nowadays become a rare and highly coveted commodity. A fortuitous shutdown of a few minutes results in a significant loss of production. This is why the control of production systems has always been the major concern of manufacturers. This undoubtedly requires a mastery of this equipment.
Thus, faced with a management that is sometimes non-rational, rather intuitive and/or by learning phenomenon, the Maintenance department of the SCT, wanted to break with this way of managing the maintenance of its machine park. One solution was to opt for a powerful quality tool that would allow us to have a photograph of the equipment to ensure its maintenance in the best conditions. Their Criticality (FMEA) of one of their workshops. Thus, the objective of this study will initially be to determine the level of criticality of the subassemblies of the equipment in the machine park. Secondly, we will prioritize them in order to draw up the preventive and sometimes even corrective actions that are necessary.
To do so, the study will be divided into three parts. In the first part, we will diagnose the shortcomings of this maintenance function in the company and will try to explain the reasons for this choice of FMECA. Then, we will present the FMEA method. Then, we will present the FMEA method. Finally, we will apply it to certain equipment in the cement sector of the SCT.
New technology for testing damage and degradation of conveyor belts was introduced in 1979. FMEA (Failure Modes and Effects Analysis) is the technique used to radically identify and analyze the potential failure modes of an industrial system. It is used to improve the production chain and the quality of the products at each operating phase. This technique is based on failure mode analysis by a group of experts. Three parameters: severity, occurrence, and detection are considered for each failure mode. These three parameters usually have values between 1 and 10 and their multiplication gives a value between 1 and 1000, which is known as RPN (risk priority number). Different failure modes are prioritized in terms of severity score as well as RPN. This method is based on human judgment and feeling and the estimates therefore face an uncertain and imprecise concept and a precise quantitative value cannot be assigned for the three parameters. [8]
In addition, granting a value between 1 and 10 to each parameter affects the certainty of the calculations.

The fuzzy theory may be able to mathematically formulate vague and imprecise intervals, essential for the calculation of the risk priority number to allow the prioritization of the main causes. This method overcomes the drawbacks of classic FMEA. [9-11]

Moreover, giving a value between 1 and 10 to each parameter influences the certainty of the calculations. The fuzzy theory can solve the problem by the mathematical formulation of the vague and imprecise intervals, essential to the calculation of the priority number of the risks to allow the hierarchy of the main causes. This method overcomes the drawbacks of classical FMEA.[8] The fuzzy FMEA method is a relatively important subject and many works, especially those of the last years have been carried out in this context. [12-16]

In this present paper, fuzzy logic was used as a complementary means to perform reliable and logical analysis and the classic FMEA model was modified and modeled considering three parameters of occurrence, severity, and detection probability of failure mode. The objective of this work is to analyze the downtime of the grinche machine in a la Société des Ciments de Tébessa.the Cement Company of Tebessais one of the most important campany of ciment of Algeria (figure 1). the Cement Company of Tebessa is located in the south of Algeria(figure 2) , border with a production of 2.2 million tons annually, the Cement Company of Tebessa operations began in 2009. [17]

The Cement Company of Tébessa is a public economic body resulting from the company cement and its derivatives from East, West and CHLEF.

The joint-stock company ERCE represents the main issuer of the project completed with the latest technology in the control system, incorporated on November 29, 1993 under the name of cement and its derivatives from the East. - ELMA LABIOD plant - then separated from this last to become a self-sustaining company with an estimated registered capital of 800,000,000 DA shared at 8000 shares at the rate of 100,000 DA.

The contributions of the initial capital 200,000.00 DA are distributed as follows;

* ERCE regional cement company in the east: 1200 shares, i.e. by 60%

* ERCO regional cement company in the west: 400 shares, i.e. 20%

* ECDE regional cement company of CHLEF: 400 shares, i.e. 20%

While the rest was in the form of a loan - BADR - Algerian Development Bank rural.

It should be noted that this project is part of the fourth four-year plan (67/80) of the development and which came into force in 1985 and under the supervision of the company national distributor of building materials EDIMCO. The current share capital:

2.700.000.000DA.

Figure IV.1: View from above of the ELMA LABIOD production unit[google earth]

The purpose of this paper is to analyze the functioning of strategic equipment (Grinder machine) , considered the most important equipment in thethe Cement Company of Algeria Two computational approaches were used s to use t consistent d logical analysis logic, and the even MEA.

IV.2 The proposed model

Fuzzy logic is based on the theory of fuzzy sets developed by Zadeh[18]. It is a generalization of the traditional set theory. This method provides flexibility for reasoning and considers inaccuracy, subjectivity, uncertainty, and imprecision[19]. Fuzzy logic provides wide opportunities for working with imprecise linguistic data by defining rules and membership functions in sets called "fuzzy sets" [20].

A fuzzy setcan be defined phatically by a membership function $\mu_A(X)$, which assigns each element n the universe of discourse X a real number in the interval [0,1]. A triangular fuzzy number $\tilde{A}$ can be defined by a triplet (*a*, *b*, *c*) as illustrated in Figure 2. [21]

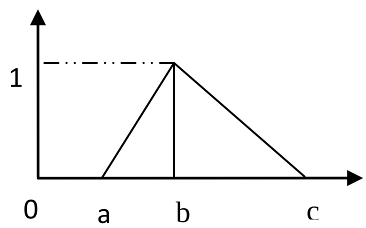

Figure. IV2

The membership function $\mu_A(X)$ is defined as

$$\begin{cases} \mu_A(X) = \dfrac{x-a}{b-a} \ \ for \ \ a \le x \le b \\ \mu_A(X) = \dfrac{x-c}{b-c} \ \ for \ \ b \le x \le c \\ \mu_A(X) = 0 \ \ Otherwise \end{cases} \qquad (IV.1)$$

Basic arithmetic operations on triangular fuzzy numbers $A_1 = (a_1,b_1,c_1)$, where $a_1 \le b_1 \le c_1$, and $A_2 = (a_2,b_2,c_2)$, where $a_2 \le b_2 \le c_2$,can be shown as follows:

Addition: $A_1 \oplus A_2 = (a_1 + a_2, b_1 + b_2, c_1 + c_2)$ (IV.2)

Subtraction: $A_1 \ominus A_2 = (a_1 - c_2, b_1 - b_2, c_1 - a_2)$ (IV.3)

Multiplication: if k is a scalar

$$k \otimes A1 = \begin{cases} (ka1, kb1, kc1), k \succ 0 \\ (kc1, kb1, ka1), k \prec 0 \end{cases} \qquad \text{(IV.4)}$$

$$A1 \otimes A2 = (a1a2, b1b2, c1c2) \quad \text{if } a1 \geq 0, a2 \geq 0 \qquad \text{(IV.5)}$$

$$A1 \varnothing A2 \approx (\frac{a1}{a2}, \frac{b1}{b2}, \frac{c1}{c2}) \quad \text{if } a1 \geq 0, a2 \geq 0 \qquad \text{(IV.6)}$$

In FMEA, S, O, and D are assigned values from 1 to 10. RPN is computed by the equation:

$$RPN = S \times O \times D \qquad \text{(IV.7)}$$

In conventional FMEA the determination of S, O, and D scores is done u, using linguistic terms. For this reason, the application of fuzzy logic is very appropriate to coordinate the problems that arise in conventional FMEA. The fuzzy rule describes the criticality level of an error for each combination of input variables. These rules are generally formulated in linguistic terms and expressed in the form of 'If – Then'. [22]

The first part of this rule describes all possible combinations of input factors. For example, we can say that we are testing a rule that deals with assumptions: If Occurance (O) is moderate AND Detection (D) is very low, AND Severity (S) is high. The problem now is to define the second part of the rule, which is what the output membership function should activate in the end.

The automated procedure here is proposed using the riskiness function to measure the subjective risk attitude of maintenance staff. This function relates the RPN values achieved by each combination of mode values of each fuzzy set (ie membership function) for each input, namely Occurrence (O), Detection (D), and Severity (S) with the linguistic sequence of error risk evaluation (final/output). This circuit responds to the traditional fuzzy output sequence: unimportant, minor, low, medium, important, and very important.

The regulatory structure of the decision system is of type: 'if ((D = Very Low) and (F = Moderate) and (S = High)), then (RPN = High); this will means if Occurrence (O) Medium AND Detection (D) Very Low AND Severity (S) High for the cause of the error, then category risk priority must be high. Once each of the three input variables can be assigned one of the five categories or classes, we have as many as 125 rules at completion for assigning RPCs to each of the causes of error analyzed in the FMEA.

IV.3 Fuzzy FMEA Input Variable Value:

We defined first the input, which is the three parameters: Occurrence, Severity, and Detectability. The numerical values of each parameter, with the linguistic terms, are presented in the tables 1. The input used in fuzzy logic is the severity index, occurrence, and detection which are categorized into 5 levels number of importance. The fuzzy sets are associated with the corresponding class from Very Low (VL) to Very High (VH) and are represented.The fuzzy sets with failure occurrence, Severty, and Detectability ranking and the corresponding member ship functions ares hown in Fig. IV.3, Fig. IV.4, and Fig. IV.5 respectively.

Table IV.1. Numeral index of category severity, Occurrence, and Detection [29-30]

Score			Category
S	O	D	
1	1	1	VL
2,3	2,3	2,3	L
4,5,6	4,5,6	4,5,6	M
7,8	7,8	7,8	H
9,10	9,10	9,10	VH

Table IV.2. Parameters of membership functions of input variables [30]

Category	Curves types	Parameter
VL	Trapezoid	[0 0 1 2.5]
L	Triangle	[1 2.5 4.5]
M	Trapezoid	[2.5 4.5 5.5 7.5]
H	Triangle	[5.5 7.5 9]
VH	Trapezoid	[7.5 9 10 10]

IV.4 Fuzzy FMEA Output Variable Value:

The resulting output value is a Fuzzy Risk Priority Number (FRPN) is also included in the membership value by entering a value range from 1 to 1000. Then the FRPN categories are filled in as can be seen in table 3.

Table IV.3. Parameters of membership functions of output variables

Category	Curves types	Parameter
VL	Trapezoid	[0 0 25 75]
VL-L	Triangle	[25 75 125]
L	Triangle	[75 125 200]
L-M	Triangle	[125 200 300]
M	Triangle	[200 300 400]
M-H	Triangle	[300 400 500]
H	Triangle	[400 500 700]
H-VH	Triangle	[500 700 900]
VH	Trapezoid	[700 900 1000 1000]

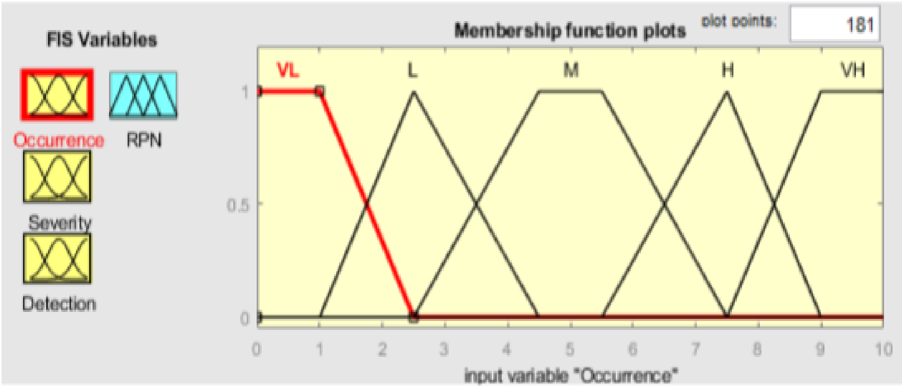

Figure IV.3. Shape of occurrence variable.

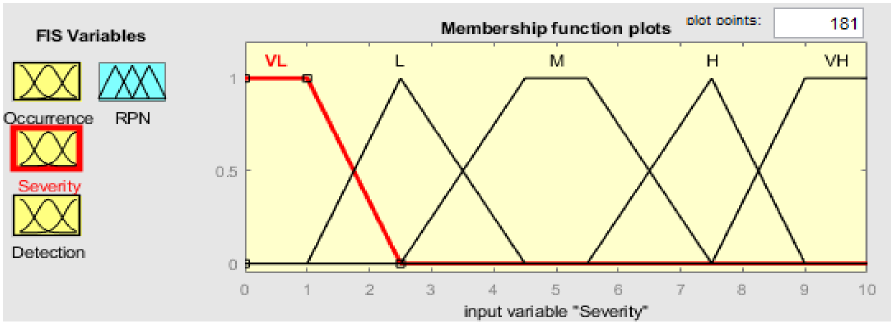

Figure IV.4. Shape of Detection variable.

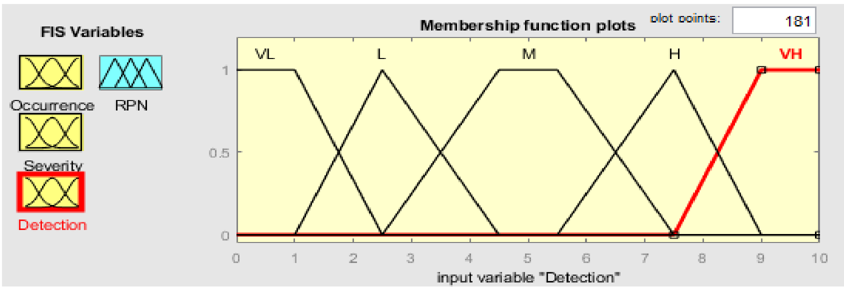

Figure IV.5. Shape of Detection variable.

Based on the membership functions of the input variables, 125 inference rules are generated; the RPN variable isdescribed in terms of the three risk parameters: severity (S), Occurrence (O), and detectability (D) (Fig. 6) using Tables 4-8. These tables are obtained by the expert opinion based on their analysis. Risk fuzzy sets are presented in Fig.IV.7. To get a numerical value of the RPN related to each risk, defuzzification is done using the centroid method. For example: if the occurrence is low (O=L), the detection is very low (D=VL) and the severity Very High (S=VH)), thus the RPN is very weak (RPN = LM).

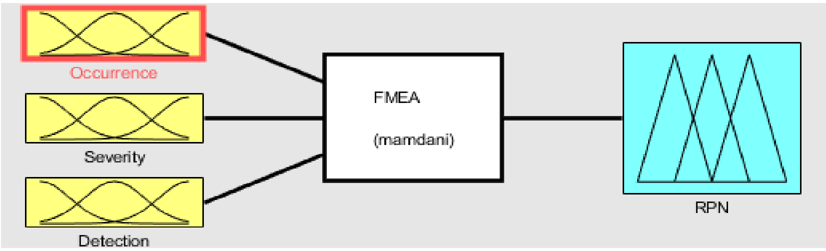

Figure IV.6. The fuzzy model.

Table IV.4. Fuzzycomputation of the outputRPNforO =VL.

Occurrence:VL						
Fuzy RPN		Severity				
		VL	L	M	H	VH
	VL	VL	VL	VL	VL	VL
	L	VL	VL	VL	VL	VL
Detection	M	VL	VL	VL	VL	VL-L
	H	VL	VL	VL	VL-L	VL-L
	VH	VL	VL	VL-L	VL-L	VL-L

Table IV.5. Fuzzy computation of the output RPN for O=L

Occurrence: L						
Fuzzy RPN		Severity				
		VL	L	M	H	VH
Detection	VL	VL	VL	VL –L	VL –L	LM
	L	VL	VL	VL –L	L	LM
	M	VL	VL	VL –L	L	LM
	H	VL	VL	VL –L	L	LM
	VH	VL	VL	VL –L	LM	M

Table IV.6 Fuzzy computation of the output RPN for O=M.

Occurrence M						
Fuzzy RPN		Severity				
		VL	L	M	H	VH
Detection	VL	VL	VL	VL	VL	VL – L
	L	VL	VL – L	L	L	LM
	M	VL	L	LM	M	MH
	H	VL	L	M	MH	H
	VH	VL - L	LM	MH	H	H

Table IV.7. Fuzzy computation of the output RPNfor O=H

Occurrence: H						
Fuzzy RPN		Severity				
		VL	L	M	H	VH
Detection	VL	VL	VL-L	L	LM	H
	L	VL	VL-L	L	M	H
	M	VL	VL-L	LM	MH	H-VH
	H	VL	VL-L	LM	MH	H-VH
	VH	VL	VL-L	LM	H	H-VH

Table IV.8. Fuzzy computation of the output RPN for O= VH

Occurrence: VH						
Fuzzy RPN		Severity				
		VL	L	M	H	VH
Detection	VL	VL	VL	VL- L	VL- L	VL- L
	L	VL	VL- L	LM	LM	M
	M	VL- L	LM	MH	H	H
	H	VL- L	LM	H	H-VH	H-VH
	VH	VL- L	M	H	H-VH	VH

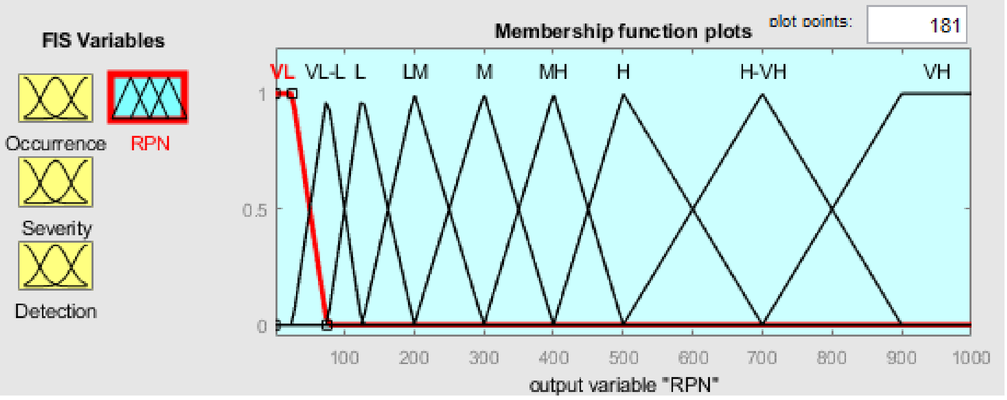

Figure IV.7. Risk fuzzy sets of risk level (RPN).

Based on the established set of inference rules (Tables IV.4-8), the fuzzy logic inference provides the risk level results according to any combination of the key risk parameters. These combinations are represented as a surface plot and illustrate three-dimensional (3D)risk profiles(Fig.8).

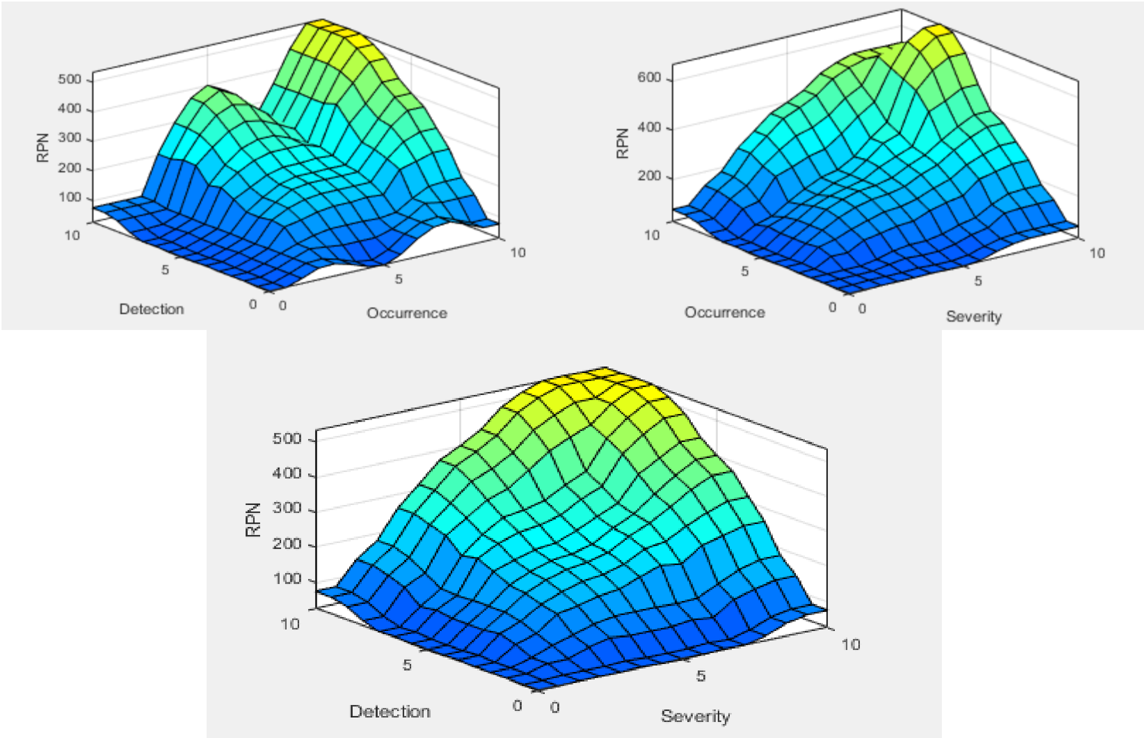

Figure IV.8: Risk level as a combination of the different riskparametes

IV.5 Case study:

The present study was carried out in The Cement Company of Tebessa. The grinder machine

2

Figure IV. 9: Grinder machine TIRAX unidon

IV.6 Description of the grinding operation:

IV.6.a Introduction:

Ball grinding was born from the observation of the reciprocal action of the pebbles at the edge of the sea, which brazed by the waves, reducing by clashing the grains of sand into more or less fine grains, at the same time as their wear gives them a more or less spherical shape.

The grinding operation is very expensive; it consumes about 50% of the energy consumed by a cement plant.

It is an operation whose yield is up to the present day very low.

IV.6.b. Behaviour of the balls in the crusher:

The speed of rotation is of very great importance. Ball mills rotate rather slowly, their speed being limited by the critical speed at which the balls stick to the walls.

In normal operation the balls must follow the drum in its upward movement and fall on top of each other following a more or less parabolic curve. Its optimal speed varies with each device, it is a function of the diameter of the grinder. The grinding bodies are driven at a speed close to 75 of the critical speed.

At the optimum speed, some cannonballs will be driven and projected onto the shielding, others driven and will fall by gravity under the influence of their weight, they will therefore act by percussion. Finally, others will roll on top of each other and slide along the embankment; they will act by friction and crushing or (trituration).

So percussion is adapted to the work of the preparer compartment and trituration to that of the finisher compartment.

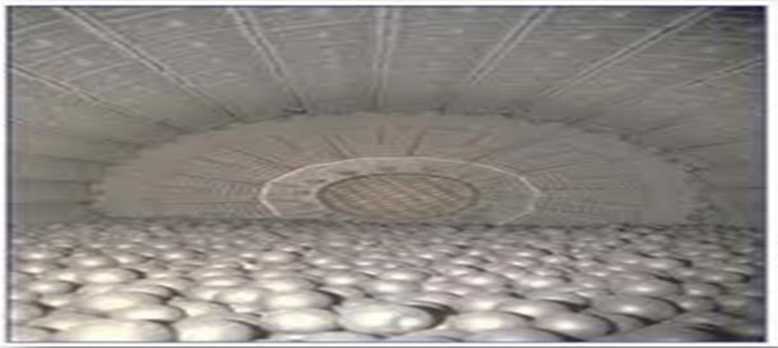

Figure. IV.10. Location of particles in the crusher

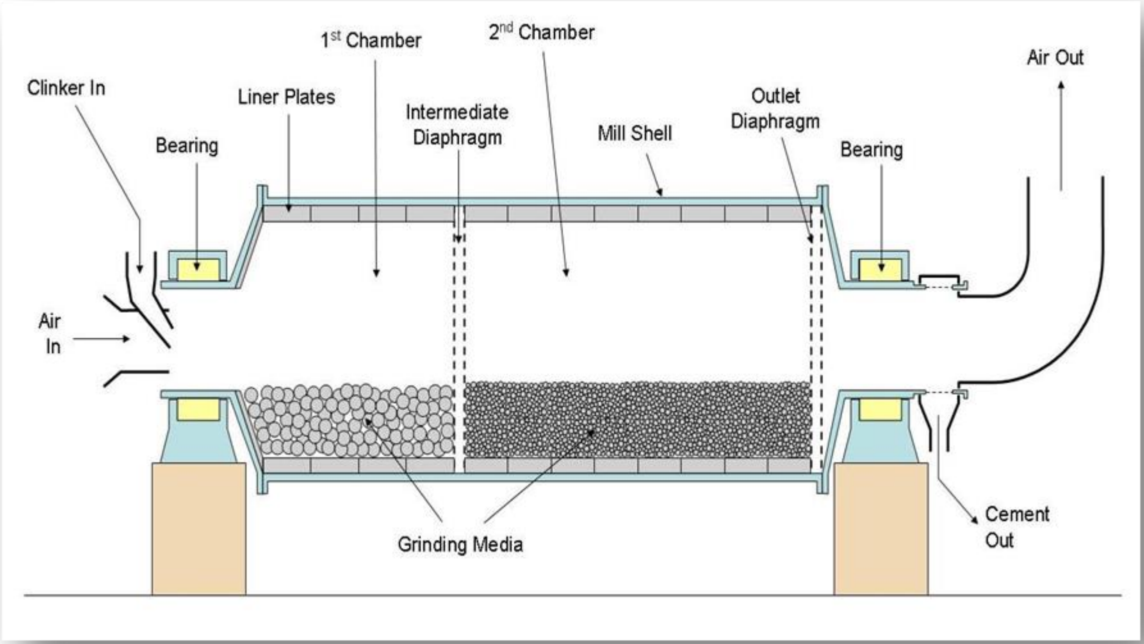

Figure IV.11. raw crusher machine

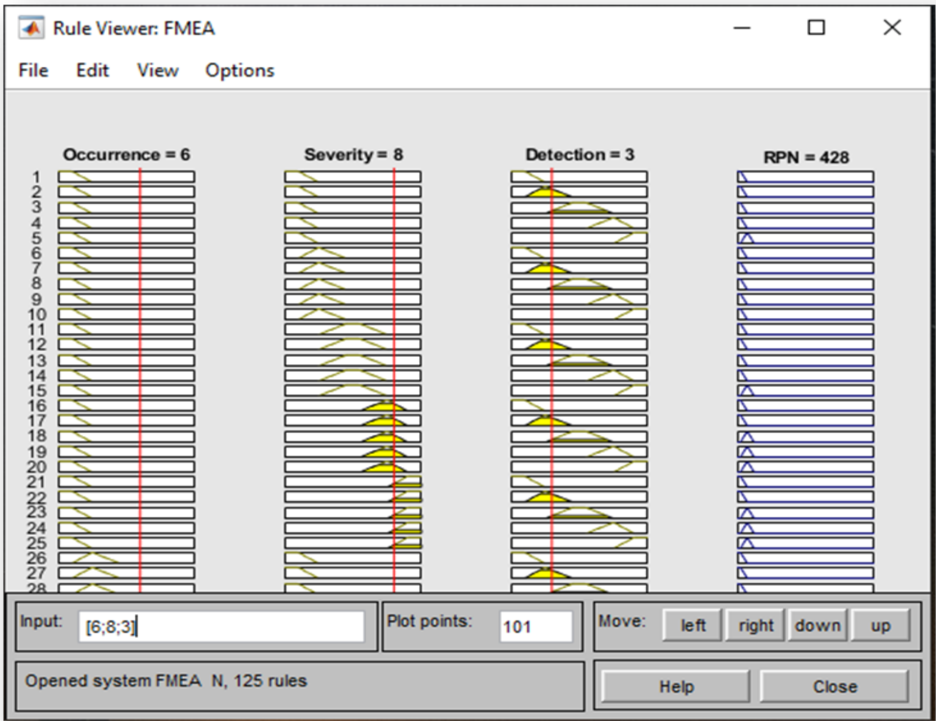

Figure IV.12: Calculation of RPN fuzzy logic model

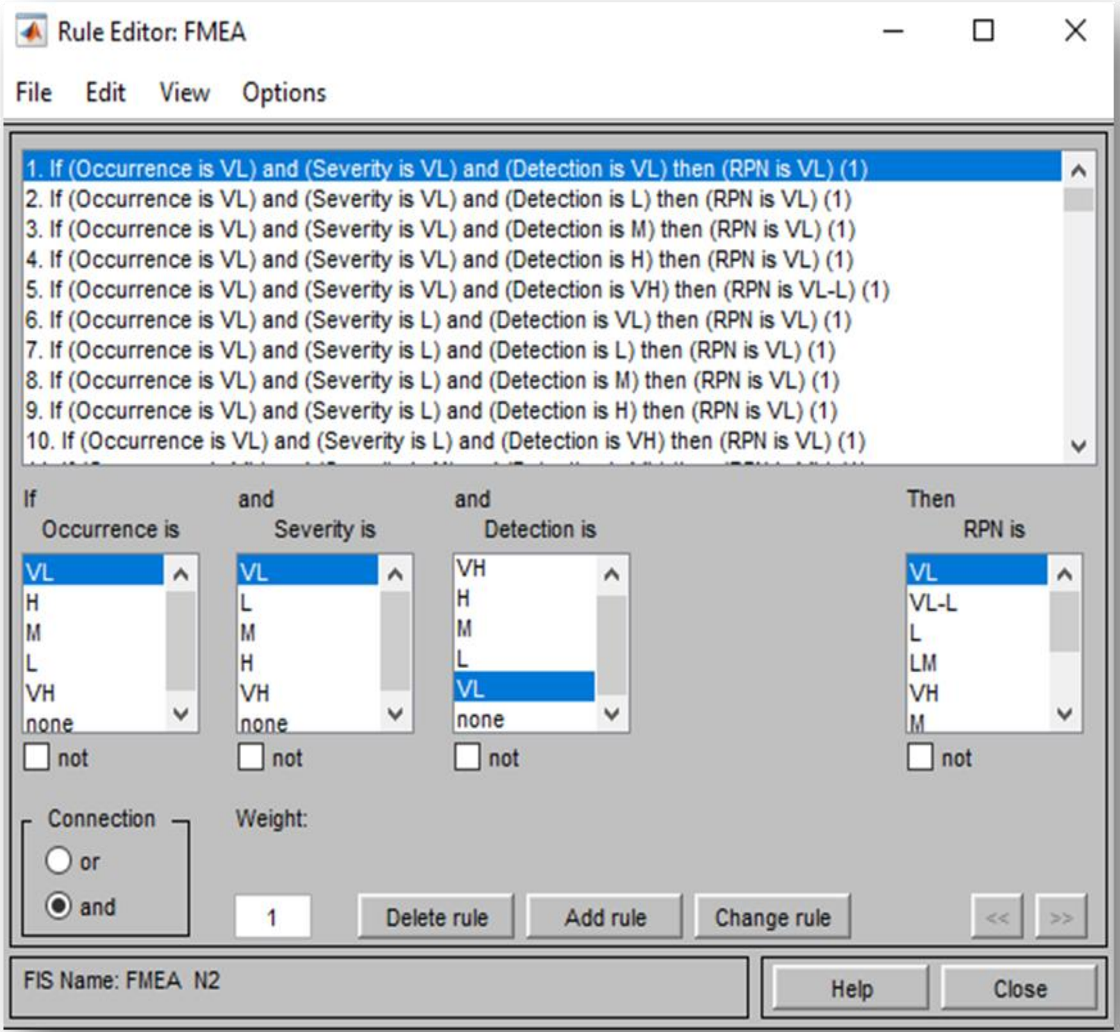

Figure IV.13: Inference rules

IV.8 Failure analysis table:

Table IV.9: Failure mode/cause/effect

Subset	Element	Mode of failure	Causes of failure	Effects	N°
Coupling GV	Coupling GV	- Wear of buffers	- Default alignment	- Contact metal/metal - vibrations	F1
Reducer	Teeth	- Wear - break	Bad lubrication misalignment	- Noise - shock	F2
	Plain bearings	- Regular wear	- misalignment TREE	- Teeth wear - High friction	F3
	TREE	- Wear of litters of plain bearings	- Bad lubrication	Teeth wear -Excess of temperature	F4
	Carter	- Wear sealing	- Loose bolts cracks	- Oil leak	F5
Coupling PV	Coupling	- Wear of teeth	- Misalignment - Fatigue	- Vibes	F6
Elongate	Landings rolling	- Wear - Breakage	Lack sealing; Fatigue	-Shaft blocked - noise of rolling	F7
	TREE	- Breakage	- Material quality - fatigue	- No transmission	F8
Shaft gear	Pinion	- Wear - break of toothing	- Bad lubrication and assembly fatigue	- Bad meshing with crown	F9
	TREE	- Breakage	- Bad alignment with coupling	- No transmission	F10
	Landings rolling	- Wear - break	- Bad lubrication - misalignment	- Noise - temperature high	F11
Crown	Teeth	- Wear - break	- System of faulty lubrication	- vibration - shock	F12
Carrier bearing	Trunnions	- Wear grooves	- Penetration of matter - bad lubrication	High friction wear of pads	F13

We took the most important failures and put it on the table (not all the failures)

Table IV.10. The comparison between RPN and fuzzy RPN (FRNP).

Failure Number	O	S	D	RPN	Priority	RPNF	Priority
F1	6	6	3	108	15	248	11
F2	6	9	3	162	11	452	5
F3	7	9	3	189	7	517	3
F4	8	9	3	216	3	531	2
F5	2	10	10	200	6	246	12
F6	9	8	3	216	4	357	8
F7	2	10	9	180	8	438	7
F8	2	8	8	128	12	197	13
F9	6	8	8	384	1	548	1
F10	6	9	4	216	**5**	488	4
F11	3	8	5	120	13	349	10
F12	6	8	3	192	9	428	6
F13	3	10	8	240	2	357	9
F14	6	6	3	108	14	248	11
F15	6	9	3	162	10	452	5

IV.9Results and discussion:

In this work, the grinder machine make was considered for the risk analysis. Three years of breakdown details were taken into consideration for the analysis. All the functional failures of the grinder machine with potential failure modes of 'F_i'are given in Table IV.9. After observation, there are 13 categorized failure modes, concerning the grinder machine, realized by the experts. The evaluation of RPN, and FRPN values is presented in Table IV.10. RPN values of conventional FMEA, with the product of S, O, and D. On the other hand, an "If–Then" rule base is created using fuzzy inference (FIS), which after defuzzification generates the fuzzy risk priority number (FRPN) (Table IV.10). The development of the Fuzzy-FMEA assessment model was made by utilizing MATLAB software.

The FRPN is calculated based on the established inference rules (Fig.IV.12), from the three in indicators Severity, Occurrence, and Detection) using the fuzzy logic inference system as shown in Fig.IV.13.

We note that the fuzzy logic model calculates the different failure modes and gives a different result for failures that have the same result as the normal RPN calculation (see Table IV.10). From these results, we notice that the calculation of the RPN risk level gives the same result while the fuzzy logic model gives more significant values.

The results of traditional FMECA (Table IV.9), show that the highest level of RPN value are: (324; F9), (240; F13), and (216; F4). The effect of the failure mode of these elements is more critical. They must be given special importance, hence the need to propose modification actions. These actions offer the possibility of increasing the life of the equipment and positively affecting the overall production of the mine. This can be achieved by applying maintenance schedules based on man the manufacturer's recommendations.

From the results (Table IV.9), a similar type of RPN value (RPN=216) was found for failure modes F10, F6. The sum RPN (108) for F1 and F14, (rank: 14 and 15).

Different new values were obtained by the fuzzy-logic method (531; F4), (375; F6), and (488; F10) with (rank: 2, 8, and 4) The Fuzzy-FMEA technique can also calculate the different failure modes and gives a different result for failures that have the same result with the normal RPN calculation.

IV.10 Conclusion:

The reliability of the equipment is ensured by continuous good operation by reducing breakdowns. The decline in the performance of factory equipment is the consequence of unexpected breakdowns. The main causes of these breakdowns are poor management, lack of spare parts, inefficient operating actions, and a delicate working environment. For these reasons, it is necessary to analyze the failure of a system to identify the main factors influencing the performance of the machine. In this study, the failure behavior of the Grinder machine (raw crusher) was analyzed in each failure mode. The results of the calculations and analysis are summarized as follows:

From the results (Table IV.9) of conventional FMEA, it was noticed that the highest level of RPN value was obtained for (324; F9), (240; F13), and (216; F4). The RPN value provides information about system elements. It is also necessary to propose modification actions necessary to improve a design or a process. For high RPN values, the effect of the failure mode is more critical. This effect reduces equipment life and negatively affects overall factory production. This can be improved by applying maintenance schedules based on manufacturers' recommendations.

a) A fuzzy rule base system based on MATLAB software was used in this study. The Fuzzy-FMEA technique can also calculate the different failure modes and gives a different result for failures that have the same result with the normal RPN calculation.

b) In this study, the Fuzzy-FMEA technique was proposed to prioritize the rankings of potential failure modes. This technique can also assess the hazard and criticality of parts of a factory machine (grinder machine) by characterizing the MATLAB database of Fuzzy IF-THEN guidelines. This technique considers vague and ambiguous data in the evaluation procedure. It was concluded that a rule-based fuzzy FMEA analysis provides strong evidence that the proposed methodology is logically useful for prioritizing RPN values. We notice that the equal values of the RPNs, the FRPNs, are representative and different.

General Conclusion

General conclusion

By minimizing breakdowns, the equipment operates in constant good condition, ensuring equipment reliability. Unexpected breakdowns lead to a decline in the performance of production equipment. Poor management, a lack of spare parts, ineffective operating procedures and a delicate work environment are the main contributors to these stoppages. For these reasons, it is essential to examine a system's failure in order to pinpoint the primary variables affecting the machine's performance. In this study, each failure mode of a grinder machine failure was classified and examined. The approach is based on fuzzy logic and FMECA. Following is a summary of the calculations' and analysis' findings:

According to the traditional FMEA results (Table IV.9), the RPN values for (324; F9), (240; F13), and (216; F4) were the highest. The RPN value offers details about system components. In order to enhance a design or a process, it is also required to suggest modification activities. The impact of the failure mode is more severe for high RPN values. This has a detrimental impact on industrial production overall and shortens the lifespan of the equipment. Applying maintenance regimens based on the advice of the manufacturer can help with this.

a) This study made use of a fuzzy rule basis system built on MATLAB software. Additionally, the Fuzzy-FMEA technique can compute the various failure modes and provides a distinct result for failures that would produce the same result using a standard RPN calculation.

b) The Fuzzy-FMEA technique was suggested in this study to order the rankings of likely failure modes. By describing the MATLAB database of fuzzy IF-THEN rules, this technique may also determine the risk and criticality of individual components of a factory machine (a grinder machine). In the evaluation process, this technique takes fuzzy and imprecise data into account. It was determined that solid evidence supporting the suggested methodology's logical usefulness for prioritizing RPN values comes from a rule-based fuzzy FMEA analysis. We see that the FRPNs, which have equal RPN values, are representative and distinctive.

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Annexes

Date of analysis: **06/07/2012**	**FMEA MACHINE – ANALYSIS OF FAILURE MODES AND THEIR EFFECTS ANOF THEIRD CRITICALITY**					Stage of functioning **2010-2011**				page: 1 / 13
	System : **UNIDAN CRUSHER**		Subset: **GV COUPLING**							Name: workshopv BC
Element	**Function**	**Mode of failure**	**Cause of failure**	**Effect of failure**	**Detection**	**criticality**				**Corrective action**
						F	**G**	**N**	**P**	
GV coupling	Transmit the motor torque at reducer	Wear of buffers	Misalignments bearing wear reducer beams Fatigue	Wear of housing buffers Metal contact metal vibes	Measure vibratory	3	6	6	108	Change of buffers
		Breakage of axes	Wrong spacing of half couplings	Vibes Reducer stop	Measure vibratory	6	9	3	162	Change
		State of the link with the key	worn groove Deadened key or dislodged Bad fitting	Beat	Measure vibratory	7	9	3	189	Change
		Wear of housing buffers	Misalignments	Vibration important Noises Wear of buffers	Measure vibratory	8	9	3	216	Change

Date of analysis: **06/07/2012**	**FMEA MACHINE – ANALYSIS OF FAILURE MODES AND THEIR EFFECTS AND OF THEIR CRITICALITY**		Stage of functioning 2010-2011	page: 2 / 13
	System :**UNIDAN CRUSHER**	Subset:**REDUCER**		Name: workshop BC

Element	**Function**	**Mode of failure**	**Cause of failure**	**Effect of failure**	**Detection**	**criticality**				**Corrective action**
						F	**G**	**N**	**P**	
Teeth Plain bearings	Transmit the couple	Wear Break	Bad lubrication System of cooling defective Gear reducer slide bearing wear	noises; shock; Excess of temperature Bad transmission	Measure vibratory	2	10	10	200	Change
		Issue sealing	Seal wear	Oil leak	Visual	9	8	3	216	Change of seals
TREE	Transmit the movement	Wear of litters of plain bearings	Worn spelter Bad lubrication	Teeth wear Excess of temperature	Measure vibratory	2	10	9	180	Change Machining
		Break	Misalignment Bad mesh Fatigue	No transmission	measure vibratory	2	8	8	128	Change
Carter	Protect all Reducer	Wear sealing	Loose bolts Cracks	Oil leak	visual	6	8	8	384	Tightening of bolts Welding

Date of analysis: **06/07/2012**	**FMEA MACHINE – ANALYSIS OF THE FAILURE MODES OF THEIR EFFECTS AND THEIR CRITICALITY**					Stage of functioning **2010-2011**				page: 3 / 13
	System :**UNIDAN CRUSHER**		Subset:**PV COUPLING**							Name: workshop BC
Element	**Function**	**Mode of failure**	**cause of failure**	**Effect of failure**	**Detection**	**criticality**				**Stock Fix**
						F	**G**	**N**	**P**	
Coupling PV	Transmit the couple by Meshing	Wear of teeth	Misalignment Bad lubrication Fatigue	Vibes Bad transmission	Measure vibratory	6	9	4	216	Change Loading + Machining
		State of the link with the key	worn groove Matted key	Beat	Measure vibratory	3	8	5	120	Machining Matting ofkey

Date of analysis: **06/07/2012**	**FMEA MACHINE – ANALYSIS OF THE FAILURE MODES OF THEIR EFFECTS AND THEIR CRITICALITY**		Stage of functioning **2010-2011**	page: 4 / 13
	System :**UNIDAN CRUSHER**	Subset:**ELONGATE**		Name: workshop BC

Element	**Function**	**Mode of failure**	**cause of failure**	**Effect of failure**	**Detection**	**criticality F**	**G**	**N**	**P**	**Stock Fix**
Rolling bearing	Guide in spin	Wear / break	Bad lubrication Lack of tightness Bad assembly of bearings; fatigue	Shaft blocked noise of rolling Excess of temperature	Measure vibratory Visual	6	8	3	192	Change of rolling
TREE	Transmit in couple	Wear of litters of rolling	adapter sleeve loose; bearings worn	Bad transmission		3	10	8	240	Tightening of sleeves Change
		Break	Bad assembly Fatigue	No transmission	visual	6	6	3	108	Change
		State of the binding by key	worn groove Deadened key or dislodged	Beat	visual	6	9	3	162	Loading groove Matting of Key

Date of analysis: **06/07/2012**	**FMEA MACHINE – ANALYSIS OF THE FAILURE MODES OF THEIR EFFECTS AND THEIR CRITICALITY**					Stage of functioning 2010-2011				page: 5 / 13
	System :**CRUSHERUNIDAN**		Subset:**GEAR SHAFT**							Name: workshop BC
Element	**Function**	**Mode of failure**	**cause of failure**	**Effect of failure**	**Detection**	**criticality**				**Stock Fix**
						F	**G**	**N**	**P**	
Pinion	Transmit the PV torque at the Crown	Wear/breakage teeth	Bad lubrication; poor assembly; fatigue	Bad meshing with crown ; shock	Visual	1	3	2	6	Change
TREE	Transmit the movement of spin	Break	Misalignment with coupling bad mesh fatigue	No transmission	Visual	1	3	2	6	Change
		Wear of the scope of bearings	bearing sleeve loose worn bearing	Vibration wear of pinion teeth; overheating	Follow up temperature	1	3	2	6	Change Litters
		Link with key	Key matted on dislodged; wear groove; bad fitting	Beat (shock)	Visual	1	3	2	6	Change of key

Landings rolling	Guide pinion rotating shaft	Wear / break	Bad lubrication; probe misalignment nonfunctional	Tooth wear pinion; bad noise mesh; high temperature	Room follow-up control	1	3	1	3	Change of rolling

Date of analysis: **06/07/2012**	**FMEA MACHINE – ANALYSIS OF THE FAILURE MODES OF THEIR EFFECTS AND THEIR CRITICALITY**					Stage of functioning 2010-2011				page: 6 / 13
	System :**UNIDAN CRUSHER**		Subset**:CROWN**							Name: workshop BC
Element	**Function**	**Mode of failure**	**cause of failure**	**Effect of failure**	**Detection**	**criticality**				**Stock Fix**
						F	**G**	**N**	**P**	
Teeth	Transmit the movement of rotation at the ferrule	Wear / breakage	System of lubrication defective; bad meshing; bearing wear carrier ; fatigue	vibration; shock	Visual	1	4	2	8	Change

Date of analysis: **06/07/2012**	**FMEA MACHINE – ANALYSIS OF THE FAILURE MODES OF THEIR EFFECTS AND THEIR CRITICALITY**					Stage of functioning 2010-2011				page: 7 / 13
	System :**UNIDAN CRUSHER**		Subset:**CARRIER BEARING**							Name: workshop BC
Element	**Function**	**Mode of failure**	**cause of failure**	**Effect of failure**	**Detection**	**criticality**				**Stock Fix**
						F	**G**	**N**	**P**	
Trunnions	Receive the pads; support the grinder	Scratch wear	System of suspension defective ; bad lubrication ; penetration of materials	Friction high; wear pads	Follow up temperature pads; pressure monitoring	2	4	2	**16**	Change of Trunnions
Pads	Guide in rotate the grinder	Bearing wear	Bad lubrication; system of cooling faulty oil; pin wear	Bad meshing of the crown ; bad guidance	Follow up temperature pads; pressure monitoring	2	4	2	**16**	Change of pads Change of oil from lubrication

Date of analysis: **06/07/2012**	**FMEA MACHINE – ANALYSIS OF THE FAILURE MODES OF THEIR EFFECTS AND THEIR CRITICALITY**					Stage of functioning 2010-2011				page: 8 / 13
	System :**UNIDAN CRUSHER**		Subset:**CRUSHER**							Name: workshop BC
Element	**Function**	**Mode of failure**	**cause of failure**	**Effect of failure**	**Detection**	**criticality**				**Stock Fix**
						F	**G**	**N**	**P**	
Gutter input	Route the clinker mix; addition and gypsum to the grinder	Drilling wear	Material abrasivene Material grade leakss ;	matter	visual	1	3	2	6	Welding of gutter
Entrance cone	Advance the material in the grinder	Drilling wear of the propeller	dilapidated cone; abrasiveness materials; quality repair	Penetration of matter ; wear trunnion	visual	1	3	3	9	Change /welding Propeller
Entrance fund	Protect the wall front plates	Wear of crusher	Impact between cannon shielding wear; bad Filling crusher; abrasiveness matter ; fatigue	balls Wall and grinder	Visual inspection	2	4	**2**	16	change of plates Wall welding grinder
Rooms of grind	Overwrite the	falling plates	Breakage/ loosening wear	Bolt wall grinder	Visual	2	4	**2**	16	tightening of bolts

	Blend	Wear of shields	Shock cannonballs /shield; Material abrasiveness;	A lot of refusal; wear ferrule	Visual	2	4	2	16	Change of plate shielding
			improperly filled grinder							
Partitions	Serve as a passage to the material from the crusher to separator	Sieve wear Central	Material abrasivene empty walkingss ;	Lots of refusal; transfer cannonballs of the chamber1 in bedroom 2		2	4	2	6	ending of grids Change ofsieve

Date of analysis: **06/07/2012**	**FMEA MACHINE – ANALYSIS OF THE FAILURE MODES OF THEIR EFFECTS AND THEIR CRITICALITY**					Stage of functioning 2010-2011				page: 9 / 13
	System :**UNIDAN CRUSHER**		Subset:**REDUCER LUBRICATION SYSTEM**							Name: workshop BC
Element	**Function**	**Mode of failure**	**cause of failure**	**Effect of failure**	**Detection**	**criticality**				**Stock Fix**
						F	**G**	**N**	**p**	
Oil pump	Ensure the transportation of the oil between the exchanger and the reducer	Flow fault	Defective seals; worn bearing ; leak	Bad lubrication; pump warm-up	sensor debit	1	3	2	6	Change Seals

Dispatchers	Distribute the oil overall of the targeted area	Corking	Foreign bodies	Bad lubrication	sensor temperature	1	3	3	9	Cleaning

Painting. IV.17

Date of analysis: **06/07/2012**	**FMEA MACHINE – ANALYSIS OF THE FAILURE MODES OF THEIR EFFECTS AND THEIR CRITICALITY**					Stage of functioning 2010-2011				page: 10/ 13
	System :**UNIDAN CRUSHER**		Subset:**REDUCER OIL COOLING SYSTEM**							Name: workshop BC
Element	**Function**	**Mode of failure**	**cause of failure**	**Effect of failure**	**Detection**	**criticality**				**Stock Fix**
						F	**G**	**N**	**P**	
Oil pump reducer	Ensure the transportation of the oil between the exchanger and the reducer	Flow fault	Defective seals; worn bearing; leak	Oil heating reducer; warming up pump	Detector of traffic debit	1	3	2	6	Change of seals Change of rolling
Filtered	Stop the particles solid	Dirtying	Presence of body in suspension	Increase in temperature clogging	visual	1	1	1	1	Change of Filtered

Exchanger	Lower the temperature of the oil of reducer	Clogging of tubing	Presence of body in suspension ; scaling of tubing	Bad cooling	sensor temperature	1	2	2	4	Change of Tubing
		Dirtying bundles	Bad filtering	Bad cooling	sensor temperature	1	3	2	6	Change of bundles
		Internal leak; extremes	Corrosion	Oil/water mixture	visual	1	3	1	3	Welding of leaks

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	System :**UNIDAN CRUSHER**		Subset:**WATER COOLING SYSTEM**							Name: workshop BC
Element	**Function**	**Mode of failure**	**cause of failure**	**Effect of failure**	**Detection**	**criticality**				**Stock Fix**
						F	**G**	**N**	**P**	
Water pump	Ensure the water transportation between the exchanger and the radiator	Flow fault	Defective seals; leak ; extra defective	bad cooling of oil; pump warm-up	Visual Sensor	1	3	2	6	Change

Water tank	Ensure the supplement in water at the circuit	Low water level	Leak ; lack water; nonfunctional security	Uncompensated leak in the circuit main; bad cooling of water and oil	Visual Sensor	1	3	2	6	Welding of leaks
Radiator	Lower the temperature of the water	Drilling	Water quality	Leak; bad cooling	visual	1	3	3	9	Welding of radiator
		Fin wear	bad surface exchange	Bad cooling	Visual	1	3	2	6	Change of fins
Ventilation	Cool water in the radiator	Broken blade	Foreign bodies	Poor mixing; bad cooling	Visual	1	2	2	4	Welding of Blades
		Loose blade	Loose bolts	Poor mixing; bad cooling	Visual	1	3	2	6	Tightness of the blades

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	System :**UNIDAN CRUSHER**		Subset:**CARRIER BEARING COOLING SYSTEM**							Name: workshop BC
Element	**Function**	**Mode of failure**	**cause of failure**	**Effect of failure**	**Detection**	**criticality**				**Stock Fix**
						F	**G**	**N**	**DTVS**	
Oil pump BP	Ensure the circulation of oil	Flow fault	Seal wear; wear of rolling ; wear of pump teeth; leak	Trunnion wear; bearing wear	sensor debit	1	3	2	6	Change of Trunnion
Distributor	Distribute the oil between thepipes of Bearings	Corking	Foreign bodies	Bad lubrication; crusher stop;	warming up	1	3	2	6	Cleaning

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	System :**UNIDAN CRUSHER**		Subset:**TURNING GROUP**							Name: workshop BC
Element	**Function**	**Mode of failure**	**cause of failure**	**Effect of failure**	**Detection**	**criticality**				**Stock Fix**
						F	**G**	**N**	**P**	
Brake	Stop the transmission	Braking delay	Lining wear	Slippage; warming up	Visual	1	1	2	2	Change of brake pads
Reducer turn	Reduce speed motor	Tooth wear	Bad lubrication; body evil strangers sealing	Noises; bad meshing	Measure vibratory	1	3	3	9	Change of toothing
		Bearing wear	Bad lubrication; poor sealing; fatigue	Warming up reducer	sensor temperature	1	3	3	9	Change of rolling