الجمهورية الجزائرية الديمقراطية الشعبية
People's Democratic Republic of Algeria

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People's Democratic Republic of Algeria
وزارة التعليم العالي والبحث العلمي
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Final Year Project to Obtain the Diploma of Engineering

- Field – Industrial Engineering

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- Subject -

A Smart RCM Implementation
- A case study on Algerian Qatari Steel and Soummam -

Realized by
KRITTER Djihane Mebarka and BOUKERROU Lylia

Members of The Jury:

Name	Grade	Role title
GOURI Rabah	**Pr**	Président
BOUDHAR Hamza	**MCB**	Supervisor
LAIDI Mohamed	**MCB**	Co-supervisor
AMRANI Mohammed	**MAA**	Examinator

Algiers, the 27/06/2023

Academic year 2022 –2023

Dedication

To my cherished mother, the twinkle in my gaze,

To my noble father, my fortress strong,

To my brothers, my guardians through life's maze,

To my dearest grandpa, my epitome of patience,

To my Susane, for with her negative vibes bids its adieu.

KRITTER Djihane Mebarka

Dedication

To my parents, I dedicate this project to express my gratitude for raising me and being always beside me through the ups and downs. Your selflessness and sacrifices have paved the way for me to find my place in this world. I am forever grateful for your unconditional love and unwavering support.

And to my sister and brother, I extend my heartfelt thanks for bringing immense joy and happiness into my life. Your presence and support have been invaluable, and I am grateful for the special bond we share.

As I conclude this important chapter of my life, I would like to express my heartfelt gratitude to all those who have been present to witness this occasion and have played a part in helping me complete this academic project.

BOUKERROU Lylia

Acknowledgement

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Last but not least, we sincerely express our respect and gratitude to the members of the jury, who have generously offered their time and attention to evaluate our work. We earnestly hope that our efforts will meet their expectations, and we deeply appreciate their commitment to assessing and acknowledging excellence.

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AQS: Algerian Qatari Steel.

RCM: Reliability Centred Maintenance.

CBM: Condition-Based Maintenance.

BN: Bayesian Network.

BNMSA: Bayesian Network for Multi-States Analysis.

DBN: Dynamic Bayesian Network.

COPQ: Cost of Poor Quality.

KPIs: Key Performance Indicators.

MTBF: Mean Time Between Failure.

MTTR: Mean Time To Repair.

FMEA: Failure Modes and Effect Analysis.

RCFA: Root Cause Failure Analysis.

PM: Preventive Maintenance.

CM: Corrective Maintenance

PdM: Predictive Maintenance.

CMMS: Comprised Maintenance Management system.

General Introduction

The evolution of industries has been a dynamic and intricate process throughout history, driven by the introduction of new technologies, changing consumer demands, and emerging economic opportunities. As industries undergo transformation, whether through the creation of entirely new sectors or the disruptive influence of innovative technologies within existing domains, companies face distinct challenges and prospects for growth and success in their respective markets.

The adoption of new equipment, technologies, and production processes becomes essential for companies seeking to leverage these opportunities and maintain competitiveness. In this context, effective maintenance practices play a pivotal role, combining managerial and technical aspects to facilitate adaptation, minimize downtime, and ensure quality production and equipment availability.

Nevertheless, the process of identifying a suitable maintenance strategy that can effectively yield these desired results requires the use of a dependable method or tool. This is precisely why Reliability Centred Maintenance (RCM) plays a pivotal and indispensable role in the maintenance of critical facilities. The significance of RCM stems from the recognition that when dealing with a valuable physical asset, it becomes imperative to ensure its continuous upkeep at the utmost level of quality.

RCM represents a structured and systematic approach that identifies and prioritizes maintenance tasks based on the criticality and impact of equipment failures on business objectives. By implementing RCM, industries can develop a cost-effective and reliable maintenance strategy that maximizes equipment performance and minimizes downtime.

Originally developed in the 1960s by engineers in the Airlines Industry to address maintenance challenges in the aviation sector, RCM has since found widespread application in diverse industries such as energy, food and beverage production, manufacturing, and transportation. Leveraging reliability analysis, RCM enables the identification of critical equipment and the evaluation of appropriate maintenance strategies to enhance equipment availability, reliability, and cost-effectiveness.

In today's era of advanced technologies, such as the Internet of Things (IoT) and data analytics, maintenance processes are becoming increasingly predictive and efficient. RCM aligns well with these evolving needs, as it embraces and integrates these technologies. By harnessing real-time data collection and analysis, RCM enables the optimization of maintenance strategies based on the current state of equipment, ensuring competitiveness and sustainability in modern industries.

While RCM is effective for simpler systems, complex systems with multiple states pose additional challenges during RCM implementation. The identification and modelling of different possible states, along with determining optimal maintenance intervals for each component in each state, become crucial considerations.

This is where Bayesian Networks (BNs), a probabilistic graphical modelling technique, prove valuable. BNs can capture the intricacies of complex systems and depict relationships between components and states. In the context of RCM implementation for complex and multi-state systems, BNs assist in modelling and quantifying uncertainties and dependencies among components, states, and maintenance actions. Such capabilities enable the determination of optimal maintenance intervals and the evaluation of the effectiveness of various maintenance strategies.

Furthermore, BNs facilitate the handling of incomplete or imperfect data and the management of uncertain or unknown system states. These features become particularly significant when data collection is limited or costly, or when the system is constantly evolving and undergoing change.

Facilitators have long been focused on achieving a flexible maintenance and operation work system, through various strategies. However, only a limited number of them have successfully implemented such a structure. These endeavours primarily prioritize the reliability of the equipment involved.

The primary goal of our project is to substantiate the efficacy of our innovative smart RCM framework through its practical implementation in two distinct sectors of industries. This framework consists of the traditional RCM process along with additional steps such as data mining, integration of the Bayesian network for multi-state analysis, and prediction of future equipment behaviour. Which will further enable informed decision-making based on valuable insights.

The first industry selected for this endeavour is the Algerian Qatari Steel Industry, specifically focusing on its rolling mill unit. This unit presents a complex and continuous manufacturing process comprising numerous linear equipment that operates with a high degree of automation. The comprehensive automation system governs the entire production flow, commencing from the handling of raw materials and culminating in the delivery of finished steel products.

The second industry where we intend to deploy our smart framework is Soummam, an Algerian agri-food company that specializes in the dairy product manufacturing sector. Our study target will be the UHT product packaging unit, initially designed as an automated facility, that incorporates the latest market technologies to streamline the entire packaging process. This comprehensive unit encompasses multiple production lines, each allowing filling and packing the UHT-treated products. With its aseptic filling techniques, the unit ensures that products are securely and hygienically filled, meeting strict quality standards and government regulations

Chapter 1:
Integrating Bayesian Network into Reliability-Centred Maintenance (RCM)

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Introduction:

The chapter highlights the importance of understanding RCM principles, benefits, and limitations to effectively manage maintenance activities and improve operational performance through RCM impact on the quality of service by reducing equipment downtime, ensuring consistent service delivery, increasing customer satisfaction, and complying with quality and safety standards. The integration of Bayesian Network for Multi States Analysis (BNMSA) enhances the ability of RCM to predict equipment behaviour, while industry-specific constraints highlight the importance of reliable equipment in different sectors. Overall, RCM plays a critical role in improving equipment reliability, safety, cost optimization, and operational efficiency.

1. Reliability-Centred Maintenance (RCM):

1.1. Definition and Principles of RCM:

RCM is a comprehensive and systematic approach to maintenance that aims to ensure the reliability, availability, and optimal performance of equipment and systems [4], [3]. It focuses on identifying and prioritizing the most critical failure modes that can significantly impact operations, safety, and costs. RCM involves analysing the functions and potential failure modes of equipment, assessing the consequences of those failures, and developing appropriate maintenance strategies to mitigate risks. The principles of RCM include understanding system functions, identifying failure modes, determining failure consequences, selecting suitable maintenance actions, and establishing a proactive maintenance program.

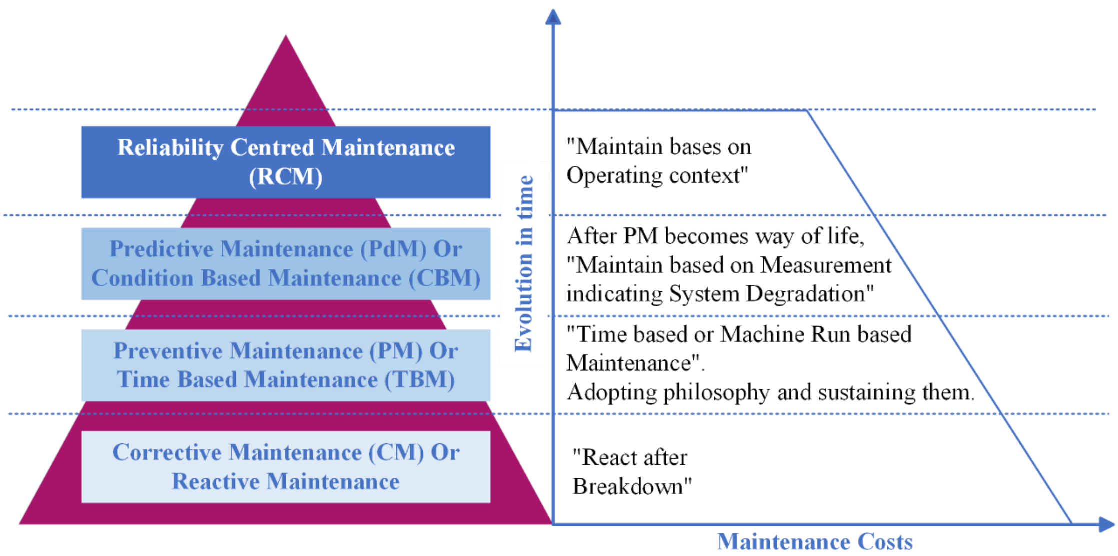

Figure 2.1: Reliability Excellence and Maintenance Philosophy.

1.2.Benefits of RCM:

RCM offers several benefits to organizations that implement it effectively:

a) Improved Equipment Reliability: By identifying and addressing the most critical failure modes, RCM improves equipment reliability and reduces unexpected breakdowns. This leads to increased uptime, productivity, and operational efficiency.

b) Enhanced Safety: RCM emphasizes the identification and mitigation of failure modes that can compromise safety. By proactively addressing these risks, RCM helps ensure a safe working environment for personnel and minimizes the potential for accidents and injuries.

c) Cost Optimization: RCM enables organizations to allocate maintenance resources effectively by focusing on critical failure modes. This approach helps optimize maintenance budgets, reduce unnecessary maintenance tasks, and minimize overall maintenance costs.

- **Maintenance Philosophy: Type of Maintenance Vs Cost:**

Earlier, maintenance strategy involved taking corrective action after an equipment failure, companies were reluctant in expending resources needed to maintain equipment resulting in huge losses. Nowadays, the emphasis is on proactive strategies with the intent of enhancing the availability, reliability & safety of equipment.

Also, the repair cost should consider including losses on Cost of Poor Quality (COPQ) and others.

However, the total cost of maintenance needs to be seen considering criticality of the equipment/system [2].

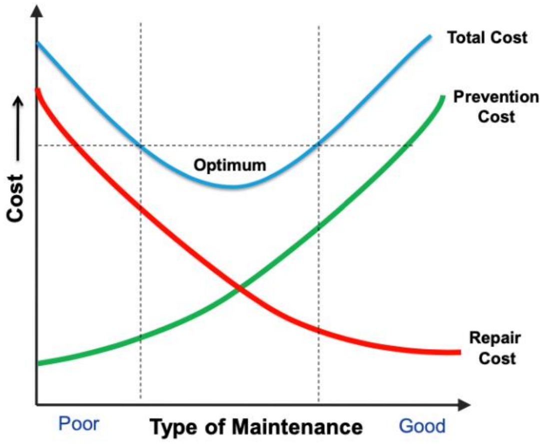

Figure 1.2: Type of Maintenance Vs Cost

d) Extended Equipment Lifespan: Through proactive maintenance strategies, RCM helps maximize the lifespan of equipment by preventing or mitigating potential failures. This reduces the need for premature equipment replacement, leading to cost savings in the long term.

e) Improved Operational Efficiency: RCM minimizes unplanned equipment downtime, improves maintenance planning and scheduling, and optimizes maintenance activities. This results in increased operational efficiency and improved utilization of resources.

~~1.2.~~1.3. Limitations of RCM:

While RCM provides significant benefits, it is important to be aware of its limitations:

a) Resource Intensiveness: RCM requires a significant investment of time, expertise, and resources to conduct thorough analyses, gather data, and develop effective maintenance strategies. Organizations with limited resources may face challenges in implementing RCM comprehensively.

b) Complex Decision-Making: RCM involves evaluating multiple factors, such as failure consequences, maintenance costs, equipment criticality, and operational constraints. Making informed decisions based on these factors can be complex and time-consuming, requiring the collaboration of experts from various disciplines.

c) Dynamic Nature of Equipment: RCM analyses are typically conducted at a specific point in time and may not fully account for changes in equipment behaviour, operating conditions, or technological advancements. Regular reassessment and updating of RCM strategies are necessary to account for these changes and maintain the effectiveness of the maintenance program.

2. Integration of Bayesian Network for Multi States Analysis:

2.1. Limitations of Failure Mode and Effects Analysis (FMEA) for Multi-State Analysis:

Traditional Failure Mode and Effects Analysis (FMEA) is a widely used technique for analysing failure modes and their effects. However, FMEA typically allows for binary analysis, categorizing failure modes as either present or absent. This binary approach may not capture the full complexity of equipment behaviour and the various states of degradation or performance that equipment can exhibit [26].

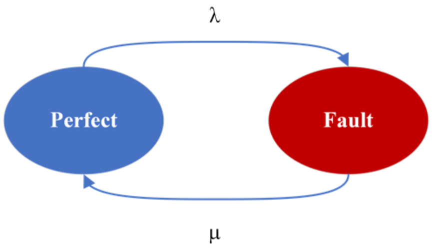

Figure 1.3: Binary States Analysis

2.2. Role of Bayesian Network of Multi States Analysis:

To overcome the limitations of FMEA, this study integrates the Bayesian Network of Multi States Analysis (BNMSA) into the RCM framework. BNMSA enables a more comprehensive multi-state analysis, allowing for the consideration of different levels of equipment degradation and performance [21]. By incorporating probabilistic relationships between variables, BNMSA facilitates the construction of models that can predict the future behaviour of equipment, enabling proactive maintenance decision-making[12]. This integration enhances the predictive capabilities of RCM, as it provides a more nuanced understanding of equipment states and their associated risks [27].

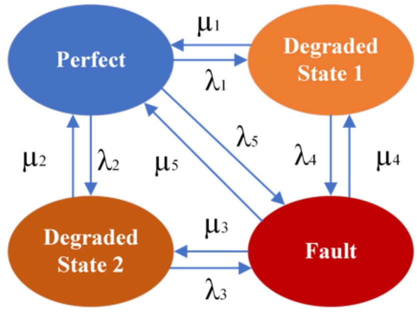

Table 1.4: Bayesian Network for Multi States Analysis

Conclusion:

In conclusion, while RCM has proven to be a highly effective process, its effectiveness can be limited when applied to complex systems that experience numerous degraded states, often yielding unsatisfactory results. However, the integration of Bayesian networks proves to be beneficial in addressing these limitations. By incorporating Bayesian networks, not only does it enable a comprehensive analysis of multiple states, but it also offers the ability to predict the future behaviour of equipment. Thus, the utilization of Bayesian networks enhances the effectiveness of RCM by providing a valuable tool for dealing with intricate systems and their degraded states, ultimately leading to more satisfactory outcomes.

Chapter 2: Industry Selection for Smart RCM Implementation

Chapter 2: Industry Selection for Smart RCM Implementation

Introduction:

This chapter delves into the rationale behind the selection of the Algerian Qatari Steel industry and the Soummam industry as case studies for implementing RCM. The decision to choose these industries was made after careful evaluation of several factors, including their unique characteristics, operational constraints, criticality, and respective positions within the supply chain. By thoroughly considering these aspects, valuable insights can be gained into the application of RCM tailored to their specific contexts and explore the potential benefits of studying these industries within the broader scope of maintenance optimization.

1. The Algerian Qatari Steel Industry:

Algerian Qatari Steel (AQS) is a prominent joint venture between the Algerian Republic and the State of Qatar, with ownership shared among Qatar Steel International, the SIDER Industrial Group, and the National Investment Funding. Operating in the Bellara industrial zone of Jijel, AQS holds a significant position in the regional steel industry due to its production capacity, operational reliability, and technological advancements. It meets the local iron market's demands and exports surplus production to regional and international markets. Starting with a production capacity of 2 million tons per year, AQS plans to expand its production capacity to over 4 million tons annually, focusing on specialized steels for various industries. It has achieved remarkable growth by integrating into the steel value chain, adopting cutting-edge technologies, and offering high-quality products at competitive prices. With a commitment to environmental sustainability, AQS prioritizes reducing dust and pollutant emissions, making it a key player in the dynamic steel industry of the Bellara industrial zone.

AQS has been chosen because of its unique characteristics and specific requirements. It operates in a challenging environment that involves heavy machinery, continuous production processes, and complex supply chain dynamics. The equipment used in steel production, such as blast furnaces, rolling mills, and conveyors, are subjected to high temperatures, abrasive conditions, and significant mechanical stresses. The reliability of this equipment is of utmost importance in ensuring uninterrupted production, maintaining market competitiveness, and supporting downstream industries that rely on steel for construction projects, manufacturing operations, and infrastructure development. By studying RCM implementation in this industry, valuable insights can be gained into managing maintenance in high-stress industrial settings and optimizing the performance of critical equipment.

2. The Soummam Industry:

The Soummam industry has its own distinct characteristics and constraints that make it an ideal case study for RCM. Soummam operates under stringent regulations and consumer safety concerns. It is crucial to maintain the reliability of equipment to ensure the quality and safety of food products. Critical equipment in the food industry includes food processing machines, refrigeration systems, and packaging lines. Any failure or breakdown in these systems can lead to product contamination, spoilage, and costly recalls, posing a significant risk to consumer health and brand reputation.

By implementing RCM in the Soummam industry, the focus is on preventing unexpected failures, meeting production quotas, ensuring on-time delivery, and maintaining customer trust in the industry's products. This case study provides valuable insights into managing maintenance in a highly regulated industry with strict quality and safety requirements.

The Soummam Dairy, founded in 1993 by the Hamitouche family from Akbou, Algeria, stands out for its constant innovation and steady growth. Since 2000, it has operated a modern production site that meets international standards. In 2009, as part of its nationwide milk production program in collaboration with independent farmers and collection centers, the dairy took the initiative to implement a milk collection project, ensuring 100% local and organic production. Presently, Soummam has the capacity to receive and process 1,450,000 liters of raw milk per day. This strategic move further reinforces its commitment to providing high-quality dairy products to meet the diverse preferences of Algerian consumers.

Specializing in yogurt, desserts, dairy beverages, UHT milk, and cheeses, the Soummam Dairy caters to the diverse preferences of consumers. With 51 production lines and an annual capacity of 1.8 million tons, it offers over 183 fresh product varieties, adapted to various consumption patterns. The company ensures strict compliance with the cold chain through efficient logistics and a fleet of refrigerated trucks that service 58 wilayas across the country.

3. Manufacturing process:

a. AQS:

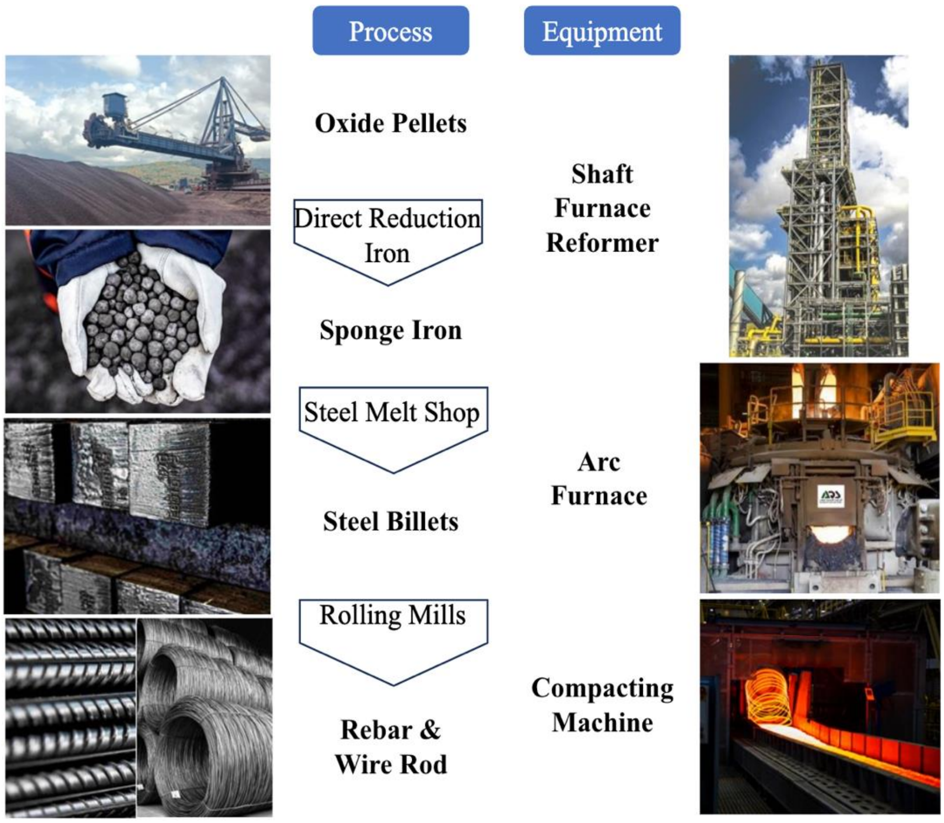

Figure 2.1: AQS Manufacturing process

b. Soummam:

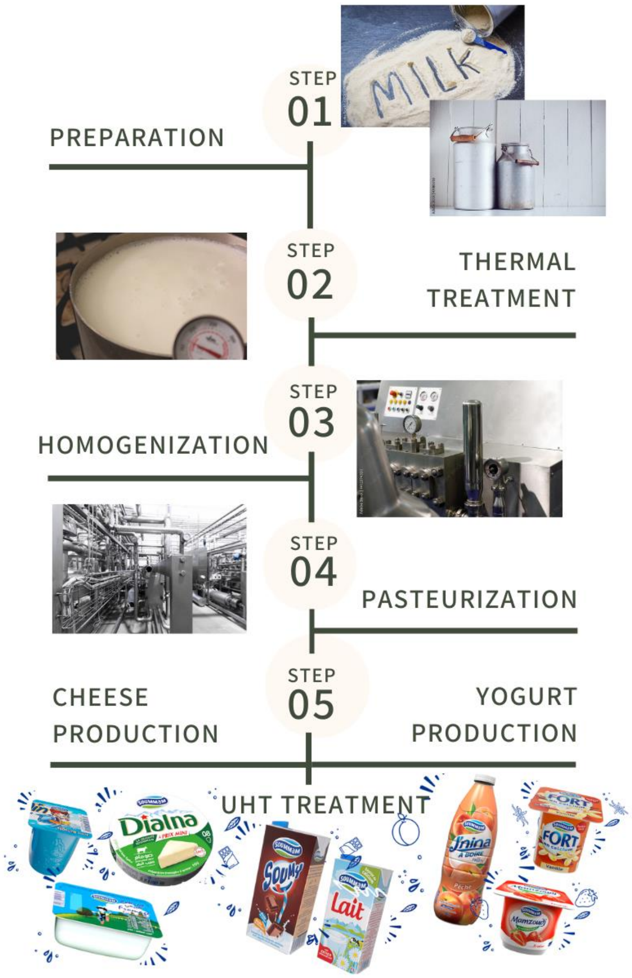

Figure 2.2: Soummam Manufacturing process

4. AQS and Soummam positioning in the supply chain:

4.1. AQS's position in the supply chain:

The placement of the Algerian Qatari Steel industry within the secondary sector, serving as a crucial link between the exploration sector and the service sector. The secondary sector encompasses industries involved in the manufacturing and processing of raw materials, transforming them into finished products.

Figure 2.3: AQS Positioning in the supply chain

4.2.Soummam's position in the supply chain:

The Soummam industry plays a pivotal role as a bridge between the exploration sector and the service sector within the secondary sector. The secondary sector encompasses industries engaged in the conversion of raw materials into finished products through manufacturing and processing.

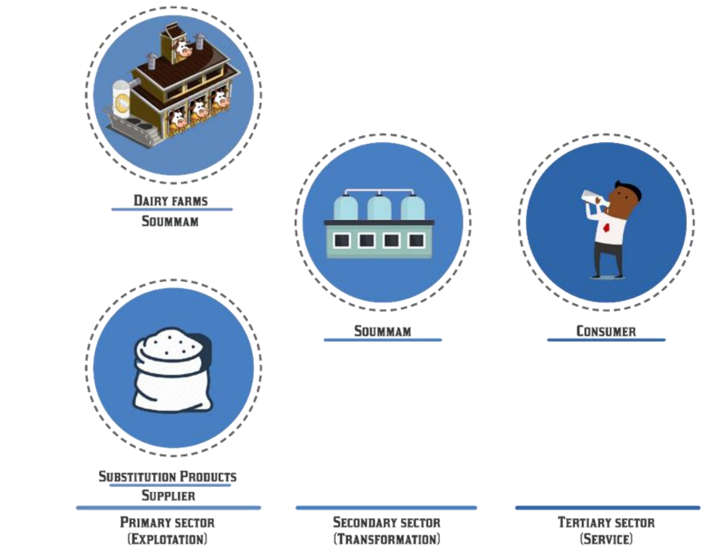

Figure 2.4: Soummam positioning in the supply chain

Conclusion:

The position of both AQS and Soummam within the supply chain contribute to their selection as case studies. Both the Algerian Qatari Steel industry and the Soummam industry play critical roles in their respective supply chains, supplying essential materials and products to downstream industries. Reliability issues in these industries can have far-reaching consequences, causing disruptions throughout the supply chain and negatively impacting the overall operational performance of various sectors. By studying RCM implementation in these industries, the aim is to develop effective maintenance strategies that not only enhance the performance and reliability of individual companies but also contribute to the overall efficiency and resilience of the entire supply chain

Chapter 3:
Unveiling System Boundaries and Conducting Functional Analysis

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Introduction:

This chapter focuses on the initial steps of our proposed framework for a Smart RCM implementation. The two crucial steps discussed herein involve unveiling system boundaries and conducting functional analysis. By clearly defining the boundaries of the system under consideration, we establish a comprehensive understanding of its scope and interconnected components. Additionally, conducting a thorough functional analysis enables us to identify key functions and their dependencies within the system.

1. Select & Define System Boundaries & functions:

1.1. Selection and System Boundaries Defining of the AQS Industry:

1.1.1. System selection:

- **Why Rolling Mill?**

The rolling mill (RM) unit plays a significant role in achieving the following targets, which are essential for building a reputable brand and enhancing the competitiveness and market position of the steel manufacturer.

Customization and Flexibility	Product Excllence	Enhancing Customer Satisfaction
Enables the customization of steel products to meet diverse customer requirements. By offering a wide range of shapes, sizes, and finishes, the unit caters to specific market demands. This flexibility positions the steel manufacturer as a reliable and adaptable partner in meeting customer needs.	The RM unit plays a crucial role in producing high-quality steel products by implementing precise control over the rolling process. This dedication to product excellence not only builds a strong brand reputation but also increases customer satisfaction.	Crucial for meeting customer deadlines and ensuring timely product delivery. By minimizing production interruptions and maintenance related delays, the unit guarantees a consistent supply of steel products. This reliability enhances the brand's reputation and builds trust with customers.
Efficient Production	**Compliance & Quality Assurance**	**Adaptability to Market Trends**
Optimizes the production process by reducing material waste. Through efficient resource utilization and minimized downtime, the unit enhances operational efficiency and cost-effectiveness. This translates into competitive pricing, a crucial factor in attracting customers and expanding market share.	Enables the steel manufacturer to adapt to evolving market trends and demands. By staying abreast of customer preferences and industry developments, the unit can adjust production accordingly. This adaptability positions the brand as forward-thinking and responsive to market needs, gaining a competitive advantage.	Compliance with safety, environmental, and quality regulations demonstrates the brand's commitment to responsible manufacturing practices. Consistent adherence to these standards ensures that the steel manufacturer delivers reliable, safe, and high-quality products to the market.

Table 3.1: AQS Targets

- **Why Rolling Mill 3:**
- RM3 started production in 2019.
- Most customer demands are to produce [8-14]mm Rebars, which are categorized as products of the RM3 unit.
- Consists of 58 of equipment forming a linear production line.
- Based on the history of injuries, most work accidents originate from the RM3 unit. [injuries incident history is confidential data, and can't be shared in this report].

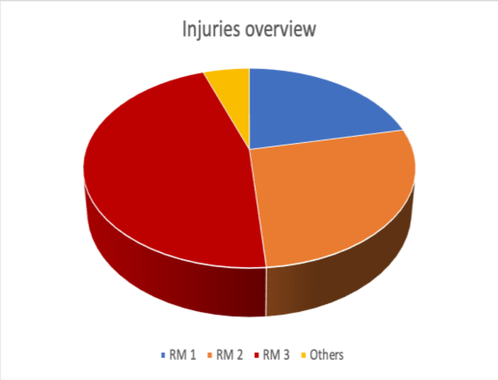

Figure 3.1: RM3 injuries overview

1.1.2. Define System Boundaries and Functions:

1.1.2.1. Rolling Mill Equipment:

The rolling mill unit of the steel-making industry adheres to several regulatory standards to ensure the reliability, efficiency, and safety of its operations. These standards include:

- **ISO 6336-2019:** specifies calculation methods for designing and rating gears used in rolling mill. It ensures that gear transmissions can withstand the operational loads and forces encountered during the rolling process.
- **ISO 10209:** provides guidelines for measuring mechanical vibrations in. By assessing the dynamic behaviour and condition of the equipment, it helps in identifying potential issues and enables timely maintenance to prevent failures.
- **ISO 12953:** outlining requirements for the design and operation of water-tube boilers used in roll cooling systems, it ensures a safe and efficient provision of cooling water, it helps maintain optimal operating conditions and prevents equipment damage.
- **ISO 14743:** covers safety requirements for manually loaded and unloaded equipment. It focuses on operator safety during the setup and operation of rolling mill unit equipment.

The rolling mill unit consists of various equipment and areas, each serving specific functions in the production process. Here is a breakdown of the equipment and their functions:

A. Reheating area:

a. Hot Charging Area:

- **Caster exit roller table:** receives the freshly casted billet from the continuous casting machine and transports them towards the billet elevator.
- **Billet elevator:** lifts the billet from level 0 to the pawl transfer in level 1.

b. Cold Charging Area:

- **Pawl transfer:** Collecting and forwarding the incoming billets to the roller table.
- **Roller table with weighing system:** incoming billet forwarding to the furnace inlet roller table.
- **Furnace inlet roller table:** incoming material forwarding to the re-heating furnace.
- **Reheating furnace:** heat the billets to the rolling temperature before being rolled in the rolling mill.

B. ROLLING MILL AREA:

a. **Rolling Mill Entry Area:**
- **Water statistic descaler:** Billet descaling.
- **Furnace outlet roller table:** incoming material forwarding to the pinch roll.
- **Pinch roll:** withdraw the rolled stock.
- **Snap Shear:** Emergency cutting of incoming material.

a. **Roughing Mill Area:**
- **Stands (8):** rolling in different positions (horizontal, vertical).
- **Crank Shear:** Head and tail cropping. Emergency chopping. Cutting to multiple lengths.

b. **Intermediate Rolling Mill Area:**
- **Stands (8):** rolling in different positions (horizontal, vertical).
- **Stand charging table:** automatic change of cartridge stand.
- **By-pass roller table:** conveying of the rolled stock.
- **Vertical looper:** Loop formation and control.
- **Looper for multi-strand slitting:** Loop formation and control.
- **Conveyors**: Rolled stock conveying.

c. **Rolling Mill Exit Area:**
- **Finishing block entry conveying troughs:** convey in the rolled stock to the finishing block.
- **Pinch roll:** to withdraw the rolled stock.
- **Crop shear:** head and tail cropping and emergency chopping.
- **Vertical looper:** loop formation and control.
- **Six stands finishing block:** rolling operation.
- **Buster pumps for FFB:** water pressure increasing from T.O.P. to the user-defined value.
- **Water quenching line:** ln-line quenching and self-tempering of deformed bars.
- **Pinch roll:** To withdraw the rolled stock
- **Booster pumps unit:** water pressure increasing from T.O.P. to the user defined value.
- **Finishing block exit conveying troughs:** conveying the rolled stock to the dividing shear.

d. **Cooling Bed Entry Area:**
- **Pinch roll**: to withdraw the rolled stock**.**
- **Crop Shear:** tail cropping and emergency chopping.
- **Dividing shear:** cut to length.
- **Conveying troughs at cooling bed entry:** Convey in the rolled stock to the double twin channel.
- **Safety guard for shears and pinch rolls:** to guarantee safety for operators.
- **Double twin bar brake:** bar braking to the proper discharging speed.

C. FINISHING AREA:

a. Cooling Bed Area:

- **Twin channel:** conveyance, braking and unloading of bars on the cooling bed.
- **Cooling bed:** step-by-step bar forwarding and cooling.
- **Cooling bed run-out roller table:** bar layer forming, transferring from cooling bed and forwarding to the cut-to-length system.

b. Cutting To Length Area:

- **Cold shear:** cutting to the final length.

c. Finished product forming area:

- **Roller table:** layer conveying to bundling station.
- **Gauge beam:** layer positioning to the defined commercial length.
- **Stacker/Bundler run-in system:** layer forwarding to finishing area.
- **Bar counting and bundle forming area:** bar counting, bundle forming and forwarding to the tying area.
- **Roller table in the tying area:** incoming bars forwarding to wire binding machine.
- **Short bar recovery system:** temporary collecting of short bars.

d. Finished Product Collecting Area:

- **Wire binding machine:** Wire binding of bar bundles.
- **Intermediate roller table:** finished product transfer to the collecting area.
- **Collecting Area:** finished product transferring to the collecting area.

- **Reliability Block Diagram of RM3 unit:**
  The RM3 typically consists of various areas, subareas and components that contribute to the overall reliability of the system.

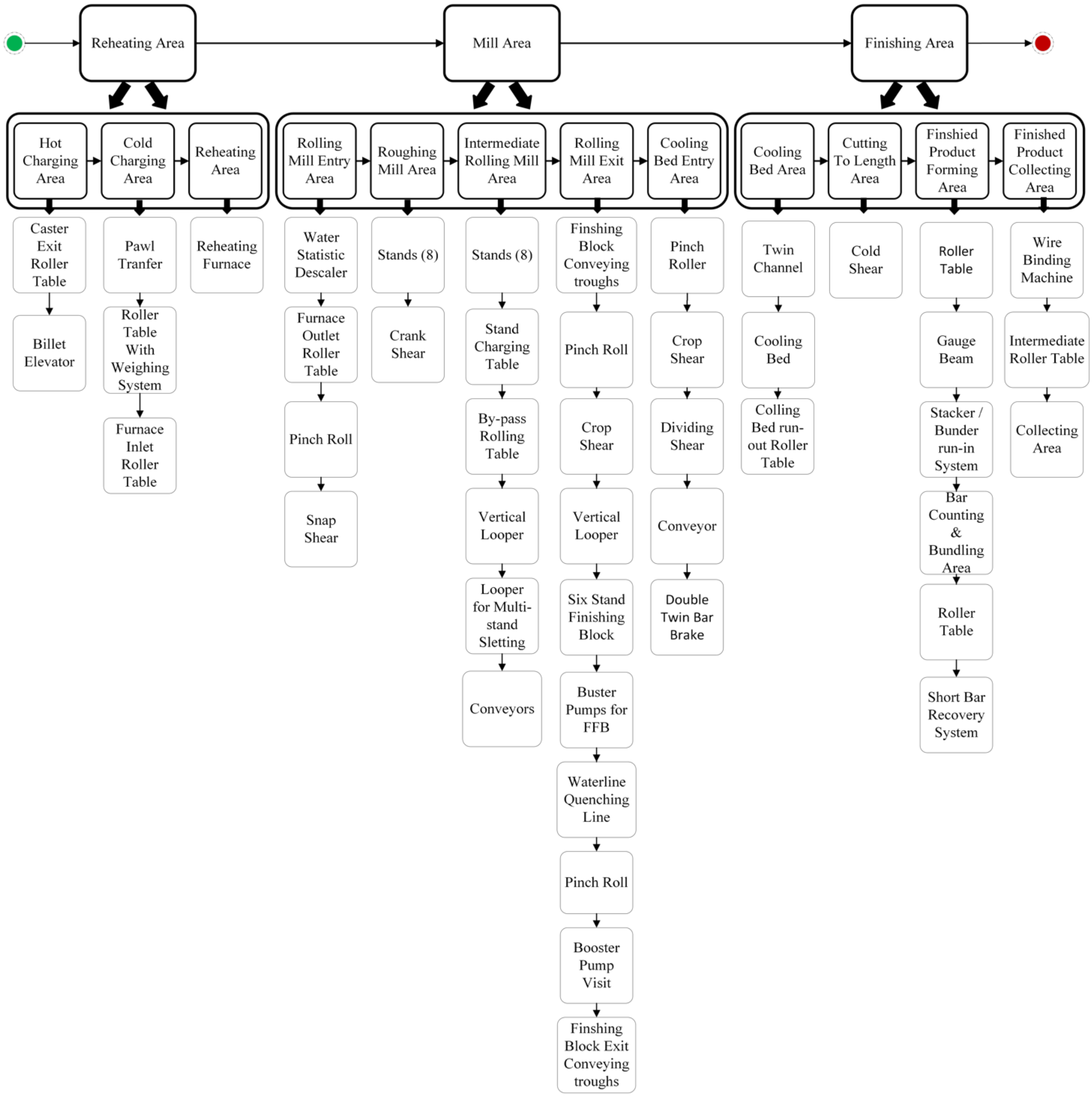

Figure 3.2: RM3 Reliability Block Diagram

1.1.3. Maintenance and Repair:

Planned maintenance activities, including routine inspections, lubrication, and adjustments of the rolling mill equipment. Unscheduled maintenance and repairs to address equipment breakdowns or malfunctions. Spare parts management and inventory control adhere to several regulatory standards to ensure the reliability, efficiency, and safety of its operations. These standards include:

- **ISO 14224:** defines a comprehensive set of failure data and coding systems for equipment maintenance and reliability analysis. It helps the RM unit plan and execute maintenance activities by providing valuable information on failure patterns, maintenance strategies, spare parts management, and reliability analysis techniques.

- **ISO 55000:** Establishes principles and requirements for asset management, including maintenance strategies and practices for rolling mill equipment. It emphasizes the
- importance of asset management planning, lifecycle management, risk assessment, and continuous improvement of maintenance processes to ensure the optimal performance and reliability of rolling mill equipment.
- **ISO 55000:** provides guidance on developing maintenance strategies that align with organizational objectives, taking into account factors such as equipment criticality, lifecycle costs, and risk management.

1.1.4. Safety Measures:

Safety protocols and equipment to ensure a safe working environment for employees, such as protective clothing, safety barriers, and emergency shutdown systems.

Regular safety inspections and risk assessments to identify and mitigate potential hazards associated with the rolling mill unit.

- **ISO 13849:** Specifies safety requirements and levels for the design and integration of safety-related control systems in machinery. It helps ensure the safe operation of automated equipment in the rolling mill unit.
- **ISO 45001:** Specifies requirements for occupational health and safety management systems. It ensures the implementation of safety measures and risk assessments to prevent work-related injuries and promote a safe working environment in the rolling mill unit.
- **ISO 12100:** Provides general principles for the design and integration of safety measures into machinery. It ensures the rolling mill unit's equipment and processes meet safety requirements to protect workers from potential hazards.

- **System Key Performance Indicators (KPIs):** provide a comprehensive view of the performance, efficiency, quality and safety of the rolling mill unit. They assist in identifying areas for improvement, optimizing maintenance strategies, and achieving operational excellence within the defined system boundaries.
  a. **Equipment Availability:** This KPI measures the percentage of time that the rolling mill equipment is available for production, indicating its reliability and the ability to meet production demands.
  b. **Overall Equipment Effectiveness (OEE):** OEE combines multiple factors, including equipment availability, performance efficiency, and product quality, to provide a holistic view of equipment performance and utilization.
  c. **Production Output:** quantifies the amount of rolled steel produced within a given timeframe, providing insight into the productivity and efficiency of the rolling mill unit.
  d. **Mean Time Between Failures (MTBF):** measures the average time between equipment failures, providing insights into equipment reliability and the effectiveness of maintenance practices.
  e. **Mean Time to Repair (MTTR):** measures the average time required to repair the rolling mill equipment after a failure, reflecting the efficiency of maintenance response and minimizing production disruptions.
  f. **Safety Incidents:** tracks the number and severity of safety incidents within the rolling mill unit, emphasizing the importance of maintaining a safe working environment.
  g. **Maintenance Cost:** Tracks the cost of maintenance activities, including preventive maintenance, repairs, and spare parts, as a percentage of the overall production cost.

Chapter 3: Unveiling System Boundaries and Conducting Functional Analysis

1.2.Selection and System Boundaries defining of the Soummam Industry:

The present study focuses on the equipment of the UHT unit, which refers to the production unit for UHT-treated products, primarily UHT milk.

1.2.1. System selection:

- **Why UHT unit:**

There are several factors that contributed to the decision to choose this unit, including:

- **Regulatory compliance:** UHT products are intended to have a long shelf life, which demands consistent monitoring and adherence to strict protocols to meet the quality requirements and food safety.
- **Product importance:** The need to adapt to a growing market demand and remain competitive is a driving force for maintaining consistent production.
- **Significant investment:** The production within this unit plays a critical role in achieving a strategic goal, which requires a consistent and reliable approach to ensure maximum return on investment and longevity.

- **Why COMBIBLOC 2:**

The decision to opt for the COMBIBLOC 2 line is associated with multiple factors:

- **Complexity:** This production line includes equipment of a new technology which means the incorporation of advanced features and functionalities, with many interdependent components.
- **Maintenance history:** The history of this production line is deemed to be more comprehensive and dependable.

1.2.2. Define System Boundaries and Functions:

A. COMBIBLOC 2 equipment:

- Combibloc Filler 312-2: **Product Filling**
- Accumulation Table CM/HSP 3: **Conveying/Accumulating**
- Combibloc ACB Applicator: **Spout Application**
- Tray packer CM/HTW: **Packing**
- Meurer Wrapper CM/HEM 60: **Wrapping**
- Handle applicator CM/HA 60 : **Handle Application**

B. Reliability Block Diagram:

The use of RBDs in RCM analysis enhances the understanding of system reliability by providing a visual representation of the system. It aids in the identification of critical equipment by highlighting their impact on overall system reliability and allowing for targeted maintenance efforts.

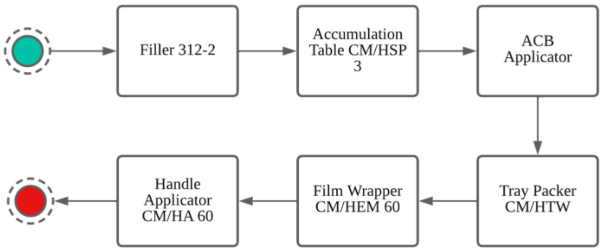

Figure 3.3: COMBIBLOC 2 Reliability Block Diagram

1.2.3. Maintenance and repair:

- **ANSI/HI 9.6.4**: It guides pump operation and maintenance, and covers various pump types such as pump in cooling unit, H2O2 system and lubrication unit.
- **NFPA 52:** It provides recommendations for the maintenance, repair, and troubleshooting of hydraulic components, including cylinders.
- **ISO 4378:** It provides guidelines for the selection, installation, and maintenance of sliding bearings and sliding bushings like in sealing, and pre-folding units.
- **ISO 15613:** It outlines the process parameters, equipment requirements, and quality control measures for achieving reliable and consistent ultrasonic welds, especially for top sealing stations.
- **ISO 5296:** This standard provides guidelines for the storage, handling, and installation of power transmission belts, including toothed belts.
- **ISO 3188:** offers recommendations for the periodic inspection and maintenance of springs, including tension springs, to ensure their reliable performance and longevity.
- **ISO 281:** It provides guidelines for the calculation of the dynamic load ratings and rating life of rolling bearings, including cam rollers.
- **API 598:** This standard specifies the inspection and testing requirements for various types of industrial valves, including gate, globe, check, and ball valves.
- **ANSI/SMRP-22:** t provides guidelines for best practices in maintenance and reliability management. It offers insights into overall maintenance strategies, including condition monitoring, inspection, and reliability-cantered maintenance.

1.2.4. Safety measures:

- **ISO 22000:** it is designed to establish the requirements for food safety management throughout the entire supply chain, encompassing procurement, production, maintenance, and distribution of the final product.
- **ISO 9001:** a standard for quality management systems, it emphasizes quality principles, such as customer focus and continuous improvement. Compliance with ISO 9001 enables to streamline operations, minimize risks, and improve efficiency.
- **EHEDG Guidelines:** It provides guidelines for hygienic design and engineering in the food industry, including aseptic processing (like in aseptic zone).

2. Functional Analysis:

In this step, FAST diagram is utilized to conduct a preliminary assessment of the systems functionalities, allowing for a clearer understanding both systems equipment interdependence.

A. RM3 functional analysis:

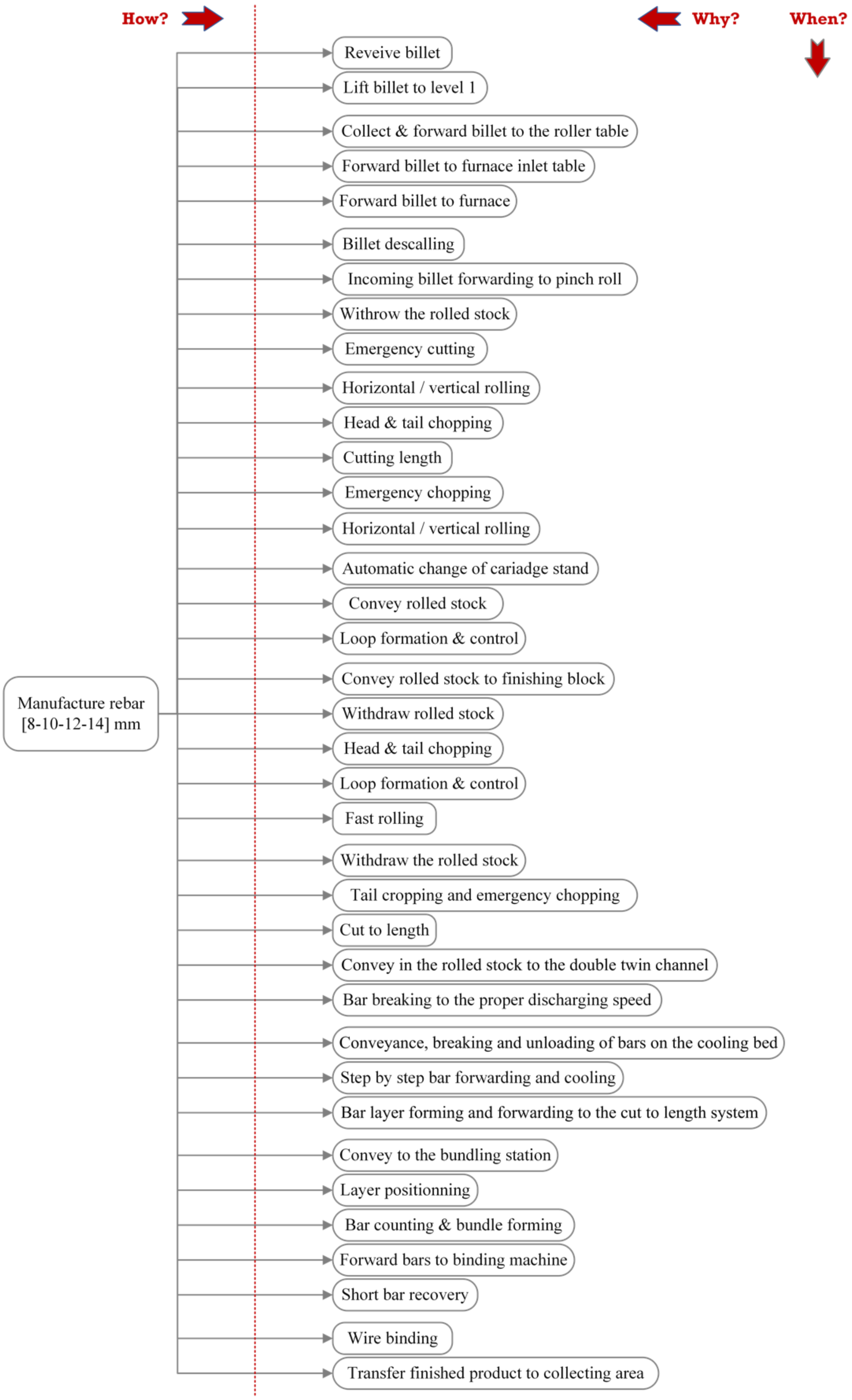

Figure 3.4: RM3 FAST Diagram

B. COMBIBLOC 2 Functional analysis:

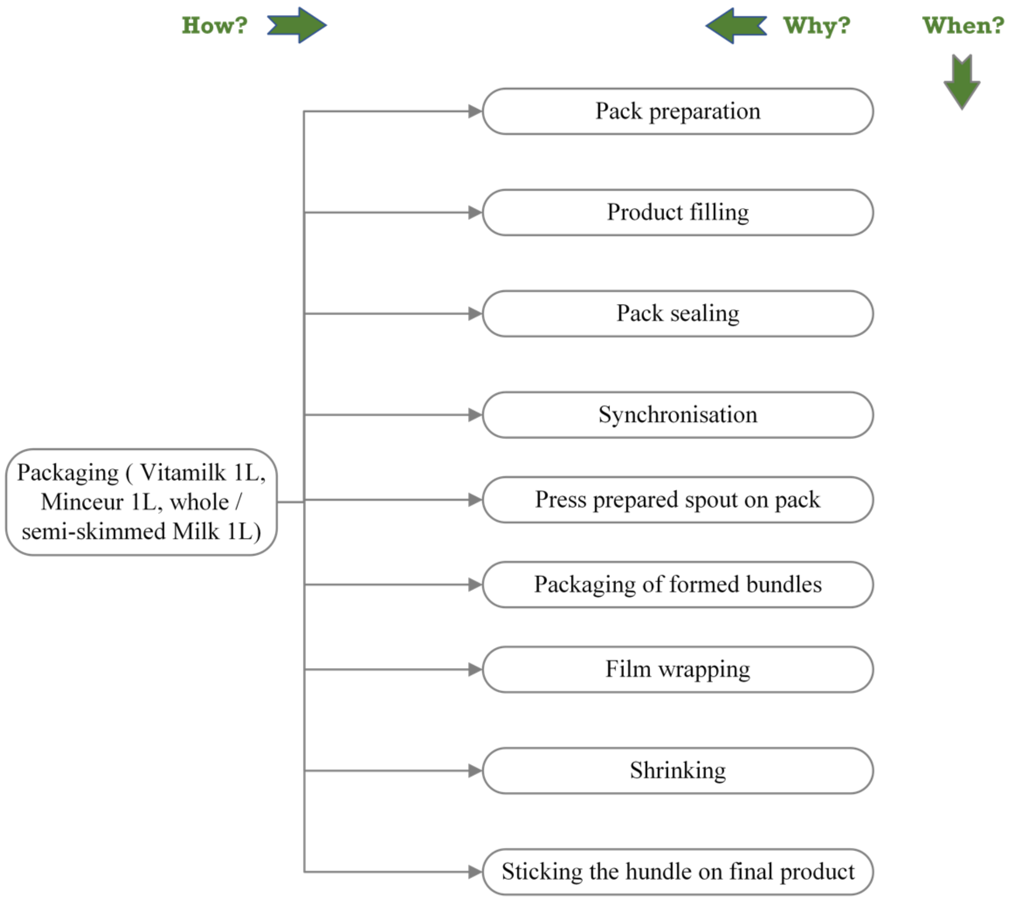

Figure 3.5: COMBIBLOC FAST diagram

Conclusion:

This chapter has successfully defined the boundaries of the system, resulting in a comprehensive understanding of its scope and the interconnectedness of its components. Additionally, a meticulous functional analysis has identified the critical functions and their dependencies within the system.
This crucial procedure lay the foundation for a robust Smart RCM implementation, providing solid information to initiate the next steps

Chapter 4:
Data Mining and Identification of Critical Equipment

Chapter 4: Data Mining and Identification of Critical Equipment

Introduction:

This chapter comprises the data mining and critical equipment identification procedures. By leveraging historical data analysis and advanced data mining techniques employing Pareto analysis, downtime vs frequency butterfly chart, impact frequency matrix and criticality criteria determined by each of AQs and Soumam, it will allow us to gain the ability to identify critical equipment, detect failure patterns, and make well-informed decisions under solid criticality assessment.

1. Data Mining:

Here are some steps and considerations we took for data mining in this context:

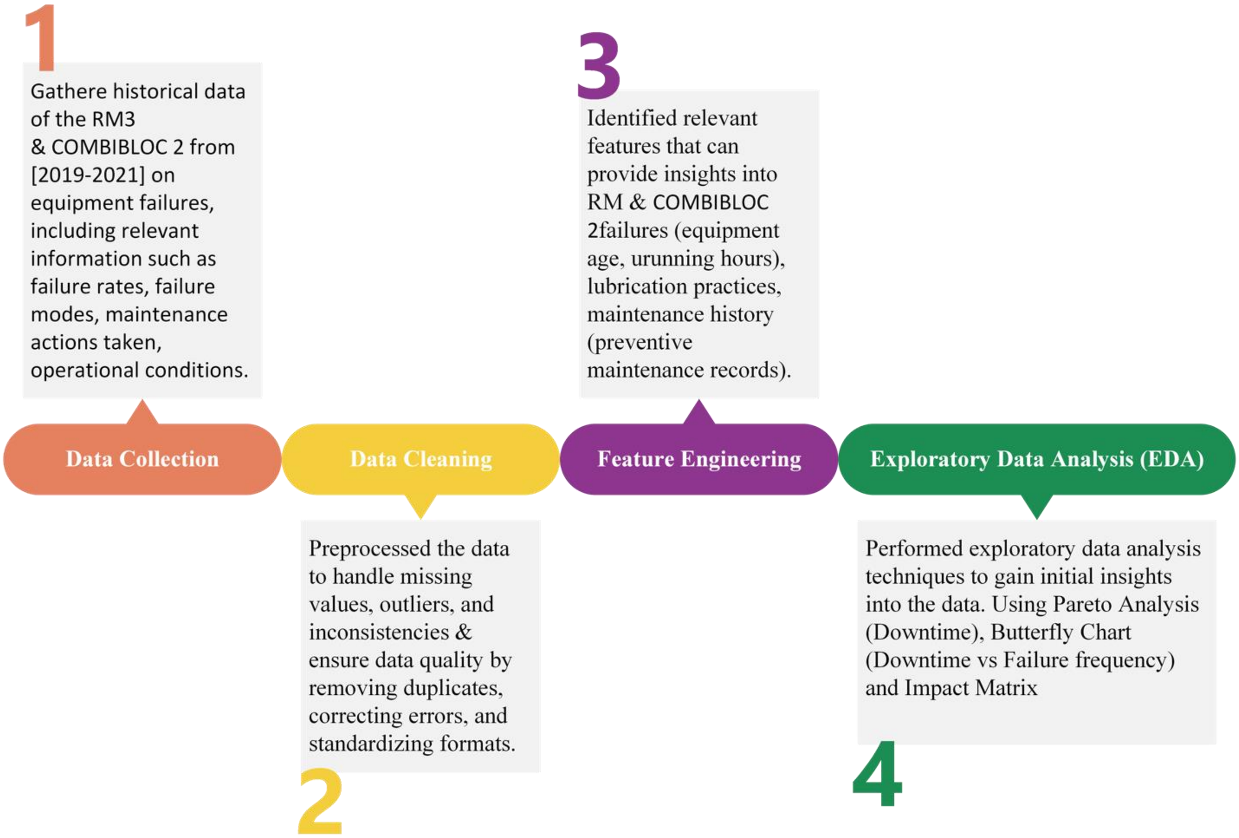

Figure 4.1: Data Mining Process

☞ **Data characteristics:**

1. **Data structure:** Since AQS didn't start using SAP and doesn't have a CMMS, failure history data were stored as XML data (database) that contains all of the RM production lines failures, structured as follows:
   - Timing of failure [From-To].
   - Discipline [Electrical, Mechanical...].
   - Operation\ Maintenance.
   - Location [Reheating area, Mill area, Finishing Area].
   - Equipment [fast finishing block, cold shear, tying machine…]
   - Delays description.

- Duration in hours.
- Date.

2. **Data history:** RM3 started functioning at the end of the year 2019, so selected data are data from 2020 to 2022.
3. **Data size:**
   - **RM3-Delays-2020:** 1335 failures.
   - **RM3-Delays-2021:** 3042 failures.
   - **RM3-Delays-2022:** 3840 failures.
4. **Data Bias:**
   - The failure description provided was insufficient to accurately diagnose the failure modes and underlying causes of the failure.
   - In certain cases, the maintenance failure history may refer to the area's name instead of explicitly stating the name of the equipment, which can create difficulties in identifying the specific equipment that experienced the failure.
   - Due to the previous bias in the data, the process of data cleansing became highly time-consuming, requiring assistance from engineers specialized in mechanical and electrical disciplines.

1.1.Data mining tools:

- **Pareto Chart:** The Pareto chart helps identify which equipment has the most significant impact on overall production.
- **Butterfly Chart: for** Impact-Frequency analysis, to see the combined effect of both impact (delay) and frequency and study the nature of the problem.
- **Impact-Frequency Matrix:** to position equipment and establish criticality by dividing downtime but its frequency of occurrence.

A. AQS study case:

1. Pareto Analysis:

→ The insight of this graph reveals that the tying machine, fast finishing block and tail brake are the equipment with the most significant impact on production.

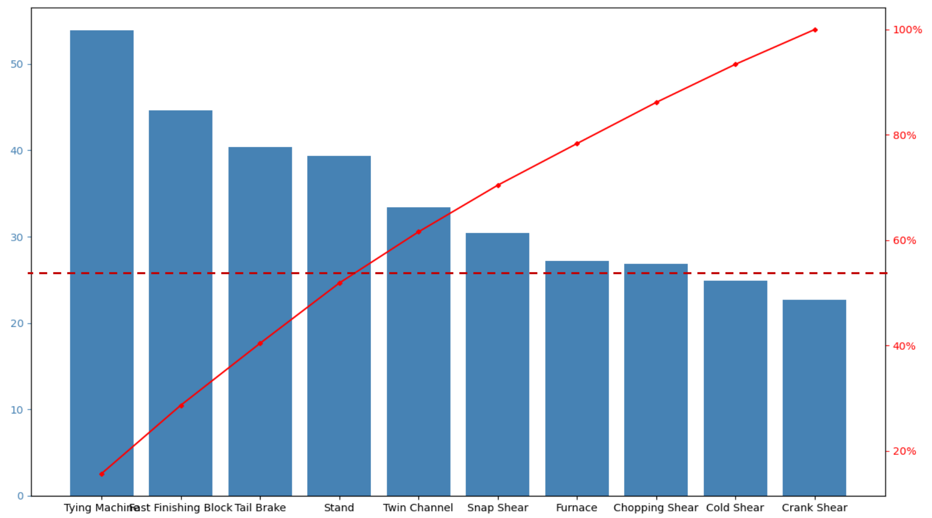

Figure 4.2: RM3 downtime pareto analysis

2. Butterfly Chart (Downtime vs Frequency):

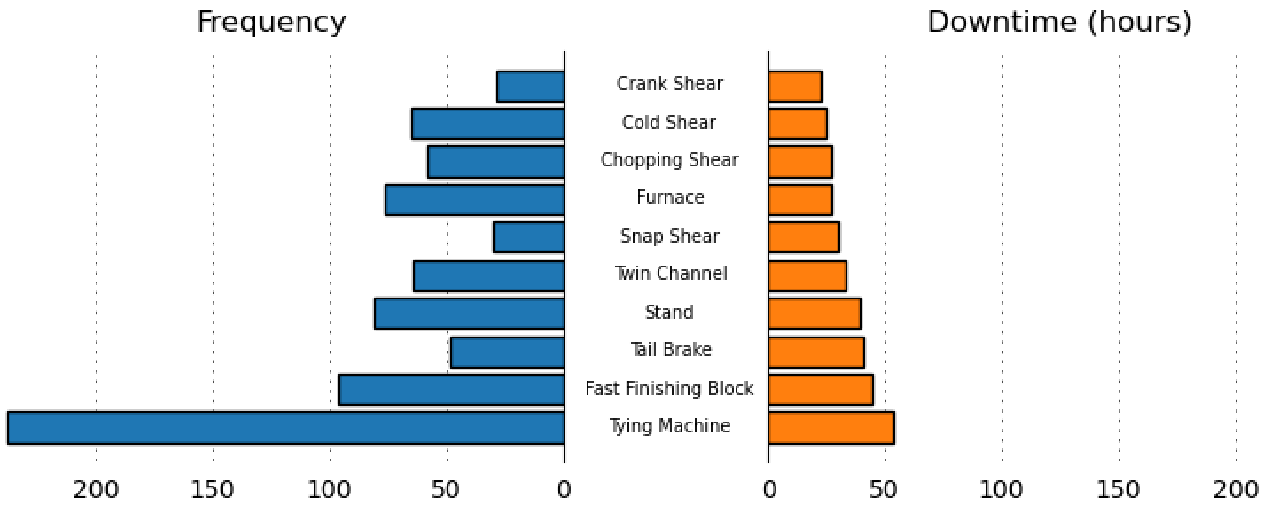

Figure 4.3: RM3 Downtime vs Failure Frequency Butterfly Chart

→ The comparative analysis between failure downtime and frequency reveals that both the tying machine and the fast finishing block machine continue to rank high in terms of their downtime and frequency.

3. Impact-Frequency Matrix:

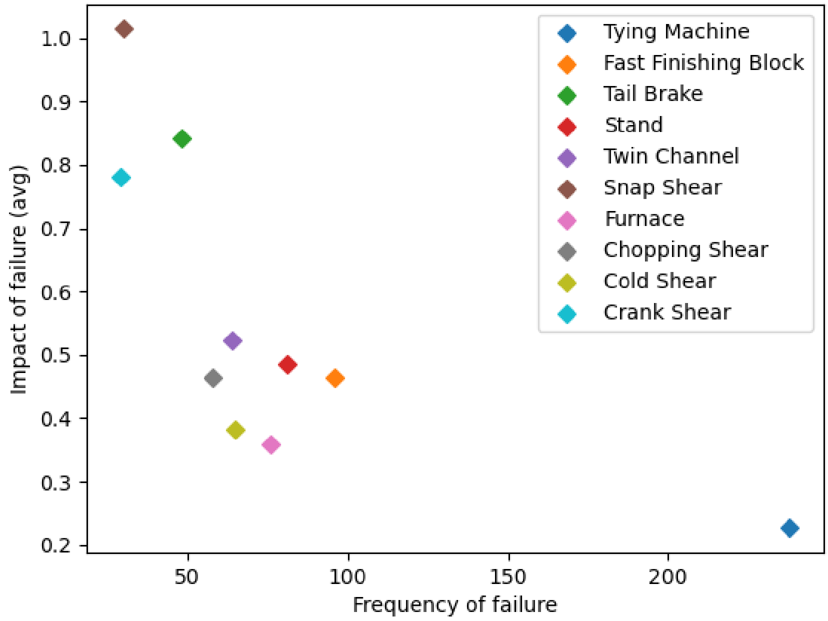

Figure 4.4: RM 3 Impact – Frequency Matrix

→ The tying Machine is the equipment with the highest Downtime as well as failure frequency.
→ For the Tying Machine, machine life-enhancing projects (MTBF projects) must be taken.
→ For the Snap Shear, Infrastructure projects (MTTR) projects must be taken.

B. Soummam study case:

→ According to the Pareto chart above, it appears that Combibloc Filler 312-2 , Tray packer CM/HTW and Meurer Wrapper are the most critical.

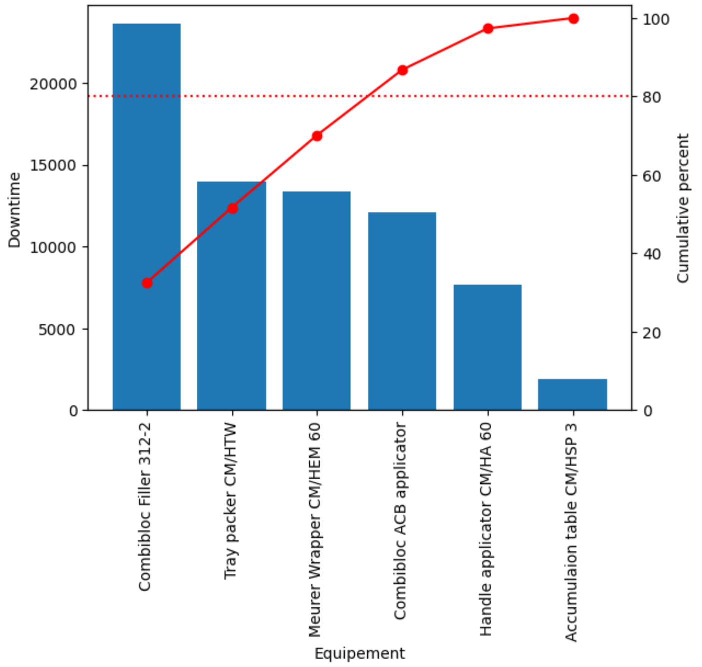

Figure 4.5: COMBIBLOC 2 pareto analysis

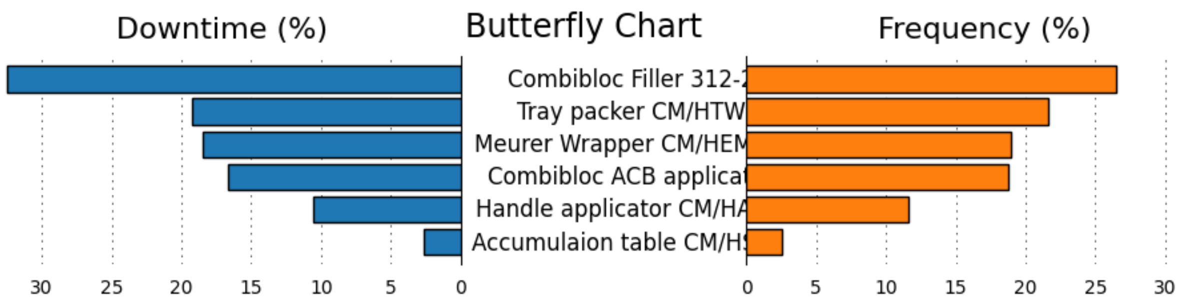

Figure 4.6: COMBIBLOC 2Downtime vs Failure Frequency Butterfly Chart

→ The Combibloc Filler 312-2 is the equipment with the highest percentage of frequency and downtime.

→ The machine Combibloc Filler 312-2 is positioned in the upper quadrant of the impact-frequency matrix, it implies that life-enhancing projects (MTBF projects). While the Tray packer CM/HTW, Handle applicator are in lower quadrant of the matrix which necessitates infrastructure projects (MTTR projects).

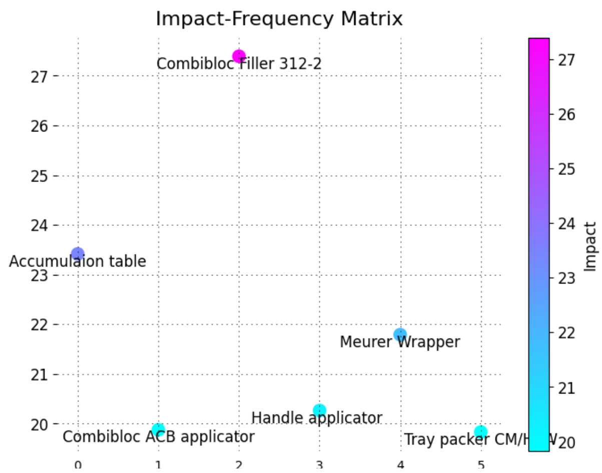

Figure 4.7 COMBIBLOC 2 Impact - Frequency Matrix

4. Identification of Critical Equipment:

During the implementation process RCM, the identification of critical equipment is a crucial step[10], [25].

A. AQS study case:

Here are the key considerations for identifying critical equipment in the RM3.

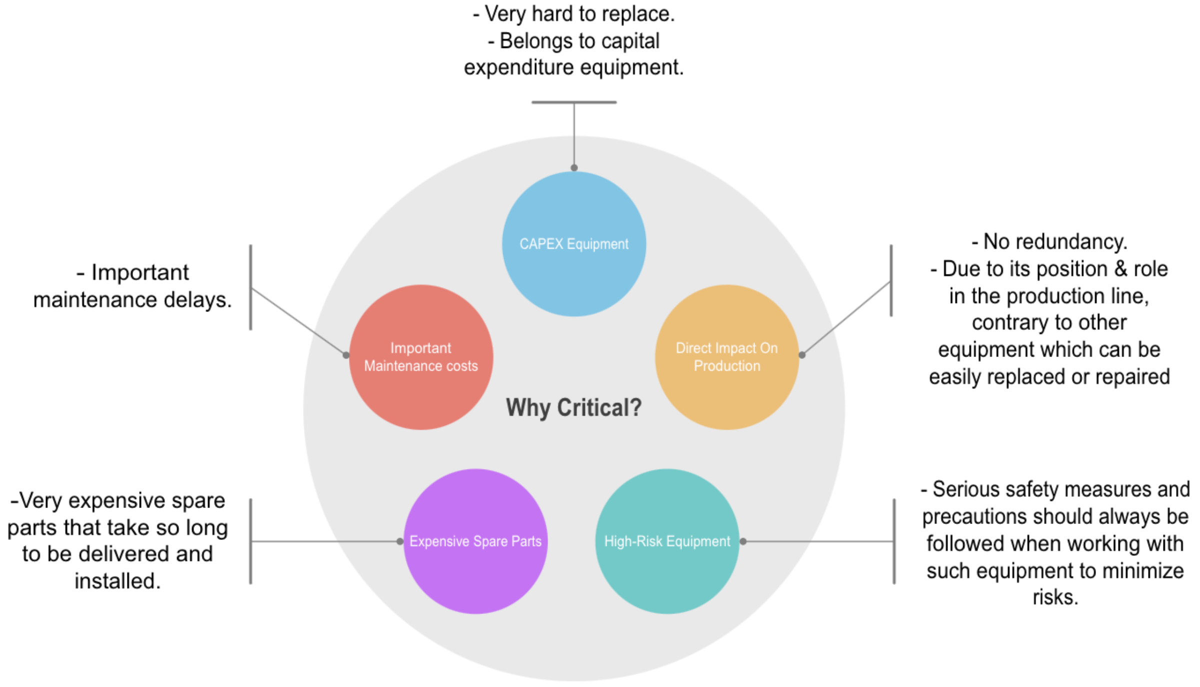

Figure 4.8: Critical equipment criteria for RM3

✓ After conducting a data mining analysis of failure history and injury records, seeking expert opinions can provide valuable insights for identifying critical equipment. Maintenance personnel, engineers, and other domain experts can provide valuable insights based on their understanding of the equipment, historical data, and industry best practices. We have come with the conclusion that the tying machine is the most critical equipment.

➢ **Tying Machine / Binding Machine:**

The binding machine is a crucial and widely recognized equipment in rolling mill units worldwide. Its primary purpose is to securely bind and bundle materials, promoting safe handling, efficient storage, and smooth operations within the rolling mill environment. It consists of the main following parts:

A. Carriage.
B. Binding Unit.
C. Vertical Carriage.
D. Wire Guide.
E. Hydraulic Unit.
F. Foundation frame with rails.

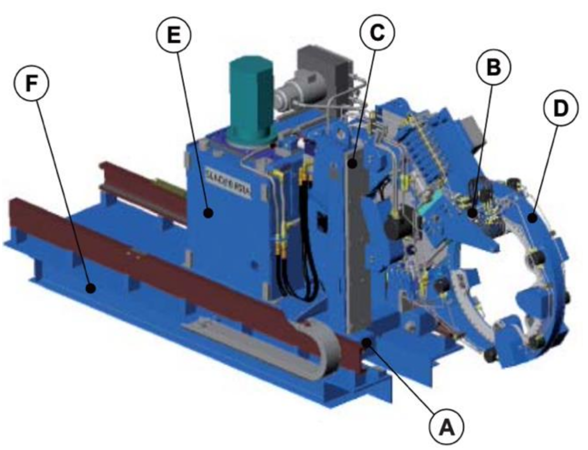

Figure 4.9: Tying Machine main component

B. Soummam study case:

- **The Analytic Hierarchy Process (AHP)** based on Saaty's scale is a methodology for multi-criteria decision-making that enables the systematic assessment and prioritization of variables and factors. Saaty's scale, developed by Thomas L. Saaty, provides a numerical framework for making pairwise comparisons between different criteria. The scale ranges from 1 to 9 and represents the relative importance or preference of one criterion over another.

→ The outcome of the classification of equipment in this line, based on three factors: repair and failure duration, quality, and maintenance costs, led to this following weighted classification:

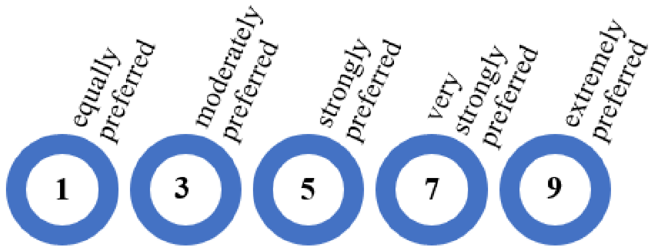

Figure 4.10: AHP prioritization criteria

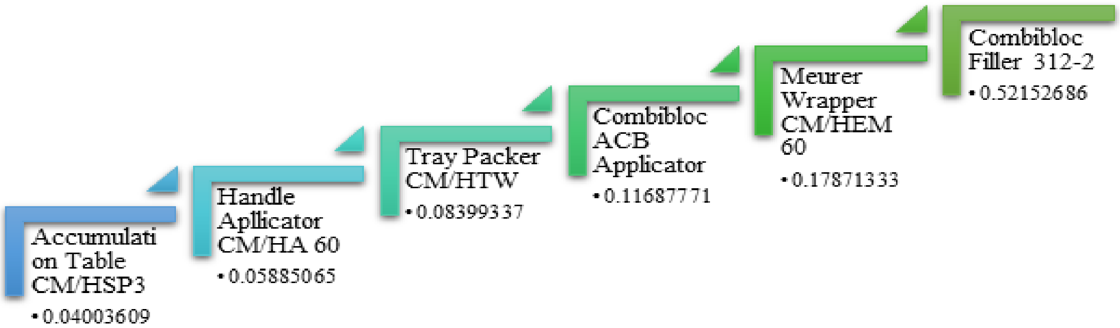

Figure 4.11: Classification of equipment

According to the results of data mining, the AHP model, and the brainstorming session, the Combibloc Filler 312-2 is considered the most critical equipment

- **Filler CFA 312-2:**
  The Combibloc Filler 312-2 is designed for the filling of liquid food- stuffs (e. g. milk and fruit juice) within these three processes which are carried out in the combibloc filling machine:
  - Forming the carton sleeves into cartons
  - Aseptic filling of products into the cartons
  - Sealing the filled cartons

  The components of a machine are categorized into three main groups, each serving a distinct function within the overall system:
  - Mandrel wheel section
  - Chain section
  - Valve knot

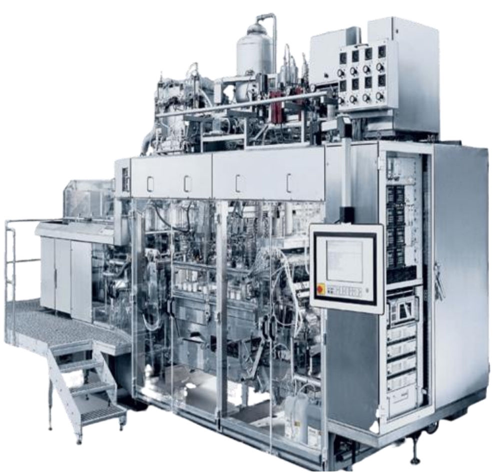

Figure 4.12 Filler CFA 312-2

Conclusion:

In this chapter, through compressive analysis using data mining tools such as Pareto analysis, downtime vs frequency butterfly chart, impact-frequency matrix, and AHP strategy has identified the tying machine/binding machine as the critical equipment in the RM3 unit of AQS industry and the Filler CFA 312-2 as the critical equipment in the COMBIBLOC 2 unit of Soummam industry. Addressing maintenance and optimization of these machines will significantly enhance operational efficiency, productivity, and overall success for both industries.

Chapter 5:

Failure Modes and Effect Analysis and Root Cause Effect Analysis

Chapter 5: Failure Modes and Effect Analysis and Root Cause Effect Analysis

Introduction:

In this chapter, we aim to further enhance the understanding and proactive management of critical equipment by utilizing Failure Modes and Effect Analysis (FMEA) and Root Cause Effect Analysis (RCEA) methodologies. Building upon the identification of tying machine/binding machine in the RM3 unit of AQS industry and Filler CFA 312-2 in the COMBIBLOC 2 unit of Soummam industry as critical equipment through data mining tools, we will employ FMEA and RCEA to analyze and address potential failure modes and root causes associated with this critical equipment. By implementing these methodologies, we seek to develop effective strategies for maintenance, risk mitigation, and continuous improvement, ultimately optimizing the performance and reliability of the identified critical equipment.

1. Failure Mode & Effects Analysis:

- **Types of FMEA:**

  There are 4 types of FMEA: System FMEA, Design FMEA, Process FMEA, and finally the one we'll be conducting on our critical equipment is the Equipment or Machinery FMEA [7].

Types of FMEA	Focus
System FMEA	Focuses on how interactions among systems might fail.
Design FMEA	Focuses on how product might fail.
Process FMEA	Focuses on how processes that make the product might fail.
Equipment / Machinery FMEA	Focuses on how machinery that perform processes might fail. (Done at level of maintainabke items)

Figure 5.1: Types of FMEA

- **What is Equipment FMEA?**

  Equipment FMEA involves the following Steps:

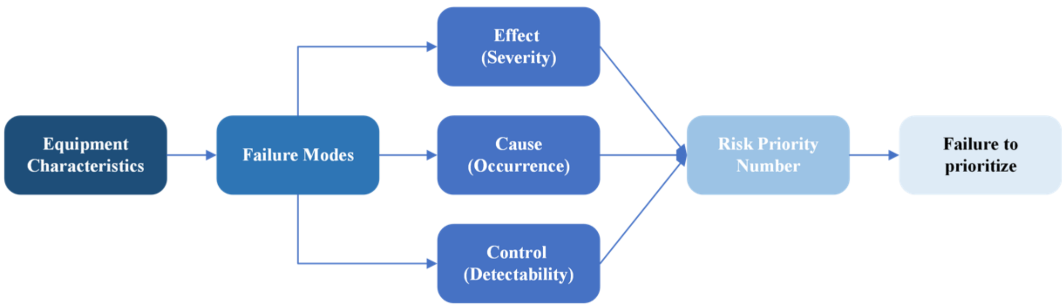

Figure 5.2: Equipment FMEA Structure

- **Equipment FMEA- Process Steps:**

To identify potential failure modes of equipment, assess their effects, and determine appropriate preventive measures. The process involves several steps:

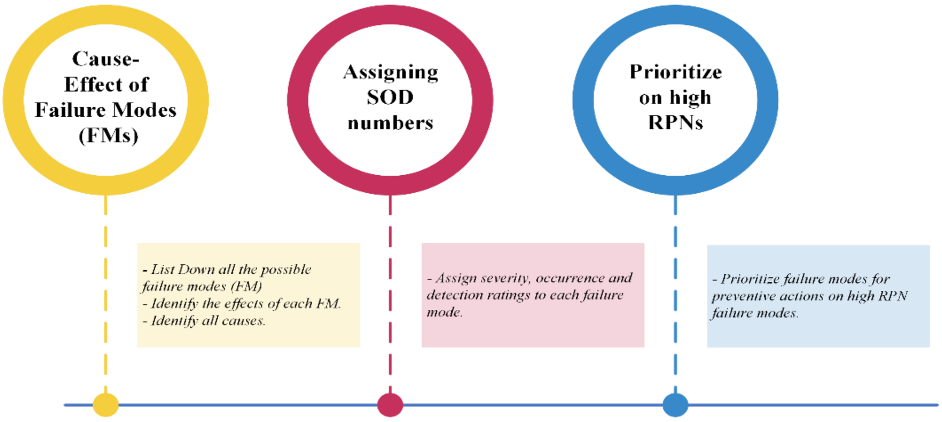

Figure 5.3: Equipment FMEA- Process steps

A. AQS case:

☞ Severity, occurrence and detectability are measured on a scale of 1-10. (See in appendix, figure 1, figure 2, and figure 3).

RPN value	Degree of criticality
<100	Acceptable
[100-200]	Tolerable
>200	Unacceptable

Table 5.1 Binding Unit criticality assessment

→ **FMEA result:**

The findings presented in Table 5.3 highlight the notable inability of the twisting head to effectively execute twisting, cutting, and clamping actions, signifying a prominent failure that carries a substantial impact.

B. Soummam case:

☞ Severity, occurrence and detectability are measured on a scale of 1-5. (See in appendix, figure4, figure5, and figure 6).

RPN value	Degree of criticality
[0-8]	Acceptable
[9-27]	Tolerable
[28-125]	Unacceptable

Table 5.2 Filler CFA 312-2 criticality assessment

→ **FMEA result:**

The findings presented in Table 5.2 highlight possible defects that have been identified in five subsystems. These include abnormal operations of the Top sealing station, Top pre-folding station, as well as issues with the Date printer, and potential incorrect outputs exhibiting dosing issues at the Filling station. These identified issues may indicate a significant failure leading to catastrophic impact.

Table 5.3: Binding Machine / Tying Machine E-FMEA

Equipment	Equipment Function	component	Component Function	Failure Modes	Causes	Effects	Detection	S	O	D	RPN
Binding Machine / Tying Machine	Bind with wire around large bundles of bars. It guides the wire, apply necessary pressure or tension, and secures it in place through twisting and knotting. It enables the wire to be properly bound, creating a finished product with reliable and secure wire binding.	**Feeding Wheel Disk**	Grips and pulls the wire during the feeding process.	Inability to rotate the feeding wheel.	Failure of the hydraulic motor due to electrical or wiring issues.	Inability to feed wire.	**Visible**	**6**	**5**	**5**	**150**
				Structural damage of the feeding wheel.	- Continuous friction and usage without regular cleaning or maintenance. - Presence of abrasive particles in the wire being fed.	Potential damage to the wire or knotting problems due to inadequate traction.	**Noise/ vibrations**	**5**	**4**	**8**	**160**
		Twisting Head	Rotates, twists, cuts and clamps the wire.	Inability to perform twisting, cutting, and clamping actions.	- Hydraulic pump failure. - Encoder malfunction.	Incorrect number of turns and types knot, leading to compromised binding quality.	**Visible**	**8**	**6**	**7**	**336**
		Pinch rollers	Press the binding wire against the feeding wheel disk.	Structural damage to the pinch roller.	- Continuous friction and pressure without regular cleaning or lubrication. - Presence of contaminants in the wire accelerate wear.	Reduced wire grip and traction, causing slipping and feeding issues.	**Noise, vibrations**	**6**	**5**	**6**	**180**
				Inability to press the wire against the feeding wheel.	- Hydraulic cylinder failure due to insufficient hydraulic fluid or pressure.	Potential damage to the wire due to inadequate pressure or uneven contact.	**Noise, visible**	**4**	**5**	**7**	**140**
		Pinch roller with pulse encoder	Provides feedback of the feeding speed, wire stretching, and detecting wire presence.	Loss of wire position and control during feeding and stretching.	- Wiring faults or short circuits. - Environmental factors like moisture or dust affect the sensor.	Loss of wire feeding control and accuracy.	**visible, excessive vibrations**	**7**	**4**	**7**	**196**
				Structural damage to the pinch roller.	Presence of abrasive particles in the wire being fed.	Inaccurate wire length measurement and stretching control.	**Noise, vibrations**	**5**	**4**	**8**	**160**
		Wire detecting wheel	Determines if the wire is correctly positioned and available within the feeding unit.	Inability to sense wire presence.	- Faulty wiring or connections between the sensor and control system. - Physical damage to the sensor or misalignment with the wire.	Disrupted feeding and stretching process.	**Vibrations**	**6**	**4**	**7**	**168**
		Wire detecting wheel shaft sensor	Detects the rotation or movement of the wire-detecting wheel.	Sensor malfunction	- Faulty wiring or connections between the sensor and control system. - Environmental factors like moisture or dust affecting the sensor's operation.	Inaccurate detection of the wire-detecting wheel position.	**Undetectable**	**7**	**4**	**7**	**196**
				Misalignment or damage to the wire detecting wheel shaft	- Excessive vibrations.	Unreliable sensor readings. leading to incorrect feedback to the control system, affecting wire feeding and stretching operations.	**Noise, vibrations**	**4**	**4**	**8**	**128**
		Hydraulic cylinder for open/close pinches rollers	Controls the opening and closing of the pinch rollers.	Hydraulic cylinder damaged or leakage.	- Insufficient hydraulic fluid or pressure. - Leakage or damage to the hydraulic cylinder seals. - Malfunctioning valves or control mechanisms.	- Inability to open or close pinch rollers, leading to wire feeding and gripping issues. - Inconsistent pinch roller operation.	**Vibrations**	**5**	**4**	**8**	**160**

		Hydraulic motor feeding wheel	Powers the feeding wheel disk, enabling its rotation.	Incorrect start-up of hydraulic pump motor	- Insufficient hydraulic fluid or pressure. - Overloading of the motor beyond its capacity. - Faulty wiring or inadequate power supply. - Misalignment or damage to motor components.	- Inability to drive the feeding wheel, resulting in halted wire feeding.	**Noise, Vibrations**	**5**	**5**	**7**	**175**
		Wire guide, single or double binding.	Guides the wire through the binding machine.	Misalignment or damage to the shuttle components	-Excessive vibration or impacts affecting the alignment. - Continuous friction and pressure without regular cleaning or lubrication. - Presence of abrasive particles in the wire being guided.	Potential wire tangling or entanglement issues.	**Visible**	**5**	**4**	**8**	**160**
		Valve blocks	Control the flow of hydraulic fluid to various hydraulic components in the binding unit.	Leakage or blockage within the valve block	- Blockage or contamination of the hydraulic fluid affecting valve operation. - Improper installation or connection of hydraulic lines. - Aging or degradation of valve block components.	- Pressure loss and ineffective component control. - Improper flow control and hydraulic system operation.	**Vibrations**	**7**	**4**	**7**	**196**
		Shuttle, at double binding.	Assists in positioning the wire properly for double binding.	Mechanical failure of the shuttle mechanism	Excessive wear or damage to shuttle components. Misalignment or lack of lubrication affecting smooth operation.	Inability to perform double binding operations.	**Visible**	**5**	**4**	**8**	**160**
				Misalignment or damage to the shuttle components	Excessive vibration or impacts affecting the alignment. Lack of proper maintenance or inspection of the shuttle mechanism.	- Improper wire positioning and binding defects. - Disrupted wire placement and knotting process.	**Visible**	**6**	**5**	**6**	**180**
		Vertical carriage	Allows the binding unit to move vertically.	Stuck or unable to move.	- Insufficient hydraulic fluid or pressure. - Leakage or damage to the hydraulic cylinder seals.	Inability to move the binding unit vertically, affecting wire positioning and knotting.	**Visible**	**5**	**4**	**8**	**160**
				Misalignment or damage to the carriage guides	- Lack of lubrication or contamination of the guide surfaces. - Excessive wear or physical damage to the guide components.		**Visible, Vibrations**	**6**	**5**	**4**	**120**

Table 5.4: Filler CFA 312-2 E-FMEA

Item/Name Requirements	Item/Function	Potential Failure Mode	Potential§ Effect(s) of Failure	End Effect(s) of Failure	Severity	Potential Cause(s) / Mechanism(s) of Failure	Occurrence	Detection	R. P. N.
Up Folding unit	•Remove sleeves from the magazine •Open up sleeves into a rectangular shape	Low suction power	Sleeve jamming	Material damage	4	Blocked suction units	2	1	8
						Vacuum pump failure	2	1	8
Pushing feeder	Push sleeves onto a mandrel on the mandrel wheel	Blocked operation	Suspend production	Machine interruption	2	Toothed belt wear	3	4	24
						Qualité sleeve	2	5	20
Mandrel wheel	Transporting the carton sleeve through the individual stations	Packs backflow on mandrel wheel	Sleeve jamming	Material damage	3	Transfer station failure	2	1	6
						Overactivation	1	4	12
Cooling unit	Cooling of mandrel wheel and bottom press	Blocked operation	Blocked mandrel wheel cooling operation	Machine interruption	2	Rate flow parameters	3	3	18
Bottom heater	Apply hot air to activate areas that need to be sealed on the bottom section of the carton	Overactivation	Blocked transfer	Packs backflow on mandrel wheel	2	Temperature parameters	1	3	6
		Underactivation / non activation		Poor bottom sealing	3	Temperature parameters	1	3	9
						Electrical resistance heaters failure	1	4	12
Bottom Lateral/Longitudinal forming unit	Pre-form the carton bottom in one work cycle.	Blocked operation		Poor bottom sealing	3	Tension springs failure	1	4	12
Bottom press	Fully press and seal the carton bottom.	Poor bottom sealing	Product leaks	Machine soiling	3	Pneumatique cylinder fault	2	4	24
Transfer station	•Remove carton from the mandrel wheel •Push carton into a pocket	Blocked operation	Packs backflow on mandrel wheel	Machine interruption	2	Three-phase brake motor failure	2	2	8
Pocket chain	•Transport carton through the downstream stations of the chain section •Separate and guide cartons	Blocked trasportation	Suspend production	Machine interruption	4	Servo drive failure	2	3	24
						Pocket wear	1	2	8
						désalignement ejecteur/déposeur	1	2	8
Bottom guide	•Support cartons •Adjust the heigh of carton according to the position of modules of the downstream stations	Poor heigh adjustment	Pack deformation	Program shutdown	3	Lever failure	1	4	12
Top pre-folding unit	Pre-fold the top section of the carton along the crease lines	Poor prefolding	Poor top sealing/forming	Pack deformation	5	Defective Sliding bush	2	4	40
		Blocked pre-folding operation	Suspend production	Machine interruption	3	Pneumatic cylinder failure	1	1	3
Pre-heater/dryer	Pre heat / dry pack with hot sterile air	Blocked sterile air injection	Suspend production	Machine interruption	1	Blocked Sterile air valaves	1	1	1
						filtre colmaté	2	1	2
H2O2 injection system	Fed cartons with H2O2		Suspend production	Machine interruption	2	Vaporization unit failure	1	1	2

		Blocked H2O2 injection				Circulating pump failure	1	2	4
Filling station	Fill the product into the carton over two stages	Dosing issues	Machine soiling	Poor top sealing	5	Uncleaned filling nozzles	2	5	50
						Bad programming	1	5	25
						PLC meter failure	1	4	20
		Perte étencheité		Product contamination	5	Bellows wear	1	5	25
		Blocked product injection	Suspend production	Machine interruption	3	Bad Counters recognition	1	1	3
						Drive cylinders failure	1	4	12
Swivel coupling	•Swivel into the production position •Swivel into the cleaning position	Bad position	Suspend production	Machine interruption	3	Pneumatic drive failure	3	3	27
Steam injection system	Inject steam before sealing the top section	Low pressure steam		Product contamination	5	Blocked steam nozzles	1	5	25
		Blocked steam injection	Suspend production	Machine interruption	2	Cycle valves failure	1	1	2
Top sealing station	Sealing of the top section of the carton with ultrasonic sealing tools	Poor sealing	Product leaks / contamination	Product leaks/contamination	5	Bad sleeve quality	2	5	50
						Soiled anvils	5	5	125
						Anvils fine adjustment	3	4	60
		Blocked sealing operation	Suspend production	Machine interruption	3	Defective Sliding bearing	2	5	30
						Servo drive failure	1	2	6
						US generator failure	3	2	18
Top forming station	•Heat the polyethylene at the top triangles and the narrow side of the carton using hot air •Fold down the top triangles	Poor forming	Pack deformation	Product jamming on discharge station	2	Hold-down devices failure	3	4	12
						Folders system failure	2	4	16
Ejector	Push out the carton from a pocket into the discharge station	Blocked ejection	Suspend production	Machine interruption	2	Synchronisation issue	1	1	2
						Servo drive failure	1	1	2
Discharge station	•Pick up cartons by toothed belts in an interlace pattern •Set cartons in guiding rails to place them on the off-conveyor	Synchronisation failure	Suspend production	Machine interruption	2	Drive toothed belt failure/ wear	1	1	2
Off-conveyor	•Turn cartons 180° during off-convoying •Transport the product at 90° angle to the working direction of the machine	Blocked trasportation	Product jamming/crush/falling	Material damage	3	Multiflex chain wear	2	1	6
Date printer	Print the expiration date on sealed and filled product	Bad date printing	Bad brand reputation due to costumer insatisfaction	Misinterpretation and confusion about product expiration date / Non-compliance with regulatory requirements / Production waste	4	Sensor failure	4	4	64
		No date on product		Bad brand reputation due to costumer insatisfaction		Bad wiring/ programming issues	2	3	24

2. Root Cause Failure Analysis:

4.1. Understanding RCFA through impact-occurrence matrix:

The Impact-Occurrence Matrix provides a visual representation of the relative risk associated with different failure modes. It helps prioritize efforts by focusing on the failure modes that have the highest potential impact and occurrence. By systematically addressing the root causes of these high-priority failure modes, organizations can improve their processes and systems, leading to increased efficiency, reliability, and overall performance [14].

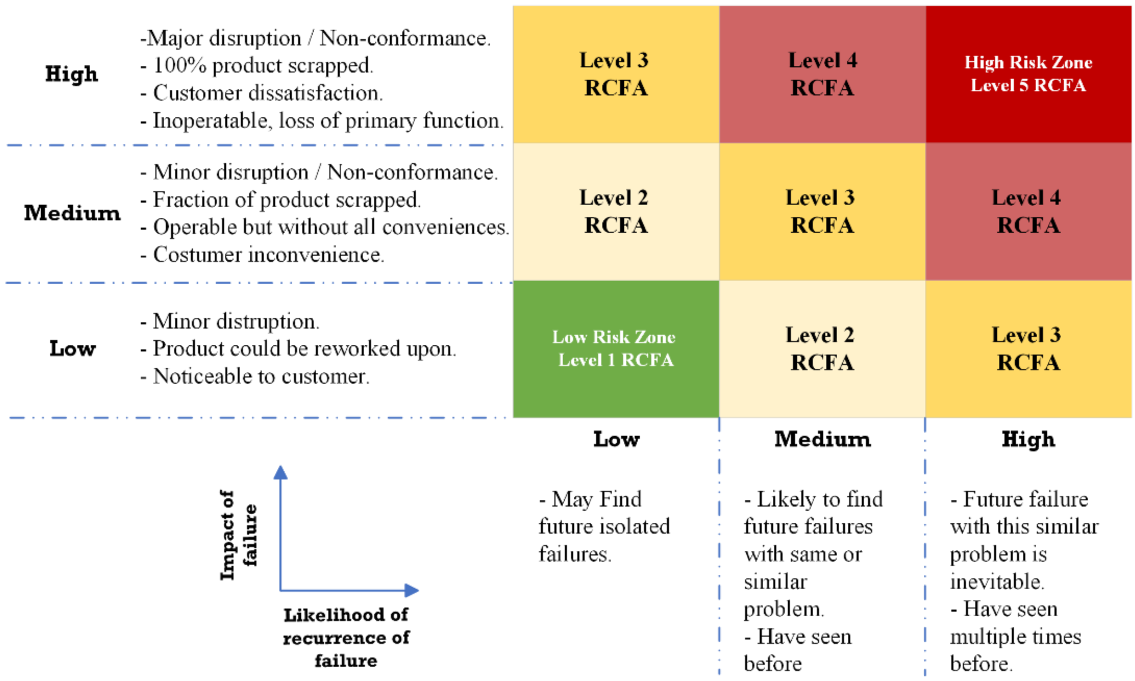

Figure 5.4: Impact-occurrence matrix

A. AQS Case:

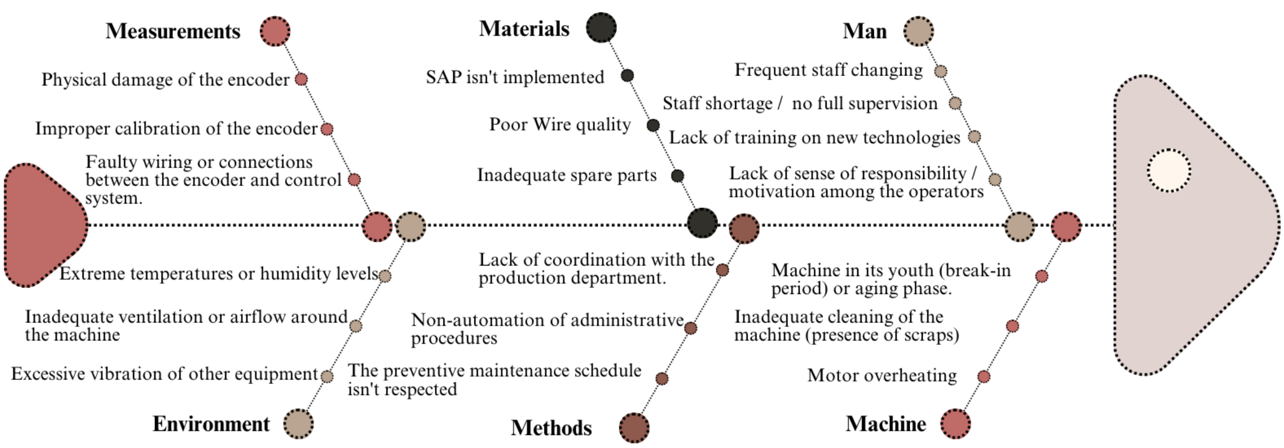

Figure 5.5: Root Cause & Effect Analysis of Twisting head

B. Soummam case study:

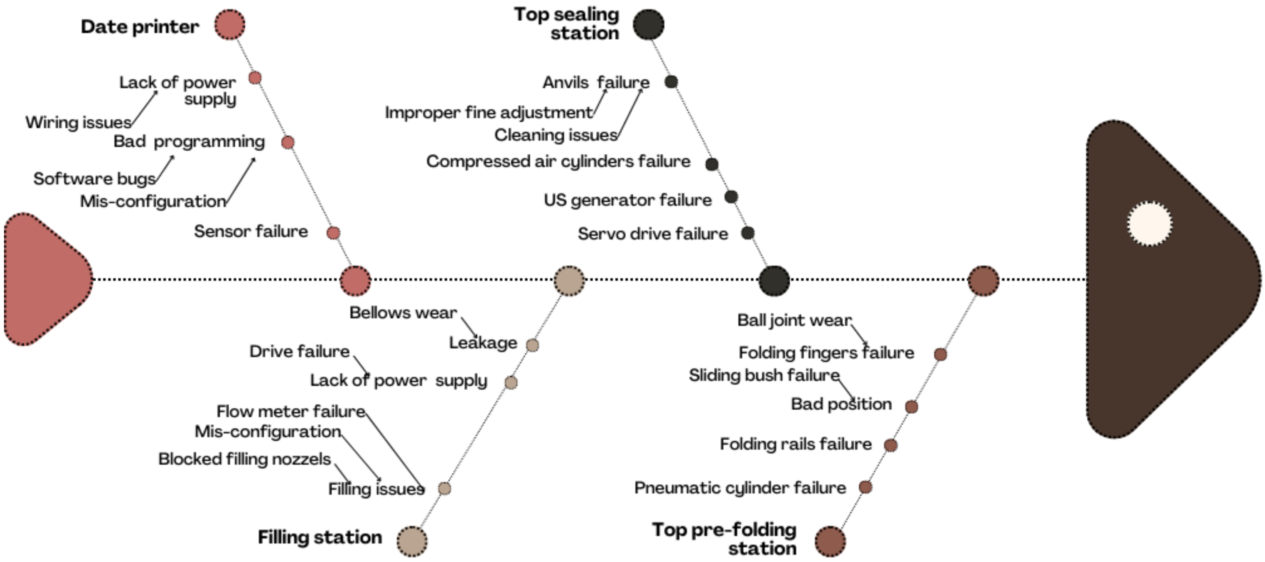

Figure 5.6 Root Cause & Effect Analysis of Filler CFA 312-2

Conclusion:

The combination of FMEA and RCFA provides a comprehensive approach for managing critical equipment failures. FMEA aids in the identification and prioritization of potential failures, while RCFA facilitates a detailed analysis to uncover the underlying causes. By following this approach, resources can be effectively allocated and focus is addressing the most significant failures.

The information we obtained in this chapter has given us a strong foundation to construct our fault tree analysis, which will be transformed into a Bayesian network in the subsequent stages.

Chapter 6: From Binary to Multi-state Analysis

Chapter 6: From Binary to Multi-state Analysis

Introduction:

In the preceding chapter, a binary analysis utilizing FMEA was performed, focusing solely on the states of complete failure and perfect functioning. However, in this chapter, we delve deeper into the examination of potential failures that were prioritized through FMEA, employing the Dynamic Bayesian Network (DBN) approach as multi-state analysis tool for more insights about equipment behaviour. By incorporating evidence or observed data, the network can update probabilities and make predictions or assessments about the likelihood of specific events or scenarios.

Is the Equipment multi-state equipment?

5. AQS case:

After carefully reviewing the equipment documentation and conducting a survey with the engineers from the RM unit, we have reached the conclusion that the tying machine qualifies as multi-state equipment, and these are the criteria we deployed:

- **Multiple Operating Modes:** The tying machine of the rolling mill unit offers various operating modes to cater to different binding requirements. It includes modes for ***wire binding***, ***strap binding***, *and* ***tape binding***. Each mode provides distinct functionalities for different types of binding materials.
- **Variable Parameters:** The tying machine allows for the adjustment and configuration of various parameters and settings. These parameters include ***binding tension, binding speed, and material type***. The operator can modify these settings based on the specific binding requirements for different types of materials and desired binding outcomes.
- **Different Output or Performance Levels:** The tying machine is capable of delivering different binding outputs and performance levels. It can achieve variations in ***binding strength, thickness, two types of knots and overall binding quality***. These differences arise from the selected operating mode, parameters, and settings.

  - **Tying machine possible failure modes and observation:**
    The key failure modes of the tying machine could be motor failure, sensor malfunction, or component wear.
  - **Relevant observations or measurements that can provide insights into the current state of tying machine:**
    - → Vibration levels.
    - → Temperature.
    - → Error codes.

- **Tying Machine different states:**
  - **Perfect state:** The tying machine operates without any issues.
  - **Pseudo-fault state:** The tying machine experiences moderate performance **degradation or faults that start to affect its functionality and efficiency.**
  - **Fault state:** The tying machine is unable to perform its intended function and requires immediate repair or replacement.

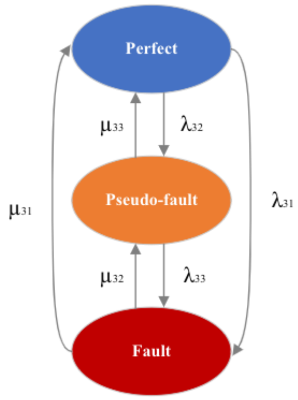

Figure 6.1 Tying machine different states

- **Equipment behaviour Dynamic Variables:**
  λ: Failure rate.
  μ: Repair rate.

- **Factors that influence state transitions**:
  Equipment aging.
  Maintenance actions.
  Environmental conditions.
  Operating parameters.

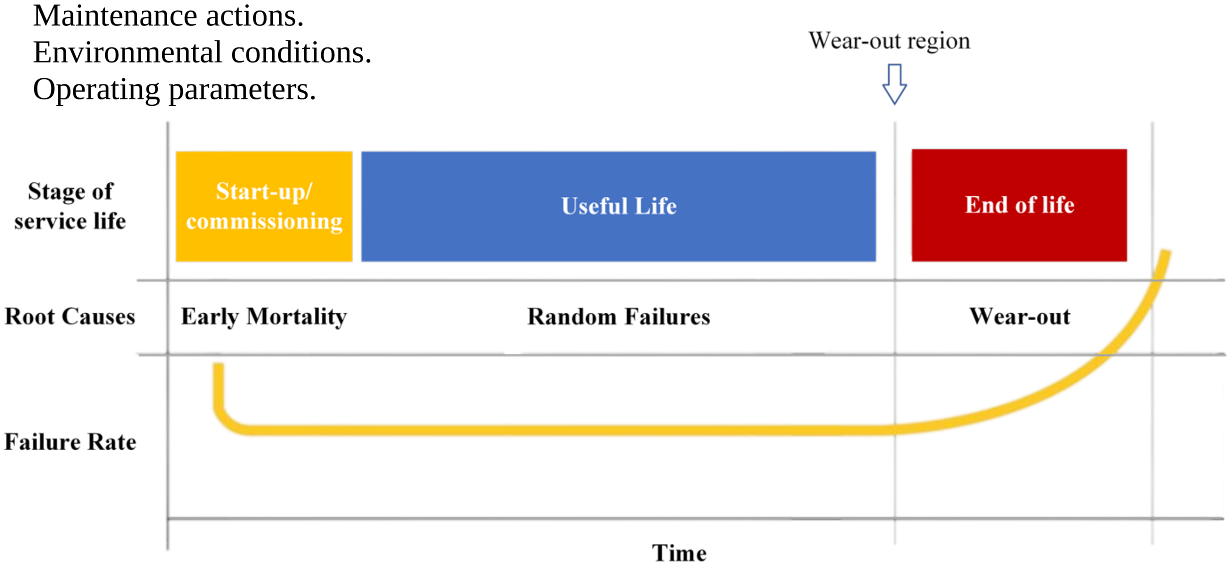

Figure 6.2: Bathtub curve

1.1.Translate into a Bayesian Network:

Building a dynamic Bayesian network (DBN) for multi-state failures of a tying machine can be a complex task requiring detailed knowledge of the system's behaviour, failure modes, and relevant data.

1.1.1. Fault Tree:

The fault tree is a graphical representation of system failures, where the top event and its contributing events are shown as nodes in the tree. Fault tree analysis involves quantifying the probabilities of these events using probability theory and Boolean algebra.

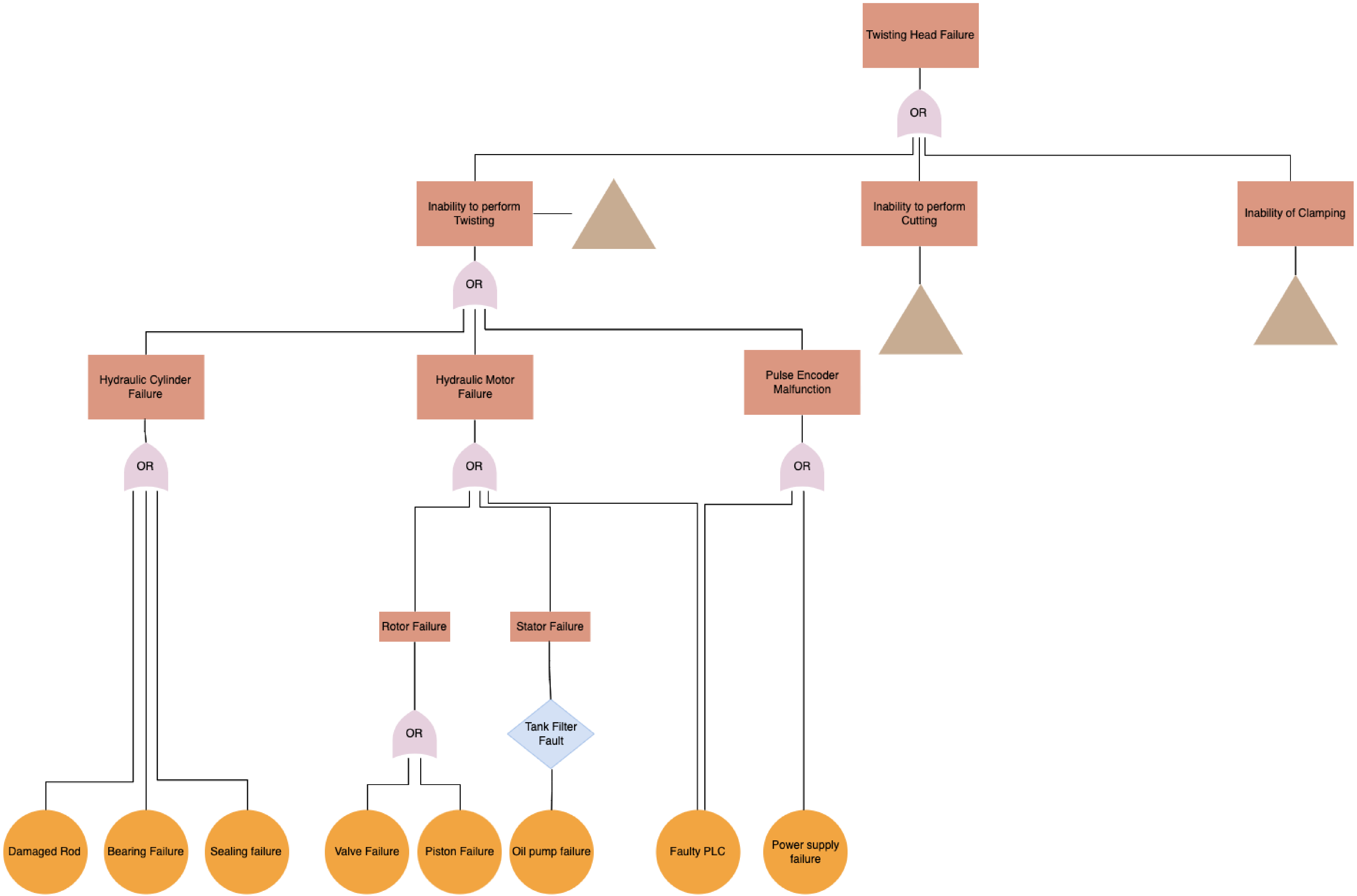

Figure 6.3: Twisting Failure Fault Tree Analysis

1.1.2. Bayesian Network:

To create a Bayesian network from a fault tree, the events and their relationships are translated into variables and conditional probability distributions. Fault events become variables in the network, and logical gates in the fault tree represent conditional dependencies in the Bayesian network[26].

The following Bayesian network enables probabilistic calculations and inferences about the system's behaviour. The top event, twisting head failure in the failure model, is caused by three intermediate events: ET, IE and Pre-TE. Event ET1 contains an OR-gate with elements E1, E2 and E3. Event ET2 contains an OR-gate with elements E3, E4, E5 and E6. In addition, event ET3 contains an OR-gate with elements E7, E8. Next, event IE1 contains an OR-gate with events ET1, same goes for event ET2 and ET3. Consequently, event Pre-TE1 contains an OR-gate with events IE1, IE2 and IE3, same goes for event Pre-TE2 and Pre-TE3. Finally, TE contains an OR-gate with events Pre-TE1, Pre-TE2 and Pre-TE3.

The unreliability for an OR-gate can be calculated as:

$$P(Y|X_{1,}\, X_{2,\dots}\, X_n) = \prod_{1\le j\le n} (1 - f_i)$$

f_i: degradation probability of each node.

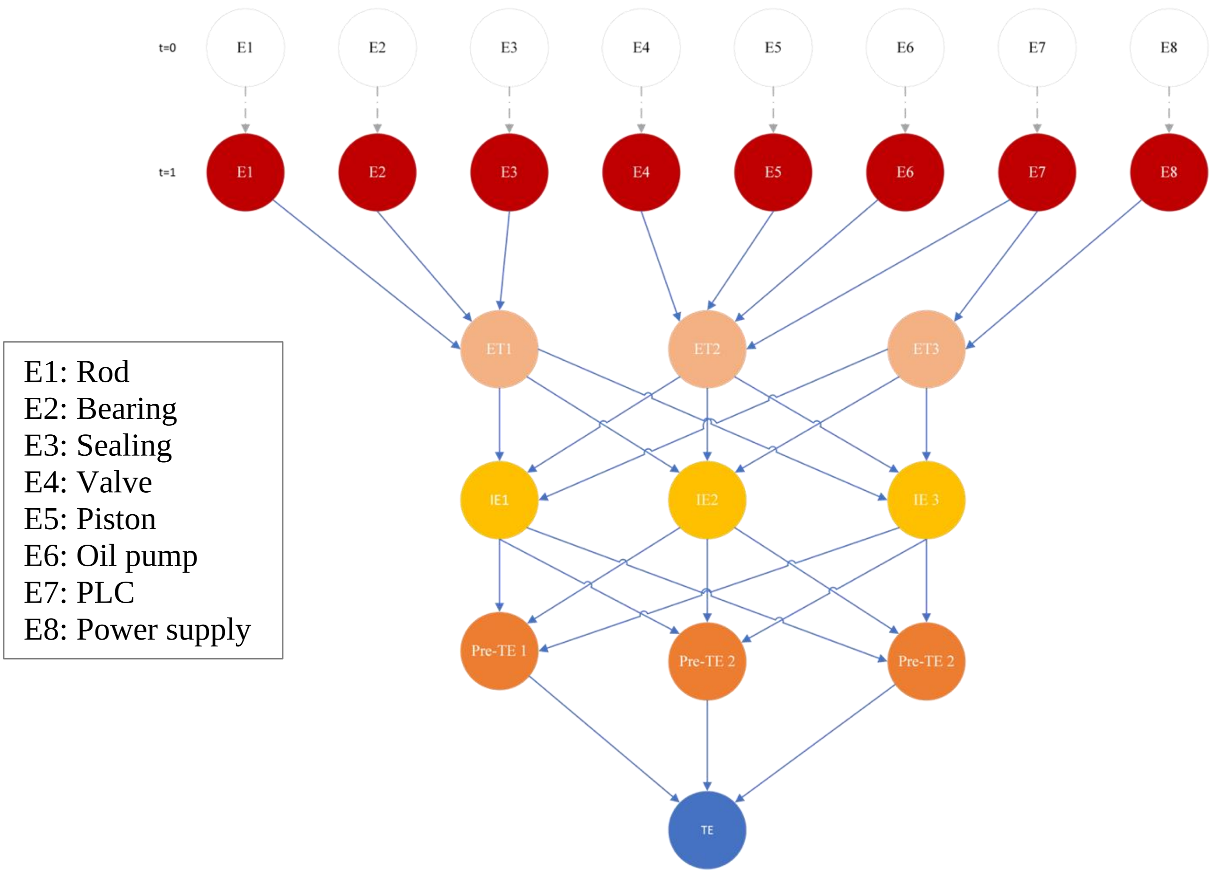

Figure 6.4 Twisting Head Failure Bayesian Network

- The following table contains failure rates and repair rates obtained from historical data of the twisting head failure:

	2019		2020		2021	
Element	**λ×10^-3**	**µ×10^-1**	**λ×10^-3**	**µ×10^-1**	**λ×10^-3**	**µ×10^-1**
E1	3.1	5.0	2.5	4.0	1.3	3.1
E2	5,4	6.1	4.7	5.7	3.5	4.3
E3	2.6	3.8	1.8	2.8	1.1	1.4
E4	4.1	4.9	3.4	3.7	2.0	2.5
E5	6.3	7.3	5.2	6.8	4.4	5.0
E6	7.1	8.1	6.2	7.0	5.2	6.0
E7	1.2	2.6	1.7	2.9	1.3	5.2
E8	3.4	5.3	2.1	3.7	1.2	2.0

Table 6.1: Failure and repair rate of the twisting head [2019-2021]

1.1.2.1. Data simulation with perfect repair:

The entire DBN model is extended from time t = 1 to time t = 3 as shown in the next figure. At the beginning of time, t = 0, all elements are in the perfect state with a full percent. With time elapses, degradation begins.

	t+Δt		
t	**P**	**P-F**	**F**
P	$e^{-(\lambda_{31}+\lambda_{32})\Delta t}$	$\frac{\lambda_{32}}{\lambda_{31}+\lambda_{32}} \times (1-e^{-(\lambda_{32}+\lambda_{31})\Delta t})$	$\frac{\lambda_{31}}{\lambda_{31}+\lambda_{32}} \times (1-e^{-(\lambda_{31}+\lambda_{32})\Delta t})$
P-F	0	$e^{-(\lambda_{33})\Delta t}$	$(1-e^{-(\lambda_{33})\Delta t})$
F	$1-(e^{-(\mu_{31}+\mu_{32})\Delta t})$	0	$e^{-(\mu_{31}+\mu_{32})\Delta t}$

Table 6.2: Transition probabilities between the states with perfect repair

1.1.2.2.Data simulation under Condition Based Maintenance (CBM):
Condition Based Maintenance (CBM):
For

	t+Δt		
t	**P**	**P-F**	**F**
P	$e^{-(\lambda_{31}+\lambda_{32})\Delta t}$	$\frac{\lambda_{32}}{\lambda_{31}+\lambda_{32}} \times (1-e^{-(\lambda_{32}+\lambda_{31})\Delta t})$	$\frac{\lambda_{31}}{\lambda_{31}+\lambda_{32}} \times (1-e^{-(\lambda_{31}+\lambda_{32})\Delta t})$
P-F	$\frac{\mu_{33}}{\lambda_{33}+\mu_{33}} \times (1-e^{-(\lambda_{33}+\mu_{33})\Delta t})$	$e^{-(\lambda_{33}+\lambda_{33})\Delta t}$	$\frac{\lambda_{33}}{\lambda_{33}+\mu_{33}} \times (1-e^{-(\lambda_{33}+\mu_{33})\Delta t})$
F	$\frac{\mu_{31}}{\mu_{32}+\mu_{31}} \times (1-e^{-(\mu_{32}+\mu_{31})\Delta t})$	$\frac{\mu_{32}}{\mu_{32}+\mu_{31}} \times (1-e^{-(\mu_{32}+\mu_{31})\Delta t})$	$e^{-(\lambda_{32}+\lambda_{31})\Delta t}$

Table 6.3: Transition probabilities between the states under CBM

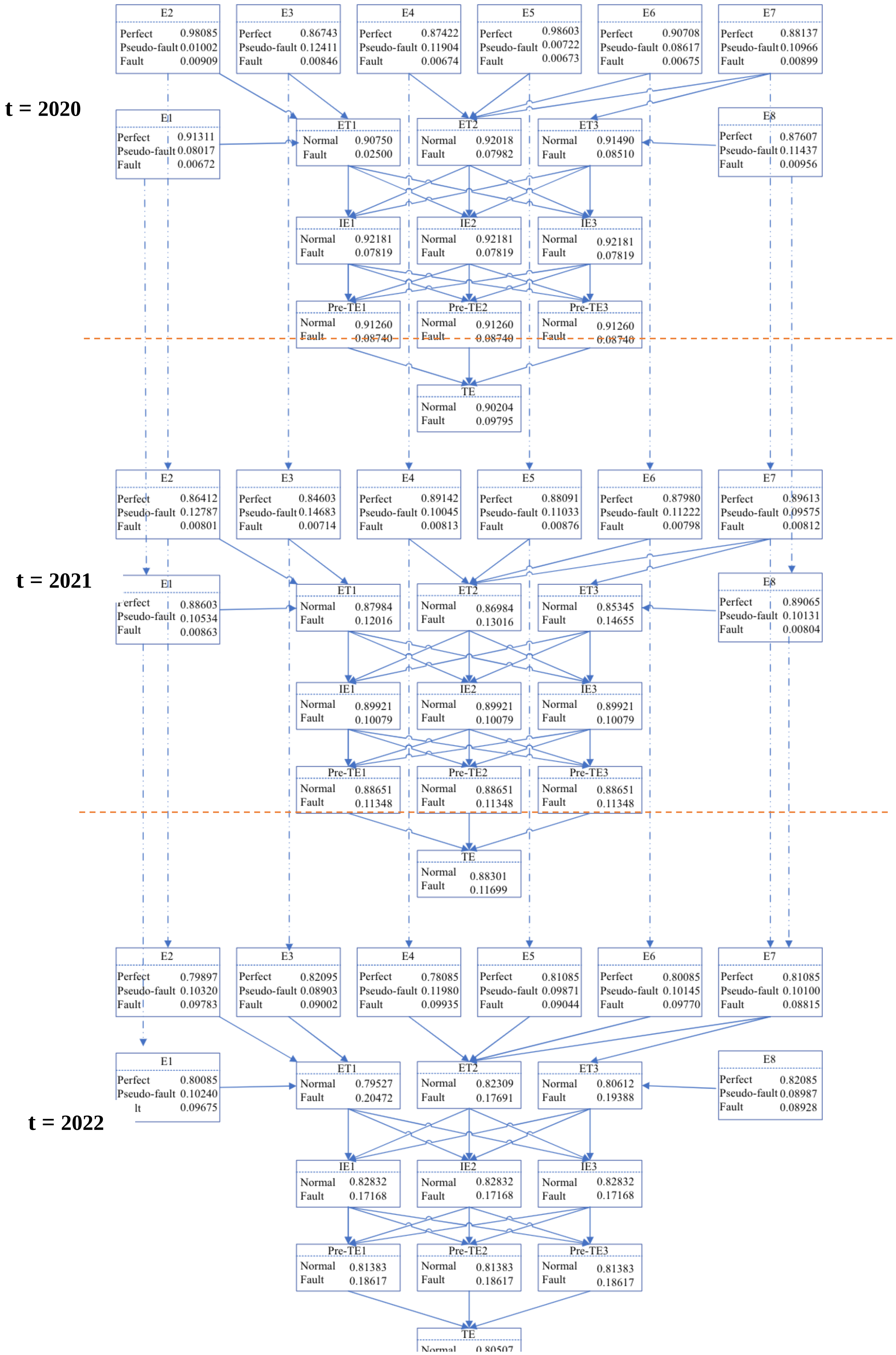

Figure 6.5 DBN under CBM [2020-2021-2022]

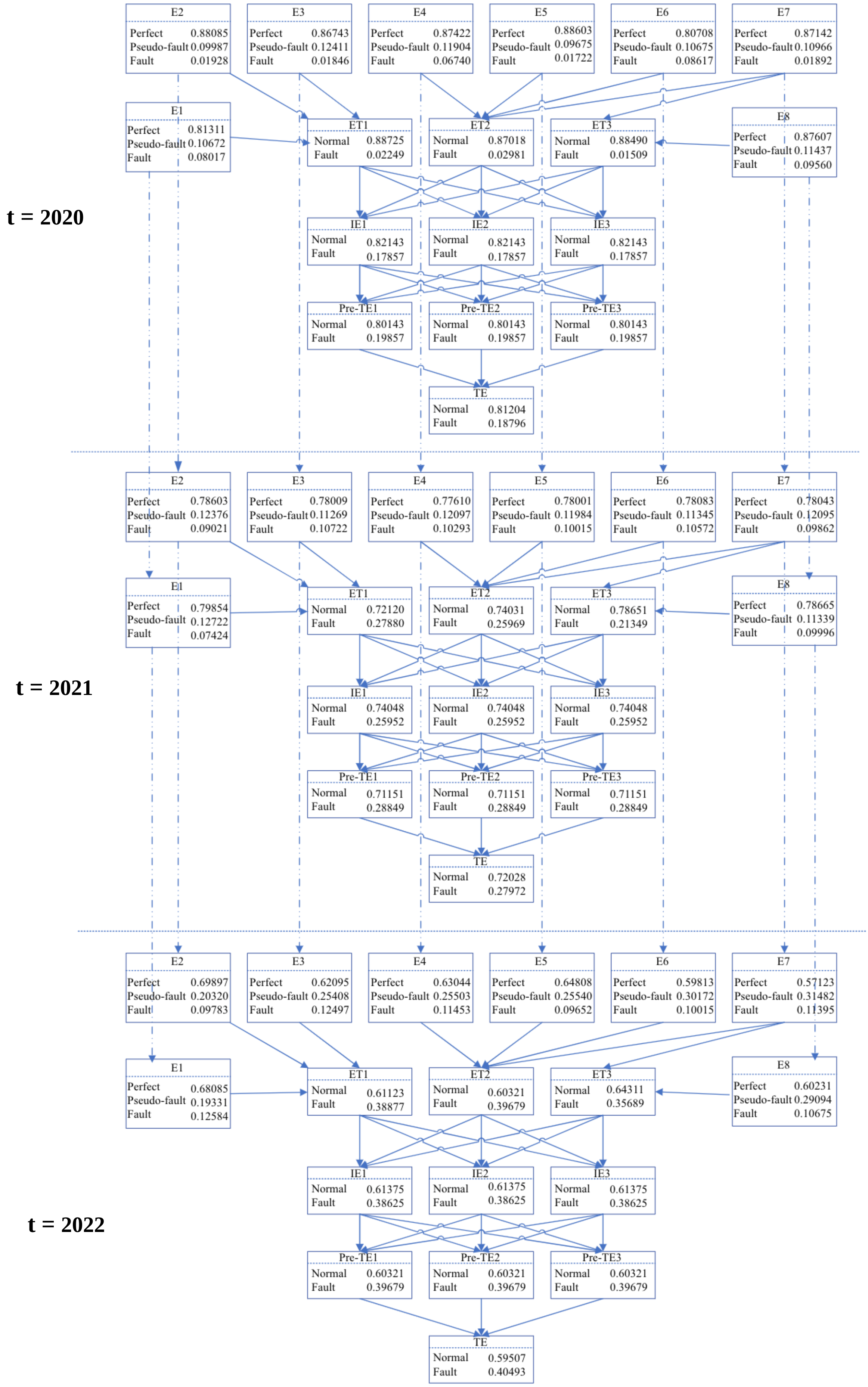

Figure 6.6 DBN with perfect repair [2020-2021-2022]

1.1.2.3.Reliability and unreliability prediction:

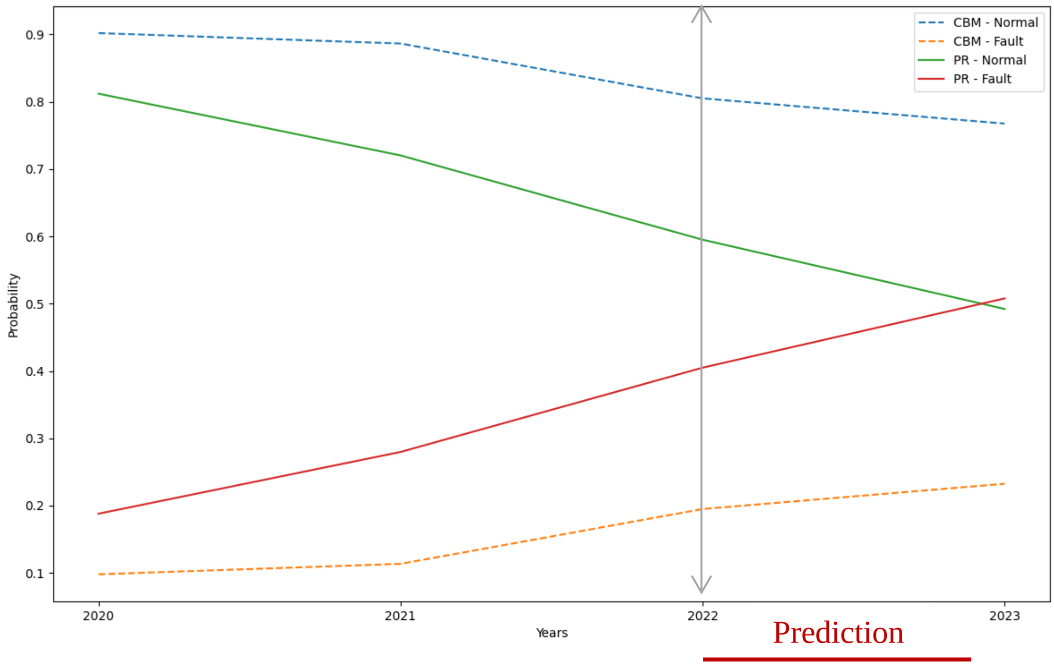

Figure 6.7 Prediction of twisting head reliability and unreliability with perfect repair and under CBM

→ The insights gleaned from this figure demonstrate that the rate of growth in unreliability is more pronounced when perfect repair strategies are implemented as opposed to condition-based maintenance (CBM) approaches. Furthermore, based on the predictions made for 2023, the probability of unreliability surpassing that of reliability becomes highly probable, which will lead to **premature aging.**

2. Soummam case study:

2.1.Machine states:

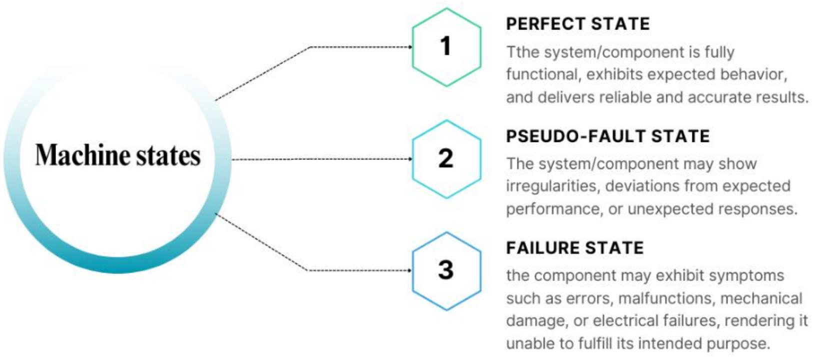

Figure 6.8: Machine states

2.2. Selection factors:

a. **Degradation indicators:** Like the key parameters or indicators that reflect the degradation or loss of performance in the machine. These indicators can include factors such as temperature, noise, wear, efficiency, or any other relevant measurable parameters.
b. **Event Characteristics:** The characteristics of events, such as frequency, severity, duration, or impact, can help define different states. Events with low frequency or

severity may indicate a good or healthy state, while events with high frequency or severity may represent a degraded or critical state.

c. **Event Consequences:** The consequences or impacts of events can be considered when defining states. Events with minor consequences may reflect a minor or tolerable degradation state, while events with severe consequences may indicate a critical or severe degradation state.

2.3.Fault tree:

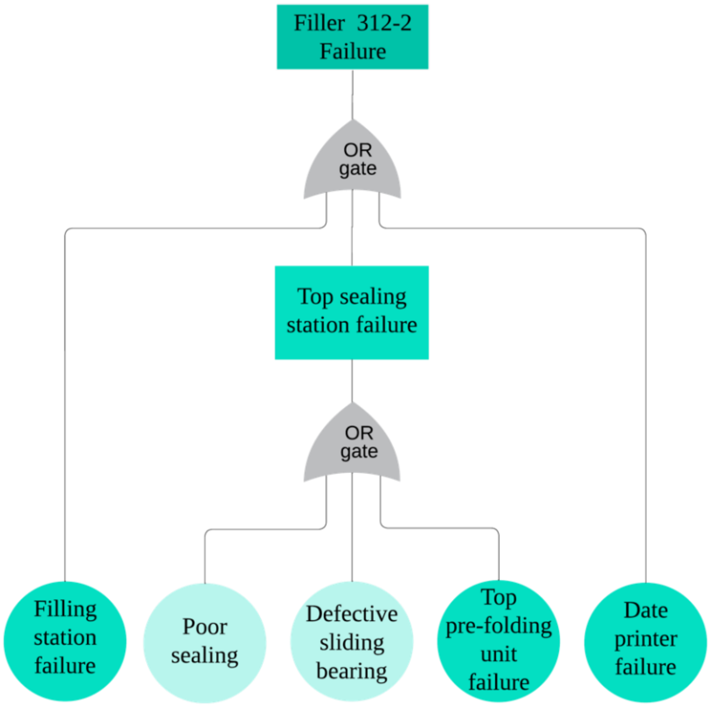

Figure 6.9: Filler CFA 312-2 Fault Tree Analysis

- The following Bayesian network enables probabilistic calculations and inferences about the system's behaviour. The top event, Filter 312-2failure in the failure model, is caused by an intermediate event Ts. Event Ts contains an OR-gate with elements SB and PS. F event contains an OR-gate with events DP, TP and Ts.

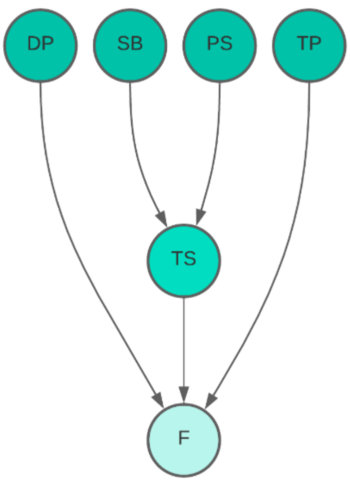

Figure 6.10: Filler CFA 312-2 Bayesian Network

- The following table contains failure rates and repair rates obtained from historical data of the twisting head failure:

Variable	2021		2022		2023	
	Failure rate	Repair rate	Failure rate	Repair rate	Failure rate	Repair rate
DP	0,001207729	3,80952381	0,001262626	1,756097561	6,07386E-05	5
PS	0,003497567	1,329479769	0,006188119	1,835486064	0,002469136	2,330097087
SB	0,003024194	2,25	0,001760563	2,80155642	0,000570776	5
PF	0,001488095	3	0,000188537	1,904761905	0,000373134	1,607142857
FS	0,007451338	1,425109064	0,007119514	1,60667252	0,014917695	2,562592047

Table 6.4: Failure and repair rate of the Filler CFA 312-2 [2019-2021]

☞ Data simulation is represented using DBN with perfect repair figure 6.11 and CBM figure 6.12

2.4.Reliability and unreliability prediction:

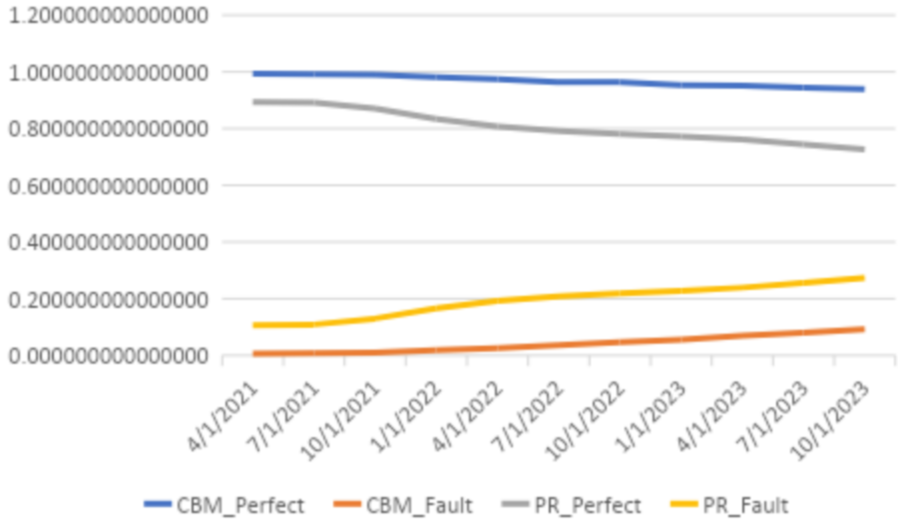

Figure 6.11: Prediction of Filler CFA 312-2reliability and unreliability with perfect repair and under CBM

→ The analysis of the figure reveals that the application of perfect repair strategies leads to a faster increase in unreliability compared to condition-based maintenance (CBM) approaches.

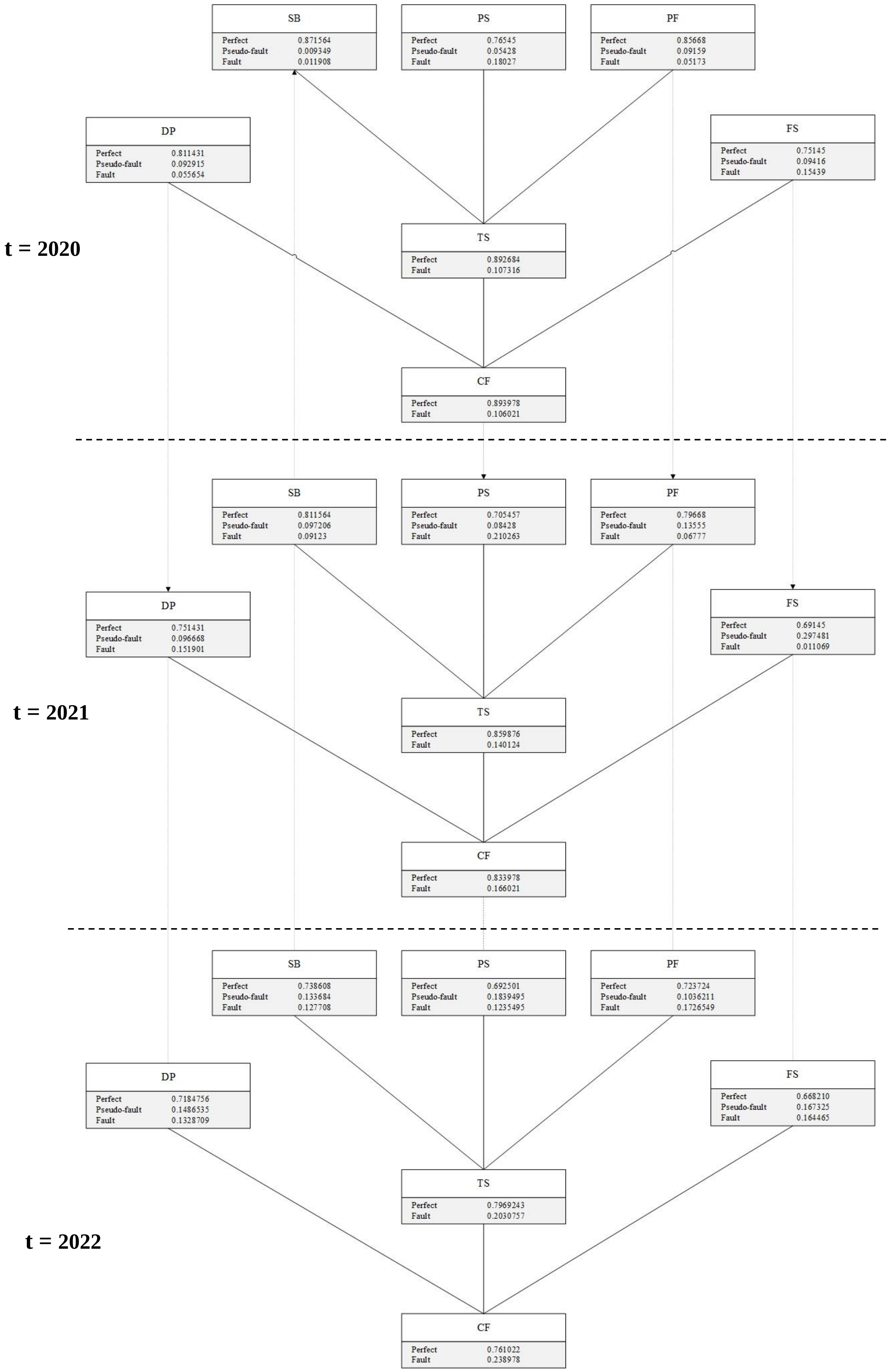

Figure 6.12: DBN with perfect repair

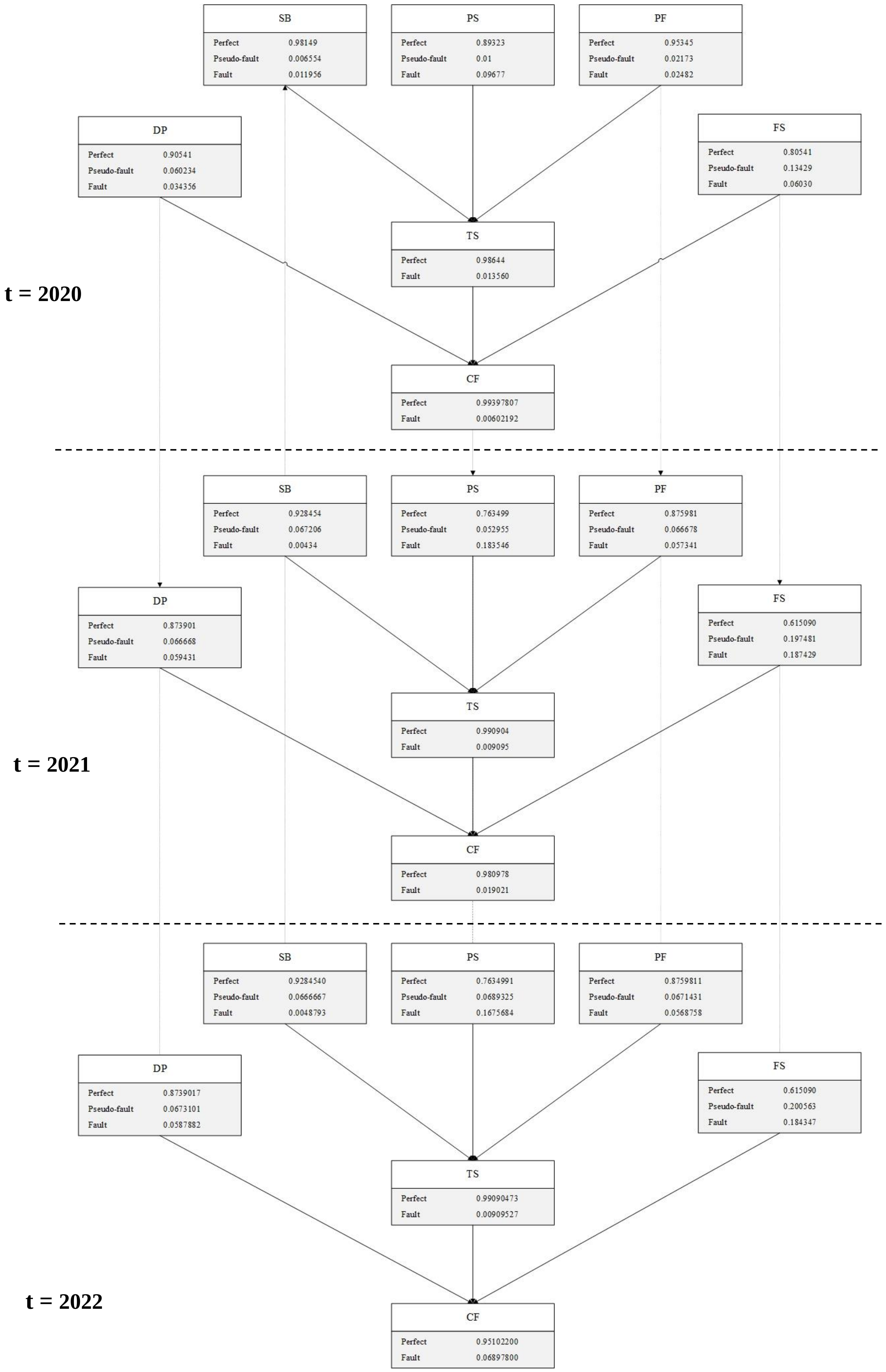

Figure 6.13: DBN Under CBM

Conclusion:

This chapter expanded on the previous binary analysis conducted using Failure Mode and Effects Analysis (FMEA) by employing the Dynamic Bayesian Network (DBN) approach for a multi-state analysis of potential equipment failures.

For the AQS industry, it is crucial to improve the reliability of all elements under CBM. Weak nodes, specifically E3, E7, and E8, require special attention. When prioritizing reliability design and assignment, elements with higher reliability should be focused on to enhance the overall performance of the system. In the other hand, Soummam case study, the analysis highlighted the significance of addressing the weak node DP to improve its reliability and ultimately enhance the system's overall performance and reliability.

By using the DBN approach, this chapter provided valuable insights into equipment behaviour and highlighted specific areas of focus for maintenance and reliability improvement in both the AQS and Soummam industries. These findings can guide decision-making processes and inform strategies for enhancing equipment performance, reducing failures, and optimizing maintenance practices.

Chapter 7:
Establish Maintenance Preventive Strategies

Chapter 7: Establish Maintenance Preventive Strategies

Introduction:

In this chapter, we will discuss the implementation of preventive measures that follow the evaluation of multiple states of elements in the preceding step.

The selection of equipment strategy and maintenance practices is determined based on our defined targets and the desired level of reliability that we aim to incorporate into the equipment design.

The Maintenance Prevention function plays a crucial role in ensuring the long-term reliability, performance, and cost-effectiveness of equipment and assets. Its primary objective is to proactively identify and eliminate potential causes of failures and performance degradation before they occur, thereby reducing the need for reactive maintenance and minimizing downtime

- **Where do we want to go?**

From...	...To
Inward looking maintenance organization attempting to improve over its own past performance.	External oriented organization driven to surpass best global benchmarks on maintenance
Looking at equipment Reliability; Availability and MTBF as the key measure	Looking at process Reliability, Plant OEE as the key measure
Trying to carry out continuous improvement on legacy equipment & systems	Upgrading to an operating with world class maintenance equipment & systems
Traditional workforce with semi-skilled personnel_ focus on MTTR reduction only	Change Maintenance organization focus to skill-based workforce - focus on reduction of % corrective maintenance
Theme based improvement programs, often overlap with existing systems and practices.	Improvement initiatives that are mutually complementary & perfectly aligned to overall Reliability vision

Figure 7.1: Smart RCM targets

1. RCM Decision Diagram based on ISO 60300:

We’ll be taking each failure mode from FMEA through the RCM Decision Diagram to analyse. We have the RCM Decision Diagram. It allows us to determine the best Failure Management Strategy (how each failure mode should be managed) In case the failure mode is evident, we eliminate the right side of the diagram and we only use the left side, same goes for the case of hidden failure mode.

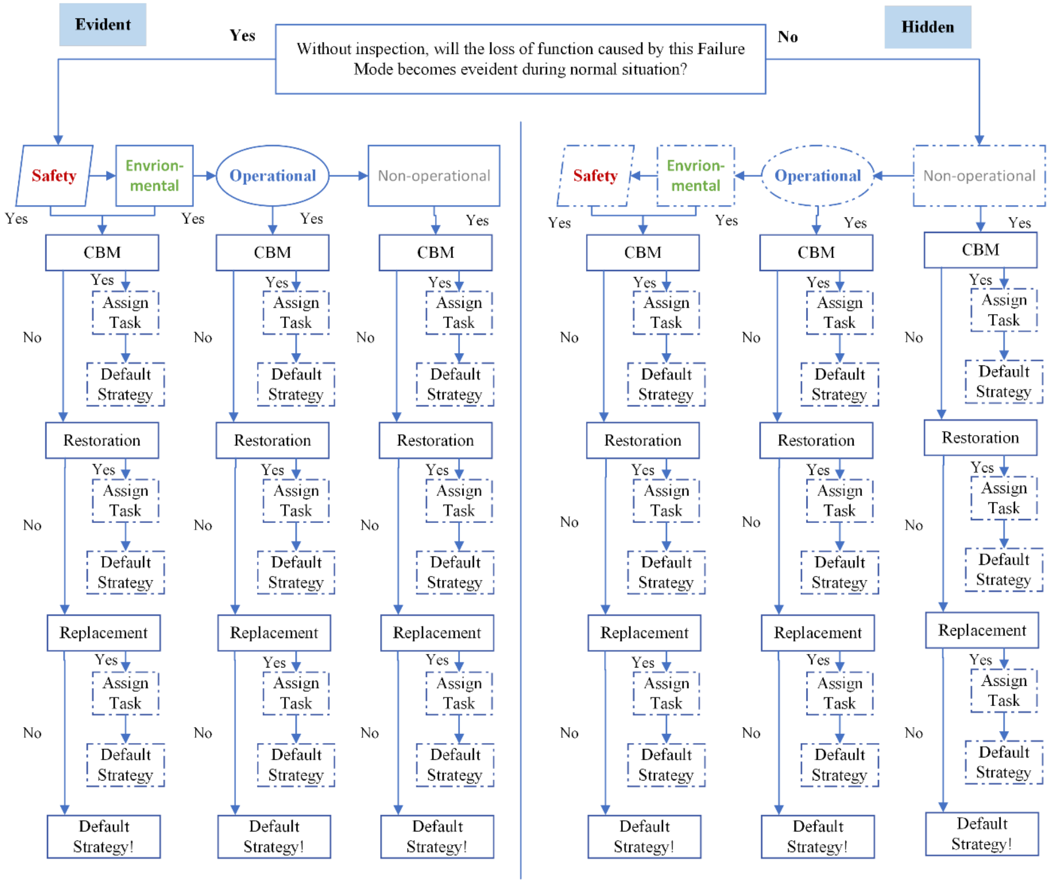

Figure 7.2: RCM Decision Diagram

6. **The choice of failure management policy:**

The level that follows in the RCM decision-making process evaluates the characteristics of each failure mode to determine the most appropriate failure management policy. There are a number of options available, namely:

a. **Condition monitoring:** Condition monitoring is a task performed either continuously or periodically to monitor the operating state of an entity against predefined parameters in order to detect deviations. It can involve inspection tasks, which are an examination of the entity against a given standard.

b. **Scheduled restoration:** Restoration involves performing necessary work to bring the entity back to a given standard. Since restoration can range from simple cleaning to the replacement of multiple parts, it is necessary to specify the content of each restoration task.

c. **Scheduled replacement:** Scheduled replacement involves taking an entity out of operation when its specified lifespan limit is reached and replacing it with an entity that meets all the required functional standards. Scheduled replacement tasks generally apply to consumable or "one-piece" parts such as cartridges, metal boxes, cylinders, turbine discs, and structural elements with a safety lifespan.

d. **Failure finding:** Failure finding is a task performed to determine whether an entity fulfils its function or not. It is solely intended to uncover hidden failures. Failure-finding tasks can range from visual inspections to quantitative evaluations against a specific functional standard. Certain applications restrict the ability to perform a complete functional test. In such cases, a partial functional test may be applicable.

e. **No preventive maintenance:** Based on the effects of failure, it may be decided that no specific task is required in certain situations. The result of this failure management policy is either corrective maintenance or no maintenance at all following a failure.

f. **Additional management actions:** Other actions may result from the application of the RCM decision-making process, including:
   - New design.
   - Modification of existing equipment, such as using reliable entities.
   - Changes to the maintenance procedure. Pre-use and post-use checks.
   - Modification of the spare parts supply strategy.
   - Additional training for operators or maintenance personnel.

7. The implementation of management actions can be divided into two distinct categories:

2.4.1.1.1. Those that require urgent and immediate action, especially for failure modes that will have an adverse impact on safety or the environment.

2.4.1.1.2. Those that may be desirable when a preventive maintenance task cannot be accompanied to reduce the consequences of functional failures that affect costs or operation. They should be evaluated through an analysis of failure modes and their effects.

A. AQS study case:

Under the implementation of Condition-Based Maintenance (CBM), the elements of the twisting head can be sustained at a consistently stable level of reliability that exceeds that of perfect repairs. Furthermore, the findings derived from data mining indicate the necessity of implementing machine life-enhancing projects (MTBF projects) for the tying machine.

- **Improving MTBF:** The following table represents strategies used to machine life-enhancing.

Table 7.1: MTBF enhancing matrix

Reasons for short MTBF	Design for Reliability	Condition assessments	CMMS / ERP	5 S	Maintenance Training	Change maintenance strategy	Protective measures
Poor Equipment Design	•					•	•
Inadequate Maintenance Practices		•	•	•	•	•	•
Harsh Operating Conditions	•			•		•	•
Substandard Quality of Components	•						•
Lack of Operator Training			•	•	•		
Inadequate Spare Parts Inventory	•	•	•		•		
Aging Equipment	•				•	•	•

→ Most Failure Modes provide evidence (**Potential Failure condition**: vibration, wear, heat) that the failure is in the process of occurring.
In order to enhance the efficacy of Condition-Based Maintenance (CBM), our decision to implement predictive maintenance solutions is driven by the sporadic and random nature of failure history. Given the criticality of the tying machine as equipment, the existing preventive maintenance schedule proves ineffective in ensuring optimal maintenance outcomes.

The P-F curve is incredibly valuable, because on- condition maintenance tasks are determined based on it.
On-condition maintenance tasks are performed at intervals less than the P-F interval, as long as the time remaining is long enough time to take action before failure occurs[1], [5].

- **N.B:** CBM tasks intervals are based on upon how quickly failure occurs once the potential failure condition is detectable and not how often the failure occurs.

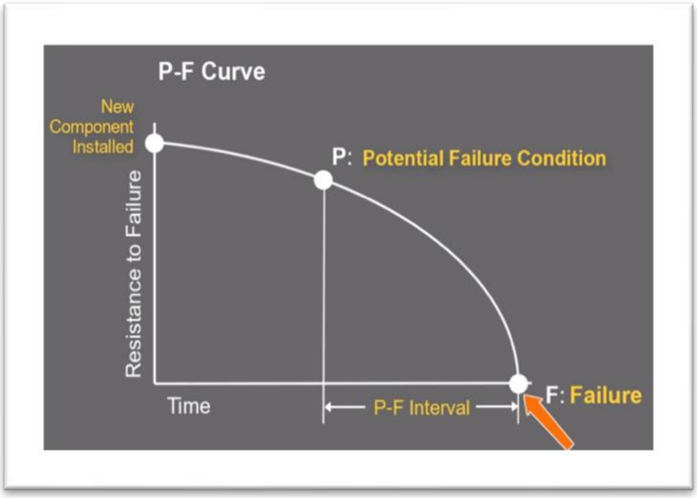

Figure 7.3: P-F curve

If the potential Failure goes undetected
and we don't interfere; eventually failure occurs.

- **Preventive maintenance activities:** The following table represents preventive maintenance activities of the tying machine/binding machine:

➢ **Recommended preventive maintenance:**

➢ **Daily:**
- Inspect the equipment for oil leaks.
- Inspect the knots to make sure that they are correct.
- Lubricate.

➢ **Weekly:**
- Check distances and tightness of proximity switches.
- Check that it is easy to open and close the covers of the wire guides.
- Check mechanical parts for wear.

➢ **Monthly**
- Clean all parts of the unit.
- Check connections and hoses with regard to leakage.
- Check all electrical connections.
- Lubrication.
- Check electrical parts for wear.
- Tighten screw joints.

→ Find in appendix, figure1, trouble shooting for problem : Motor won't start

- **Recommended predictive maintenance:**

Table 7.2: Recommended predictive maintenance strategies for AQS study case

Component	Failure Mode	Predictive Maintenance Techniques	Description
PLC	Software malfunction	Real-time monitoring of program execution and error logging	Use monitoring tools to capture and analyse PLC program execution. Implement an error logging system to record and categorize software errors.
	Communication failure	Monitoring communication status and analysing network traffic	Continuously monitor the communication status of PLCs, verifying network connectivity and data transmission. Analyse network traffic for any anomalies or deviations.
	Overheating	Temperature monitoring and analysis of cooling system performance	Implement temperature sensors to monitor the heat generated by PLCs. Analyse the performance of cooling systems to ensure efficient heat dissipation.
Power Supply	Voltage instability	Continuous voltage monitoring and analysis of fluctuations	Employ voltage monitoring devices to continuously monitor power supply voltage levels. Analyse voltage fluctuations and trends to detect instability.
	Overload	Load monitoring and analysis of power consumption	Use load monitoring techniques to track the power supply's load. Analyse power consumption patterns to detect overloading situations.
	Overheating	Temperature monitoring and analysis of heat dissipation	Implement temperature sensors to monitor the temperature of power supply units. Analyse heat dissipation mechanisms to ensure efficient cooling.
Sealing	Wear and tear	Visual inspection for signs of wear and scheduled replacement	Regularly inspect seals visually for signs of wear, such as cracks, fraying, or distortion. Schedule replacement based on wear and tear conditions.
	Cracks or deformities	Vibration analysis to detect abnormal vibrations	Employ vibration sensors to monitor equipment and detect abnormal vibrations that may indicate seal cracks or deformities.
	Inadequate lubrication	Lubrication analysis and scheduled maintenance	Monitor lubrication levels and quality in machinery with seals. Analyse lubrication conditions and schedule maintenance actions to ensure proper lubrication.
	Environmental damage	Monitoring environmental conditions and protecting seals	Monitor environmental factors such as temperature, humidity, and exposure to corrosive substances. Implement protective measures to prevent environmental damage.

- To provide evidence for the effectiveness of the previous tables, the brainstorming technique is used based on the history of failure for the twisting head. By brainstorming potential failure scenarios and evaluating how the listed predictive maintenance practices could have mitigated or prevented those failures, we can demonstrate the efficiency of the table.

- **Brainstorming Potential Failure Scenarios:**

- **Scenario 1: Premature sealing failure in the twisting head.**
  Predictive Maintenance Practice: Component Wear Analysis By regularly inspecting and measuring the wear of sealings, the maintenance team would have identified excessive wear in advance. They could have planned for timely sealing replacement, avoiding the risk of sealing failure and minimizing unplanned downtime.
- **Scenario 2: Undetected crack in a critical gear of the twisting head.**
  Predictive Maintenance Practice: Non-Destructive Testing (NDT) If NDT techniques were employed periodically, the crack in the gear could have been detected during inspections. This would have prompted maintenance intervention, such as gear replacement or repair, preventing a catastrophic failure that could lead to extensive damage and production losses.
- **Scenario 3: Unanticipated motor overheating leading to motor failure.**
  Predictive Maintenance Practice: Trend Analysis and Remote Monitoring Through trend analysis and remote monitoring, the maintenance team would have noticed abnormal motor temperature trends and received real-time alerts indicating overheating. They could have investigated the root cause and taken preventive actions, such as cleaning cooling systems or replacing faulty motor components, before the motor failed completely.
- **Scenario 4: Failure Mode: Software malfunction in the binding machine's PLC**
  In a steel rolling mill, the binding machine's PLC experiences a software malfunction, resulting in incorrect binding patterns and causing quality issues in the finished steel coils.
  Predictive Maintenance Techniques: By implementing real-time monitoring of program execution and error logging, the predictive maintenance techniques listed in the table could have helped prevent or minimize the impact of this failure. Real-time monitoring would have captured the execution data of the binding machine's PLC program, allowing operators or maintenance personnel to identify any deviations or errors in the binding patterns as they occurred. An error logging system would have recorded and categorized the software errors, enabling quick identification and resolution of the issue. With these techniques in place, the software malfunction could have been detected early, reducing the production of defective coils, minimizing customer complaints, and avoiding the need for extensive rework.
- **Scenario 5: Failure Mode: Overheating of the binding machine's power supply unit Scenario**
  In a steel rolling mill's binding machine, the power supply unit (PSU) responsible for providing electricity to the machine overheats due to inadequate cooling. The overheating leads to the failure of the PSU, causing production downtime and requiring the replacement of the PSU.
  Predictive Maintenance Techniques: By implementing temperature monitoring and analyzing the cooling system performance, as suggested in the table, this failure could have been prevented. Temperature sensors installed in the binding machine's PSU would continuously monitor the heat generated, alerting operators or maintenance personnel if the temperature exceeded safe thresholds. Analysis of the cooling system's performance, such as fans or heat sinks, would ensure efficient heat dissipation and prevent overheating. With these predictive maintenance techniques in place, the overheating issue could have been detected early, allowing for proactive measures to be taken, thus preventing PSU failure, minimizing production downtime, and avoiding the need for PSU replacement.

☞ By analysing potential failure scenarios and correlating them with the listed predictive maintenance practices, we can see how each practice would have contributed to mitigating or preventing failures based on the history of failure. This validates the effectiveness and relevance of predictive maintenance in improving maintenance strategies and reducing downtime and associated costs.

B. Soummam study case:

➢ **Preventive maintenance (constructor's recommendations):**

Table 7.3: Preventive maintenance (constructor's recommendations) for Soummam study case

Sub-system	Failure mode	Preventive actions	Interval
Top pre-folding unit	Inconsistent operation (Defective Sliding bush)	Control of Bearing bushes for wear	2000h
		Control of Sliding bearing (bushes holder)	2000h
		Replacement of Sliding bearing	4000h
Filling station	Erroneous output (Dosing issues because of blocked filling nozzles)	Automatic cleaning	48h
Top sealing station	Inconsistent operation (Anvils failure/ inconsistent anvils adjustment)	Control of Bearing bush of anvils lever for wear	2000h
		Control of adjustment anvil	2000h
	Physical obstruction or stuck of sealing system	Replacement of Sliding bearing	8000h
Date printer	Inconsistent operation (Detection Sensor failure)	Replacement of sensor when it fails (corrective action)	

➢ **Recommended predictive actions:**

Table 7.4: Recommended predictive actions for Soummam study case

Sub-system	Failure mode	Prediction actions	Description
Pre-folding	Inconsistent operation (Defective Sliding bush)	Acoustic emission system	Acoustic emission-based sensors can detect the characteristic acoustic signals generated by defects such as frictional vibrations or impact events, allowing for the early detection and monitoring of bearing abnormalities.
		Establish vibration sensors	Vibration sensors are also a good alternative for tracking the changes in vibration patterns and abnormal vibrations of sliding bearings.

Filling station	Erroneous output (dosing issues because of blocked filling nozzles)	Pressure sensors	The aim in implementing such a system, is to detect any changes in filling pressure in case nozzles are blocked.
		Vision sensors	They can be configured to verify the state of nozzles, and for early detection.
		Capacitive proximity sensor (for splashes)	In the case of filling nozzles being blocked, it can lead to splashes or spills as the pressure builds up and the liquid finds alternative paths of escape. The Capacitive proximity sensor can play a role in detecting this effect and providing valuable feedback.
		Container filling level verification system	It ensures that the packaged agricultural products meet the desired weight or volume specifications, comply with regulatory standards, and align with customer expectations, if this not verified that means dosing issues(blocked nozzles)
Sealing station	Inconsistent operation (Anvils failure/ inconsistent anvils adjustment)	Vacuum/Pressure sensor	In case of poor sealing, the vacuum or pressure sensor can be effective in detecting possible leaks of vacuum which is inside the packed product
		Acoustic emission system	Acoustic emission systems can detect misalignment of anvils in sealing processes by monitoring the acoustic signals or vibrations generated during the operation.
		Displacement/laser sensors	The use of these sensors can provide accurate and precise measurements of the distance between the weld location and the pack's external walls.
		Capacitive proximity sensor	It can detect issues such as underfilling or overfilling, as well as any potential leaks or spills within the pack.
	Physical obstruction or stuck of sealing system	Acoustic emission system	
		Establish vibration sensors	
Date printer	Inconsistent operation (Detection Sensor failure)	Predictive analytics and Machine learning	

Conclusion:

In this chapter preventive strategies were established for enhancing equipment performance, reducing failures, and optimizing maintenance practices based on the valuable insights gained from the previous chapter, which shed light on equipment behaviour and identified specific areas of focus for maintenance and reliability improvement in the AQS and Soummam industries. By implementing these strategies, organizations in these industries can work towards achieving improved equipment reliability and overall operational efficiency.

Chapter 8:
Comparative Analysis Between Implementing RCM on AQS and Soummam.

Chapter 8: Comparative Analysis Between Implementing RCM on AQS and Soummam.

Introduction:

This chapter provides a comprehensive comparative analysis of RCM implementation in the AQS and Soummam Industries. The analysis explores equipment complexity, maintenance objectives, planning and execution strategies, and industry-specific considerations for both sectors. While the AQS industry emphasizes reliability, uptime, and safety, the Soummam industry prioritizes product quality, safety, and compliance with food safety regulations. Adapting RCM to address these unique challenges enables organizations to enhance maintenance strategies, improve operational efficiency, and effectively mitigate risks. Six Thinking Hats is employed to gain more insights into the distinct challenges and priorities associated with each industry.

1. Complexity of Equipment:

a. AQS Industry:

The steelmaking process involves complex and massive machinery, including blast furnaces, converters, electric arc furnaces, and rolling mills. These assets are subject to extreme conditions such as *high temperatures*, *intense mechanical forces*, and *corrosive environments*. As a result, maintenance in the steelmaking industry requires specialized expertise, advanced inspection techniques such as **ultrasonic testing**, **eddy current testing**, and continuous monitoring of equipment health like **vibration analysis** and **thermography**.

b. Soummam Industry:

While the equipment complexity in the food industry may not match that of the steelmaking industry, it presents *unique challenges*. Food processing equipment encompasses conveyors, mixers, ovens, and packaging machines, which *require regular cleaning, sanitization, and adherence to strict hygiene standards.* Maintenance in the food industry emphasizes preventive measures to prevent contamination risks, including **implementing regular cleaning** and **inspection schedules, monitoring wear and tear of equipment components**, and **ensuring compliance with food safety regulations** such as **Good Manufacturing Practices and HACCP**.

2. Maintenance Objectives:

a. AQS Industry:

Reliability and safety are *key objectives* in the steelmaking industry. Equipment failures can result in significant production disruptions, leading to substantial financial losses and potential risks to personnel and the environment. Consequently, RCM implementation in steelmaking focuses on identifying critical equipment failure modes, assessing their impact on **safety and production**, and developing maintenance plans that **minimize downtime** and **ensure safe operations**. Proactive strategies like predictive maintenance techniques *(vibration analysis, oil analysis)* are employed to detect potential failures before they occur.

b. Soummam Industry:

In the food industry, maintenance objectives encompass **product quality, safety, and regulatory compliance.** Equipment failures can compromise food safety, resulting in **product recalls, legal implications, and damage to brand reputation.** RCM implementation in the food industry emphasizes identifying failure modes that could affect product integrity, implementing preventive measures *(regular cleaning, lubrication, calibration)*, and establishing robust maintenance practices to **meet quality and safety standards**. This includes adhering to **strict hygiene protocols, conducting microbiological tests, and maintaining accurate records for regulatory audits.**

3. Maintenance Planning and Execution:

a. AQS Industry:
Maintenance planning in the steelmaking industry involves a thorough understanding of **equipment criticality and failure modes**. RCM analysis identifies maintenance tasks such as *routine inspections, component replacements, and restorations* that are strategically scheduled to minimize downtime and optimize resource allocation. Additionally, **condition monitoring techniques**, such *as vibration analysis and thermography*, help detect early signs of equipment degradation, allowing for timely intervention. Regular equipment *performance reviews* and *reliability data analysis* facilitate continuous improvement and optimization of maintenance strategies.

b. Soumam Industry:
Maintenance planning in the food industry centres around ensuring product integrity and compliance with food safety regulations. RCM analysis identifies critical control points, such *as temperature control, sealing integrity, and sanitation processes*, which can impact product **quality and safety**. Maintenance tasks are developed to address failure modes that could compromise these control points. This includes regular equipment *cleaning, calibration, lubrication, and inspections* to ensure equipment reliability and prevent contamination risks. Documentation and record-keeping play a vital role in demonstrating compliance during audits.

4. Industry-Specific Considerations:

a. AQS Industry:
The steelmaking industry requires *specialized maintenance practices* due to the **challenging operational environment**. Maintenance personnel need to be trained in *safety protocols, heat-resistant gear, and handling heavy equipment*. Maintenance activities must also consider the structural integrity of equipment, ensuring that components are not compromised by mechanical stresses or corrosion. Techniques such as thermal imaging, non-destructive testing, and structural integrity assessments are employed to detect and address potential issues proactively.

b. Soummam Industry:
Maintaining hygiene and sanitation is paramount in the food industry. RCM implementation must consider equipment cleanability, including the accessibility of critical components for cleaning and inspection. Equipment design features such as smooth surfaces, removable parts, and appropriate sealing mechanisms are emphasized to facilitate effective cleaning practices. Furthermore, maintenance activities should be carried out without introducing contamination risks. Proper equipment disassembly, cleaning procedures, and validation processes are implemented to ensure compliance with food safety standards.

- **Six Thinking Hats technique for a comparative analysis of RCM Implementation in the AQS and Soummam industry:**

This method provides fostering balanced perspectives and a comprehensive understanding through the consideration of different thinking styles that includes various aspects such as facts and information, emotions and intuitions, critical judgments, optimism and benefits, creativity and innovation, and an overview of the analysis. It also helps minimize biases, encourages creativity, and facilitates effective communication of valuable insights for well-informed decisions and optimizes maintenance strategies accordingly.

➢ **Facts & Information:**

- AQS operates with heavy and complex equipment which requires specialized maintenance knowledge and skills.
- Steelmaking involves high temperatures, mechanical stresses, and corrosive environments, leading to accelerated equipment degradation and challenges for maintenance.
- Soummam encompasses equipment that requires specific maintenance considerations.
- Food safety regulations demand strict adherence to maintenance practices to ensure hygienic production environments and prevent contamination.

➢ **Creativity & Innovation:**

- Integration of advanced technologies: Exploring the use of predictive maintenance technologies like vibration analysis, thermography, and remote monitoring for early fault detection.
- Leveraging data analytics and machine learning to identify patterns, predict failures, and optimize maintenance strategies.
- Exploring non-invasive monitoring methods like acoustic emissions or optical sensors to detect equipment anomalies in real-time.

➢ **Optimism and Benefits:**

- RCM implementation can identify critical failure modes, enabling proactive maintenance strategies that reduce unplanned downtime and enhance equipment reliability.
- Preventing catastrophic failures, optimizing maintenance schedules, and improving equipment lifespan can lead to significant cost savings over time.
- RCM helps identify critical control points and failure modes, ensuring proactive maintenance interventions to maintain product quality, integrity and safety.
- Optimized maintenance strategies minimize unplanned downtime, reduce equipment breakdowns, and enhance overall operational efficiency.

- **Critical Judgment:**

  - Implementing RCM in the AQS involves substantial upfront investment in training, specialized tools, condition monitoring systems, and maintenance resources.
  - Steelmaking equipment often requires specific spare parts, which may have long lead times or limited availability, potentially affecting maintenance turnaround time.
  - Implementing RCM in the Soummam industry requires planned downtime for maintenance activities, impacting production schedules and potentially causing supply chain disruptions.
  - Ensuring a competent maintenance workforce with expertise in both food processing equipment and RCM methodologies can be challenging.

- **Emotions and Intuition:**

  - Equipment failures in the steel industry can lead to significant financial losses, production delays, and safety hazards, heightening the emotional importance of reliable maintenance practices.
  - Resistance to change: Established maintenance practices and traditional mindsets may hinder the adoption of new approaches like RCM.
  - Consumer trust: Maintaining product quality and safety is crucial to preserve consumer confidence and reputation, making robust maintenance practices emotionally significant.
  - Time sensitivity: Equipment breakdowns can lead to perishable food waste, revenue loss, and potential health risks, adding urgency to maintenance decisions.

- **Overview and Conclusion:**

  - Implementing RCM in the AQS industry offers the potential for enhanced reliability, cost savings, and increased operational efficiency. However, challenges related to complex machinery, harsh operating conditions, cost implications, and resistance to change must be overcome.
  - In the Soummam industry, RCM can ensure product integrity, safety, and operational efficiency. However, considerations such as regulatory compliance, production interruptions, skills gaps, and maintaining consumer trust need to be addressed.
  - Successful RCM implementation in both industries requires a fitted approach that addresses industry-specific factors, engages stakeholders, and embraces innovation and technology.

Conclusion:

RCM implementation offers significant benefits to both the AQS and Soummam industries, including enhanced reliability, safety, product quality, and regulatory compliance. However, challenges related to complex machinery, resistance to change, cost implications, skills gaps, and consumer trust must be addressed for successful implementation. A tailored approach that considers industry-specific factors, engages stakeholders, and embraces innovation and technology is crucial for achieving optimal maintenance strategies in both sectors.

General Conclusion

RCM should be treated as a living process, it's important to review RCM analysis when circumstances that affect the equipment change, these changes may lead to a change of our expectations from this equipment, that's why failure data mining and DBN plays a central role in our proposed framework.

By calculating probabilities of different states for each variable within the model, the DBN facilitates the selection of the most suitable maintenance decision between CBM and PR. The results clearly demonstrate that CBM outperforms PR in maximizing the operational lifespan of the studied systems, showing a high probability of functioning and gradual degradation. Consequently, proposed solutions are implemented to proactively address critical failures.

It is important to acknowledge that there are persistent challenges to be addressed, including the absence of robust information management systems, human factors, and the need for further research on evaluating system reliability and implementing RCM applications using the DBN model. Overcoming these challenges necessitates ongoing efforts to achieve a more comprehensive and accurate implementation of this framework.

Our internship experience has provided valuable insights into the implementation of proposed frameworks into two different sectors. While we had intended to implement all suggested frameworks, the constraints of limited time hindered our ability to do so. It is important to note that the full impact of proactive strategies and their corresponding feedback often requires a longer-term perspective to fully manifest. Despite these limitations, our internship has contributed to our understanding of the potential benefits and challenges associated with the implementation of proactive strategies in real-world scenarios. Further research and exploration are warranted to explore the long-term effects and effectiveness of such strategies in various contexts.

To conclude, this thesis effectively demonstrates the efficacy of our proposed RCM framework using the DBN model to determine the optimal maintenance strategy. The findings establish a robust foundation for enhancing maintenance practices in relevant industries, underscoring the importance of ongoing research to achieve a more comprehensive and precise application of this promising approach.

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Appendix

1. AQS FMEA rating:

a. Severity Matrix:

Effect on	Criteria: severity of Effect	
Hazardous _ without warming	Very high severety ranking - Affects operator or maintenance personnel, safety and/or affects noncompliance with government regulations	10
Hazardous _ with warning	High severity ranking - Affects operator, or maintenance personnel, safety and /or affects non-compliance with government regulations	9
Very high downtime or Defective Parts	Downtime of more than 8 hours or defective parts loss more than 4 hours of production	8
High Downtime or Defective Parts	Downtime of 4 to 7 hours or defective parts loss of 2 to 4 hours of prodction	7
Moderate Downtime or Defective Parts	Downtime of 1 to 3 hours od defective parts loss of 1 to 2 hours of production	6
Low Downtime or Defective Parts	Downtime of 30 minutes to 1 hour or defective parts loss of up to 1 hour of production	5
Very low downtime _ No Defective Parts	Downtime up to 30 minutes _ no defective parts	4
Minor Effect	Process parameter variability **exceeds** Upper/Lower control limits. Adjustment or other process controls need to be taken - no defective parts	3
Very Minor Effect	Process parameter variability **within** Upper/Lower control limits. **Adjustment** or other process controls **need to be taken** - no defective parts	2
No Effect	Process parameter variability **within** Upper/Lower control limits, **adjustment** or other process controls **not needed to be taken** - no defective parts	1

a. Occurrence matrix:

Likelihood of Occurrence	Criteria: Possible Failure Rates / Mean Time Between Failure (MTBF)	
Extremely High	Intermittent operation resulting in 1 failure in 10, or MTBF is less than 1 hour	10
Very High	Intermittent operation resulting in 1 failure in 100 production pieces or MTBF of 2 to 10 hours	9
High	Intermittent operation resultinfg in 1 failure in 1000 production pieces or MTBF is of 11 to 100 hours	8
Average	Intermittent operation resultinf in 1 failure in 10,000 production pieces or MTBF of 101 to 400 hours	7
Moderate	MTBF of 401 to 1000 hours	6
Fair	MTBF of 1001 to 2000 hours	5
Mild	MTBF of 2001 to 3000 hours	4
Minor	MTBF of 3001 to 6000 hours	3
Low	MTBF of 6001 to 10,000 hours	2
Remote	MTBF more than 10,000 hours	1

b. Detection matrix:

Detection	Criteria: Likelihood of Detection by personnel or Machinery Controls	
Absolute Uncertainty	Machinery Controls CANNOT detect a potential cause and subsequent failure, or there is no Design or Machinery Control	10
Very Remote	Very remote chance a Design/Machinery Control will detect a potential cause subsequent failure mode	9
Remote	Remote chance a Design/Machinery Control will detect a potential cause and subsequent failure mode, and Machinery Control will prevent an imminent failure (e.g, stop machine)	8
Very Low	Intermittent operation resultinf in 1 failure in 10,000 production pieces or MTBF of 101 to 400 hours	7
Low	Low chance a Design/Machinery Control will detect a potential cause and subsequent failure mode and Machinery Control will prevent an imminent failure (e.g., stop machine)	6
Moderate	Moderate chance a Design/Machinery Control will detect a potential cause and subsequent failure modem and Machinery Control will prevent an imminent failure (e.g., stop machine) and isolate the cause	5
Moderately High	Moderatly High chance a Design/Machinery Control will detect a potential cause and subsequent failure mode and Machinery Control will prevent an imminent failure (e.g., stop machine) and isolate the cause. Machinery Control MAY be required	4
High	High chance a Design/Machinery Control will detect a potential cause and subsequent failure mode and Machinery Control will prevent an imminent failure (e.g., stop machine) and isolate the cause. Machinery Control MAY be required	3
Very High	Very High chance a Design/Machinery Control will detect a potential cause and subsequent failure mode. Machinery controls NOT required	2
Almost Certain	Design Controls will almost certainly detect a potential cause and subsequent failure mode. Machinery Controls NOT required	1

2.Soummam FMEA rating:

a. Severity matrix:

Effect	Severity criteria	Ranking
Minor	No significant repair duration (0-15 min) or min maintenance (SPR exploitation(consumables))	**1**
Low	Moderate-duration repair (15 min -1 hour) or maintenance (wear SPR).	**2**
Moderate	Requiring a long-duration intervention(1-4 hour).	**3**
High	Highly critical, requiring a major intervention(4-8 hours).	**4**
Hazardous	**Safety/Quality:** Personal/ Machine/ Food safety or very high repair duration (> 24h)	**5**

c. **Occurrence matrix:**

Probability of Failure Occurrence	Possible Failure Rates Criteria	Ranking
Remote: Failure unlikely	Almost non-existent failure on similar installations in operation (< 300 days)	**1**
Low: Relatively few failures	Rarely occurring failure on similar equipment in operation (< 30 days)	**2**
Moderate: Occasional failures	Occasionally occurring failure on similar equipment in operation (< 07 days)	**3**
High: Repeated failures	Moderately occurring failure on a known component or similar equipment in operation (< 24 hours)	**4**
Very high: Failure is almost inevitable.	Frequently occurring failure on a known component or similar equipment in operation (< 01 hours)	**5**

d. **Detection matrix:**

Detection	Likelihood of Detection	Ranking
Almost certain	The failure is immediately detected by integrated real-time monitoring systems (e.g., sensors), enabling prompt intervention to prevent severe effects.	**1**
High	Visual or audible alarms are triggered when precursor signs of failure are detected, alerting the operator who can take necessary measures to avoid production disruptions.	**2**
Moderate	A monitoring system detects the failure occurrence and generates an error message with production interruptions.	**3**
Low	The cause and/or mode of failure are difficult to detect, or the detection elements are not easily exploitable. Additional validation tests may be required.	**4**
Absolute uncertainty	There is no means to detect the failure before the effect occurs: this is the case of no detection.	**5**

Appendix

- **Trouble shooting motors (motor won't start)**

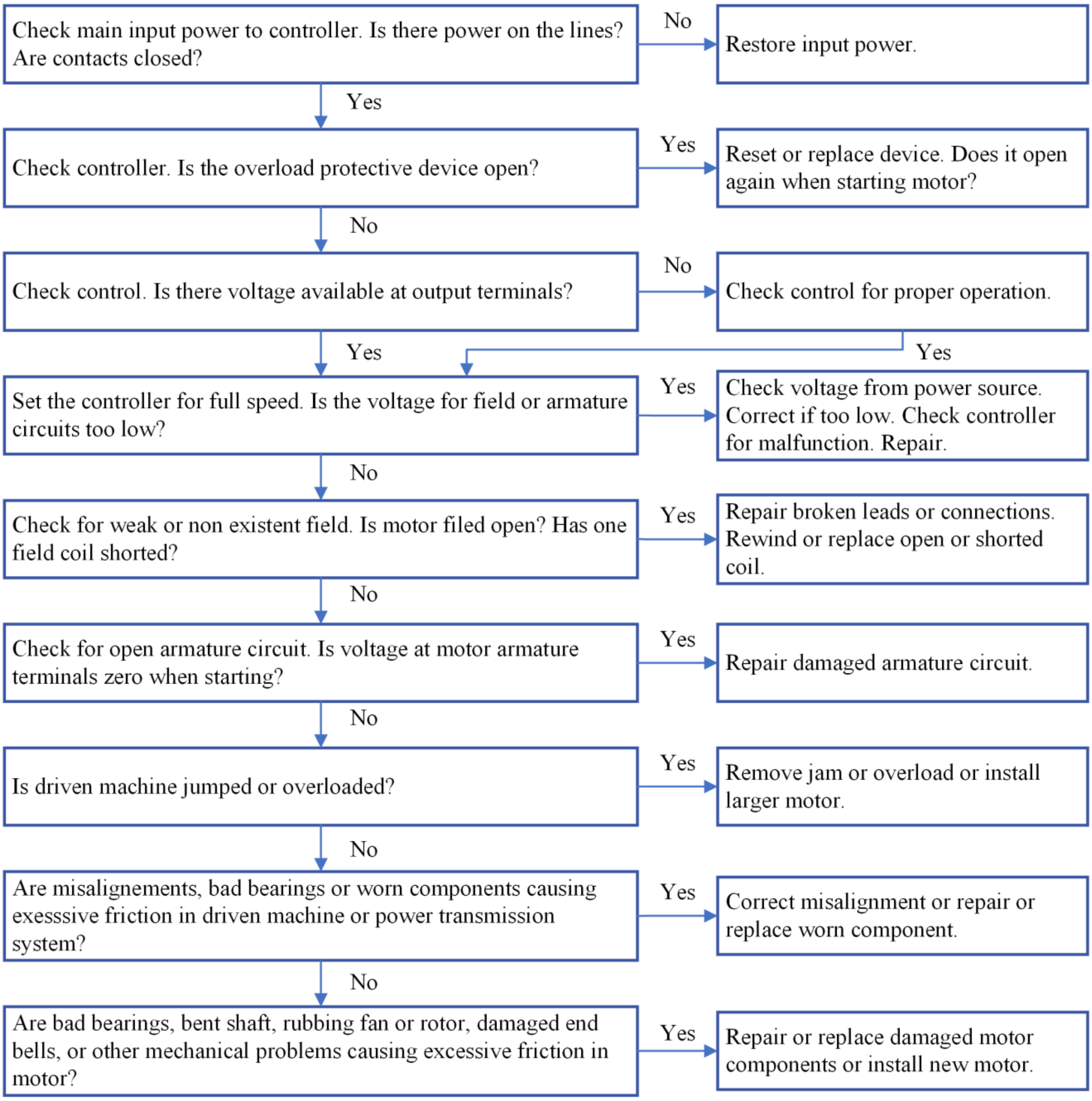

Figure 1: Trouble shooting for motor won't start

Abstract

This project aims to implement Reliability Centred Maintenance (RCM) in a smart and effective manner by integrating Dynamic Bayesian Network (DBN) modelling and prediction techniques. By analysing historical data and utilizing machine learning algorithms, a DBN model is trained to predict future system behaviour and estimate the likelihood of different states and outcomes. These predictions are then incorporated into the maintenance strategy to enable proactive measures, such as preventing failures, optimizing repair schedules, and minimizing downtime.

The objective is to develop an advanced maintenance strategy that acknowledges the multi-state nature of systems and leverages predictive analytics for improved decision-making. The project will demonstrate the effectiveness of this approach through two case studies conducted in different industries.

Key words: RCM, CBM, KPIs, MTBF, MTTR, FMEA, RCFA, DBN, prediction.

Résumé

Ce projet vise à mettre en œuvre la maintenance centrée sur la fiabilité (RCM) de manière intelligente et efficace en intégrant des techniques de modélisation et de prédiction basées sur les réseaux bayésiens dynamiques (DBN). En analysant les données historiques et en utilisant des algorithmes d'apprentissage automatique, un modèle DBN est entraîné pour prédire le comportement futur du système et estimer la probabilité de différents états et résultats. Ces prédictions sont ensuite intégrées dans la stratégie de maintenance afin de prendre des mesures proactives, telles que la prévention des pannes, l'optimisation des plannings de réparation et la réduction des temps d'arrêt.

L'objectif est de développer une stratégie de maintenance avancée qui reconnaît la nature multi-états des systèmes et exploite l'analyse prédictive pour améliorer la prise de décision. Le projet démontrera l'efficacité de cette approche à travers deux études de cas menées dans différentes industries.

Mots clés : Maintenance centrée sur la fiabilité, maintenance conditionnelle, MTBF, MTTR, AMDEC, analyse de la cause racine de la défaillance, approche bayésienne dynamique.

ملخص

بهدف تنفيذ صيانة مركزة على الموثوقية بطريقة ذكية وفعالة , يتم في هذا المشروع دمج تقنيات النمدجة و التنبؤ القائمة على الشبكة البيزية الديناميكية يتم ذالك من خلال تحليل البيانات التاريخية و استخدام خوارزميات التعلم الآلي, حيث يتم تدريب نموذج البايزن ناتورك على توقع سلوك النظام المستقبلي وتقدير احتمالية حدوث حالات ونتائج مختلفة تُدمج هذه التوقعات في استراتيجية الصيانة لتمكين التدابير الاستباقية، مثل منع الأعطال وتحسين جداول الإصلاح وتقليل وقت التوقف

المبتغى هو تطوير استراتيجية صيانة متقدمة تأخذ في الاعتبار الطبيعة المتعددة الحالة للأنظمة وتستفيد من التحليل التنبؤي لتحسين عملية اتخاذ القرار. سيتم توضيح فعالية هذا النهج من خلال دراستي حالة تنفذان في مصنعين من قطاعين مختلفين.

الكلمات المفتاحية: مؤشرات الأداء الرئيسية، متوسط الوقت بين الإخفاقات، متوسط وقت الإصلاح، الصيانة الشرطية، لصيانة التي تركز على الموثوقية، الشبكة البيزية الديناميكية، النمدجة و التنبؤ.