Hanieh Raeyatinezhad

Activities Within Maintenance Management

Master's thesis in Reliability, Availability, Maintainability, and Safety (RAMS)
Supervisor: Per Schjølberg
June 2023

Master's thesis

NTNU
Norwegian University of Science and Technology
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Department of Mechanical and Industrial Engineering

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Preface

The thesis is titled "Activities Within Maintenance Management" and it is a part of Reliability, Availability, Maintainability, and Safety (RAMS) program at NTNU. This thesis of TPK4950 will fulfil the need of 30 credits and finishing the master's degree.

This report examines Maintenance Management and it's Trends which is crucial to assuring the optimal performance, dependability, and durability of assets in a variety of industries. Maintenance management involves the systematic planning, organization, and control of maintenance activities to maximize equipment availability, minimize delay, and reduce operational costs. As industries continue to evolve and become more reliant on complex machinery and technology, maintenance management is also undertaking significant changes.

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Hanieh Raeyatinezhad

Acknowledgment

First and foremost, I would like to thank and express my deepest gratitude to my supervisor, Per Schjølberg, for his unwavering guidance, expertise, and continuous support throughout the entire process. His dedication to my academic growth, insightful feedback, and constructive criticism have played a pivotal role in shaping the outcome of this research.

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Furthermore, I express my gratitude to my family and friends for their constant encouragement, understanding, and patience during this demanding period. Their belief in my abilities has been a source of motivation and strength.

H.R.

Executive Summary

This thesis aims to explore the maintenance management trends and innovations that are shaping the future of maintenance practices. By examining these trends, we can obtain insight into the emerging strategies, technologies, and methods that are driving improvements in the effectiveness, efficiency, and sustainability of maintenance.

The report delves into several key trends, such as predictive maintenance, digitalization, condition-based monitoring, sustainability, and the incorporation of maintenance into asset management. These trends are transforming the manner in which maintenance is performed, transitioning from reactive to proactive and data-driven strategies. By adopting these trends, organizations can improve asset reliability, reduce unplanned downtime, optimize maintenance schedules, and enhance operational performance as a whole.

Furthermore, the report explores the effects of these trends on maintenance decision-making, resource allocation, and workforce development. It will emphasize the significance of leveraging data analytics, advanced technologies, and collaboration between maintenance teams and other stakeholders to achieve organizational goals.

This report serves as a comprehensive guide to understanding the trends shaping the future of maintenance, allowing organizations to make informed decisions, implement innovative strategies, and drive continuous improvement of maintenance operations.

For organizations seeking to optimize asset performance, minimize downtime, and ensure long-term sustainability, the study of maintenance management and its emerging trends is essential.

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Chapter 1

Introduction

1.1 Introduction

Contemporary manufacturing enterprises encounter increasingly strict demands related to the dependability of their production infrastructure and the need to ensure uninterrupted operations, free of any unscheduled downtimes. The task at hand may present challenges due to unforeseen circumstances that may arise during the operation of the equipment. A significant challenge arises from the heightened level of uncertainty surrounding production stoppages, and the need to effectively anticipate such threats with appropriate reserves of time. It is highly likely that disruptions in the optimal functioning of plants result in significant reductions in productivity, quality, and overall performance. These negative effects are noticeable and can have serious consequences. The mitigation of undesirable defects and failures in machines, as well as the reduction of their adverse effects, can be achieved through the implementation of appropriate maintenance actions within a production management system. Also, the modern industry's advancements in manufacturing processes, mechanization, computerization, and highly advanced technological devices have resulted in new challenges for maintenance engineers. Maintenance management involves a diverse array of tasks that are essential for guaranteeing this ideal functionality, dependability, and durability of assets within enterprises. The aforementioned activities entail a methodical approach to organizing, carrying out, and overseeing maintenance duties with the aim of optimizing equipment accessibility, reducing periods of inactivity, and managing maintenance expenses.

1.2 Objectives

The objective of studying maintenance management activities is to gain a thorough understanding of the principles, techniques, and best practices involved in administering maintenance operations within organizations. Another purpose is to equip individuals with the knowledge and abilities required to optimize asset performance, minimize downtime, control costs, ensure safety and compliance, drive continuous improvement, effectively utilize resources, and promote sustainability in maintenance operations.

1.3 Contribution

The study of maintenance management activities is a significant resource for individuals, particularly students, who are just starting out in the subject of reliability and maintenance. This topic provides essential knowledge and guidance also for businesses and people looking to build a solid basis for their maintenance strategy. By studying the principles, techniques, and best practices of maintenance management, individuals can acquire a thorough understanding of how to manage maintenance operations effectively. This knowledge is especially useful for students and newcomers who are just beginning to investigate the complexities of the field, as it equips them with the confidence to navigate the world of reliability and maintenance. This study can provide students with a solid foundation for their future endeavors. Students can develop a solid comprehension of maintenance principles by grasping the fundamental concepts and methodologies, enabling them to contribute effectively in industry roles and pursue further specialization in the field. This information serves as a springboard, enabling students to implement their learnings and make significant contributions to the field of reliability and maintenance.

In addition, the insights obtained from studying maintenance management activities can have a significant impact on businesses attempting to optimize their maintenance procedures. By applying the learned principles and strategies, organizations can improve asset performance, reduce costly disruptions, and maintain continuous operations. This knowledge can serve as a governing framework for businesses, equipping them with the tools required to establish a robust and effective maintenance strategy.

1.4 Limitations

Initially, I intended to collaborate with the DNV company in order to acquire required data necessary to my research. Unfortunately, after a month and a half of coordination, the company informed me that due to their policies, and of course my nationality, they are unable to provide me with the necessary sensitive data. This unanticipated occurrence had a significant impact on the development of my thesis, resulting in a significant loss of time during the initial phases. Due to the circumstances encountered, I was compelled to completely change the project and start again from the beginning. Given the resulting time constraints and challenges faced, I had limited opportunity to select a suitable new title as desired. It is important to note that the topic at hand is extensive and comprehensive, presenting difficulties in narrowing its scope effectively.

1.5 Outline

An overview of this thesis report can be seen as list below:

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Chapter 2

Maintenance and Income in Norway

2.1 Background

Norway has a strong economy and a high standard of living, which is supported by a number of different industrial sectors contributing to the country's income. Maintenance, which encompasses sectors including oil and gas, maritime, transportation, and infrastructure, is one substantial issue.

- **The oil and gas sector**: Norway is one of the major producers and exporters of oil and gas worldwide. The nation's offshore petroleum industry, which is predominantly based in the North Sea, has been a pillar of its economy for many years. The upkeep of drilling rigs, pipelines, refineries, and other associated equipment is a part of this sector's maintenance activities.

- **Maritime Industry**: Norway has a lengthy coastline and a long history in the nautical industry. The nation is renowned for its proficiency in offshore services, shipping, and shipbuilding. In the marine industry, maintenance includes fixing ships, maintaining offshore platforms, and doing other related tasks.

- **Transportation**: The road, rail, airport, and public transit systems in Norway are all very well-developed. To guarantee effective and secure transportation, these infrastructures must be operated and maintained. To sustain high standards and promote economic activity, the government makes investments in infrastructure maintenance.

- **Infrastructure**: Maintenance of Norway's infrastructure, which includes its buildings, bridges, tunnels, and utilities, is of utmost importance. Safety, usability, and sustainability are prioritized. Regular inspections, repairs, and infrastructure modernization are all included in maintenance operations.

In terms of income, Norway benefits from various sources:

- **Oil and Gas Revenue**: The income of Norway is largely derived from the oil and gas sector. One of the biggest sovereign wealth funds in the world was created by the government: the Government Pension Fund Global, also known as the Norwegian Oil Fund. In order to provide income for future generations, it invests excess oil and gas money in global markets.

- **Trade and Export**: Norway's economy is export-oriented, and its top exports are metals, chemicals, seafood, petroleum and petroleum products, natural gas, and equipment. These exports bring in money that goes into the national budget.

- **Services industry**: The services industry is very important to the economy of Norway. The generation of income is highly influenced by sectors including banking, information technology, consultancy, tourism, and healthcare. The country of Norway has a highly qualified workforce, which draws foreign investment and fosters economic expansion.

- **Public Sector**: A significant portion of Norway's income comes from taxes and levies collected by the government. These funds are used by the government to support welfare, healthcare, education, and infrastructure-building initiatives. It is noteworthy that Norway places a great emphasis on social welfare and equality in its approach to income distribution. A largely egalitarian society is ensured by the nation's high tax rates, which go toward funding public services and wealth redistribution initiatives.

2.2 The Relationship between Maintenance Trends and Maintenance and Income in Norway

Maintenance is a critical aspect of petroleum operations in Norway, a nation renowned for its substantial involvement in the oil and gas sector. Its significance lies in upholding safety, dependability, and effectiveness. The oil and gas industry has played a crucial role in driving Norway's economic growth and prosperity by generating substantial income. Maintenance procedures have undergone changes over the years due to advancements in technology and shifts in industry patterns. The emergence of digitalization, automation, and the Internet of Things (IoT) has led to maintenance procedures that are increasingly reliant on data and advanced technology. The adoption of predictive and condition-based maintenance strategies has been facilitated by this shift, whereby maintenance operations are executed in accordance with real-time data and equipment health monitoring. Incorporating these maintenance trends has the capacity to enhance operational efficiency, minimize downtime, and optimize resource allocation, resulting in cost reductions and heightened profitability. Through the utilization of cutting-edge technologies and sophisticated data analysis techniques, maintenance teams can proactively identify potential equipment malfunctions, optimize maintenance scheduling, and mitigate any adverse effects on production and profitability.

The correlation between Maintenance Trends and the influence of technological advancements and automation on maintenance practices and revenue in Norway is predicated on the acknowledgement that the adoption of novel technologies and the execution of contemporary maintenance methodologies can augment asset efficacy, enhance productivity, and ultimately bolster the comprehensive income generation and profitability of the Norwegian petroleum industry.

Furthermore, Norway's dedication to sustainability and environmental responsibility has resulted in the incorporation of ecologically-friendly maintenance techniques into its maintenance methodologies. The aforementioned statement is in line with the worldwide inclination towards sustainable maintenance, wherein entities strive to curtail energy consumption, optimize resource utilization, and mitigate the ecological ramifications of maintenance operations. The management of offshore installations and renewable energy infrastructure in Norway has played a significant role in the advancement of maintenance practices that prioritize the optimization of asset longevity and operational efficiency.

Moreover, the strict safety standards and regulations followed by Norway have had a significant impact on the increasing emphasis on safety in maintenance trends across the globe. Norwegian maintenance practices prioritize the implementation of safety barriers, risk assessments, and safety management systems as essential elements. These are consistent with the worldwide tendency to give precedence to safety in maintenance procedures in order to safeguard personnel, resources, and the adjacent ecosystem.

Chapter 3

Maintenance Trends

3.1 The Importance of Maintenance Trends in Today's Industry

The role of maintenance is of paramount importance in providing the dependable functioning and durability of equipment, infrastructure, and systems in diverse industries. Maintenance practices have undergone significant changes in recent times, owing to technological advancements, evolving customer demands, and the necessity for enhanced efficiency. The aforementioned advancements have given rise to various significant maintenance patterns that are altering the manner in which entities undertake maintenance operations. Presently, maintenance is perceived as a strategic undertaking that can enhance an organization's operations, rather than a reactive and financially burdensome function.

Contemporary maintenance practices emphasize the utilization of technology, data analytics, and inventive techniques to optimize the performance of assets, minimize downtime, and augment overall operational efficiency.

The trends in maintenance are subject to constant evolution in order to keep up to the dynamic demands of various industries. Current industry developments center around predictive maintenance, digital transformation, remote maintenance, augmented reality, sustainability, and autonomous maintenance. The aforementioned trends underscore the significance of utilizing technology, data, and inventive methodologies to maximize the performance of assets, minimize periods of inactivity, and augment overall operational efficacy. By keeping themselves updated with these trends, organizations can enhance their maintenance practices and attain a competitive advantage in their respective fields.

Businesses must maintain their competitiveness in order to maximize return on investment. Keeping costs under control will help businesses stay competitive. How then can maintenance managers perform maintenance that is affordable?

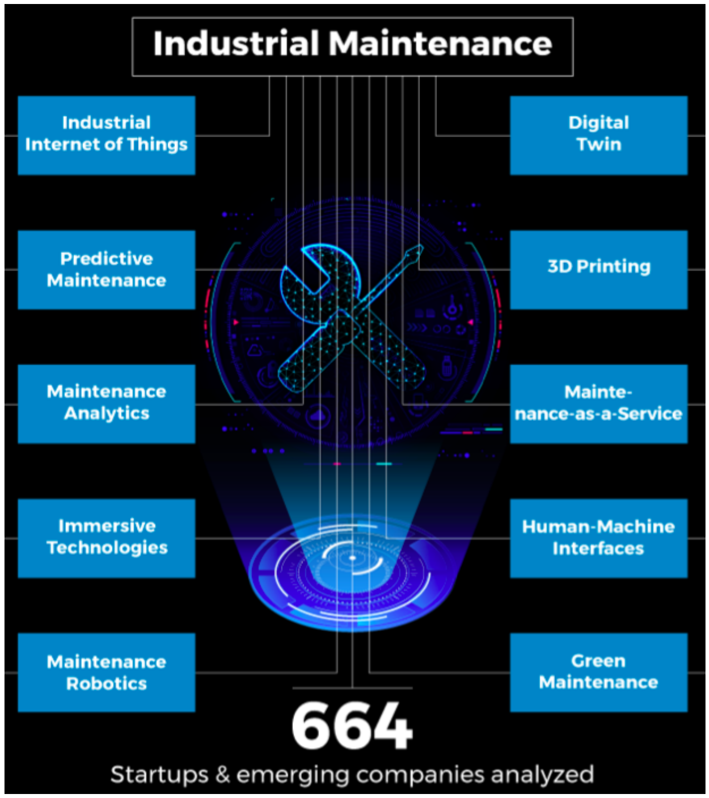

Figure 3.1: Industrial maintenance trends (StartUs Insights (2023))

3.2 Industrial Maintenance Trends in 2023

Industrial maintenance procedures have the potential to be more productive and cost-effective thanks to emerging technologies. It's vital to be informed of the industrial maintenance trends that are anticipated to have an impact throughout the year and beyond, as facilities face crucial decisions in 2023 to retain profitability. These cutting-edge strategies frequently result in process and margin gains that are exceptional and unforeseen. Maintenance trends that are likely to be significant lately based on current industry trends and predictions (Selcuk (2016)). Each trend delivers distinct advantages and developments that help to increase operational effectiveness, decrease downtime, optimize resources, and boost overall production. As is shown in figure 3.1 there are 10 top industrial maintenance trends explains as below that become the most significant trends in 2023 due to following reasons[1]:

- Technological Advancements: The influence of maintenance trends can be significantly affected by the evolution of technology and the accessibility of novel tools and solutions. The significance of maintenance trends may be influenced by advancements in domains such as data analytics, artificial intelligence, Internet of Things (IoT), or augmented reality,

[1]https://www.startus-insights.com/innovators-guide/industrial-maintenance-trends/

as these technologies offer novel prospects for enhancing optimization and efficiency.

- Industry-specific Challenges: Various sectors may encounter distinct obstacles that can amplify the importance of particular maintenance patterns. Industries that are involved in managing critical infrastructure, such as those related to energy or transportation, may give priority to the implementation of predictive maintenance strategies in order to reduce downtime and ensure consistent and dependable operations. Comprehending the particular requirements and obstacles of an industry can have an impact on the identification of the most noteworthy maintenance trends.

- Regulatory Requirements: The significance of maintenance trends can be influenced by regulatory standards and requirements. Industries that are bound by stringent environmental regulations may give precedence to maintenance practices that are centered on sustainability. Organizations may be motivated to adopt certain trends in order to ensure compliance with regulations and standards, thereby avoiding potential penalties.

- Economic Factors: The significance of maintenance trends can be influenced by economic conditions, market competition, and financial considerations. Organizations may give precedence to trends that present cost-saving prospects, enhanced efficiency, or competitive advantages that are in line with their financial goals and market requirements.

- Environmental and Social Responsibility: The rising significance of environmental sustainability and social responsibility is progressively influencing the priorities of businesses. The adoption of maintenance practices that prioritize energy efficiency, waste reduction, and sustainable measures may become increasingly important for organizations seeking to conform to societal expectations and exhibit their dedication to sustainable operations.

3.2.1 Predictive Maintenance

Predictive maintenance is a maintenance strategy that uses data from sensors, Internet of Things (IoT) devices, and other sources to predict when maintenance is needed before a failure occurs. By analyzing data such as temperature, vibration, and other metrics, predictive maintenance algorithms can identify patterns and anomalies that may indicate a potential problem. This allows maintenance teams to address the issue before it becomes a serious problem, reducing downtime and maintenance costs. It uses a variety of techniques to analyze data and make predictions. These techniques include machine learning algorithms, artificial intelligence (AI), and statistical models. The algorithms analyze historical data to identify patterns and predict future outcomes. The models use data from sensors and other sources to create a mathematical model of the equipment, which can be used to predict when maintenance is needed. Predictive maintenance can be applied to a wide range of equipment, including manufacturing equipment, Heating, Ventilation, and Air Conditioning (HVAC) systems, and vehicles. The benefits of predictive maintenance include reduced downtime, increased equipment lifespan, and lower maintenance costs. By identifying problems before they occur, predictive maintenance can also improve safety and reduce the risk of accidents. To implement predictive maintenance, organizations need to invest in the necessary sensors, IoT devices, and data analytics tools. They also need to collect and store data from these devices and analyze it using machine learning and other techniques. This requires a team of data scientists, maintenance engineers, and other specialists with expertise in predictive maintenance. However, the benefits of predictive maintenance can outweigh the costs, making it a valuable investment for many organizations. This trend is expected to continue in 2023, with the increasing use of machine learning algorithms and artificial intelligence to analyze data and predict maintenance needs (Artesis (2022)).

3.2.2 Digital Twins

Digitalisation of maintenance processes is expected to become even more widespread in 2023, with the increasing use of cloud-based systems, mobile apps, and other digital tools to manage maintenance activities. This will enable maintenance teams to work more efficiently and reduce downtime. It involves using digital tools and technologies to manage maintenance activities. This includes everything from scheduling and planning maintenance tasks to collecting and analyzing data from sensors and other sources.

One key aspect of digitalisation is the use of computerized maintenance management systems (CMMS). CMMS software enables maintenance teams to manage maintenance activities, including scheduling tasks, tracking work orders, and managing inventory. These systems can also provide real-time data on equipment performance, enabling maintenance teams to identify issues before they become serious problems.

In addition to CMMS, digitalisation also involves the use of other digital tools such as mobile apps and sensors. Mobile apps can provide technicians with access to real-time data and enable them to perform tasks such as entering data and updating work orders while in the field. Sensors can provide data on equipment performance, such as temperature, vibration, and other metrics, which can be used to predict maintenance needs and optimize maintenance schedules.

Cloud computing is also a key enabler of digitalisation in maintenance. By storing data in the cloud, maintenance teams can access it from anywhere, making it easier to collaborate and share information. Cloud-based systems can also provide real-time data analytics, enabling maintenance teams to identify trends and patterns that may indicate a potential problem.

The technology available today is not sufficiently sophisticated to keep track of the dynamic changes that arise in industrial processes and machinery. By building a virtual replica of genuine equipment, DIGITAL TWINS provides a remedy by enabling manufacturers to continuously monitor its actual operating conditions and envision potential future scenarios. Manufacturers can employ digital twins for predictive maintenance to identify abnormalities and trouble spots before they lead to equipment breakdown. Also, digital twins can model various scenarios to comprehend the risk factors that influence machine performance, resulting in more educated choices and doable plans to avoid serious issues (Artesis (2022)).

This technology can provide many benefits, including increased efficiency, reduced downtime, and lower maintenance costs. However, it requires investment in digital tools and technologies, as well as training for maintenance teams to ensure they are able to use these tools effectively.

3.2.3 Industrial Internet of Things, Wireless Sensor Networks and Automated Data Collection

Predictive maintenance will make greater use of the Internet of Things (IoT). Smart meters and other IoT gadgets, including sensors, can gather data on equipment performance in real-time. In order to schedule maintenance and identify potential issues before they arise, this information can then be utilized (Artesis (2022)).

To obtain maintenance insights and knowledge, it is necessary to accurately gather data on assets and equipment. Most of the time, maintenance data is gathered from a variety of sources, including various kinds of sensors (such as vibration, acoustic, and thermal imaging). Advanced algorithms and expert systems can later analyze this data.

Data collecting used to be a manual process that called for qualified individuals to physically access the equipment just a few years ago. With the rise of wireless sensor networks and the Internet of Things, this process is fundamentally changing. Access to low-cost, multi-purpose sensors and sensor networks, which may be connected to industrial machinery in a variety of ways, has increased recently. As a result, contemporary facilities frequently use hundreds of sensors to gather maintenance information. IoT also makes it possible to build smart sensor networks, particularly wireless sensor networks, which make it easier to gather sensor data automatically.

Automated data gathering eliminates the need for manual data collection techniques, which are frequently expensive, time-consuming, and prone to error. It also enables the close-to-the-source pre-processing of data. By streamlining the processes involved in data preparation and cleansing, this offers additional advantages. This method allows IoT devices for data collecting to effortlessly link with systems for data analytics, saving time and effort.

IoT-based automated data collection, which is a crucial component of digitizing the maintenance workforce, decreases the time required to acquire information and boosts worker efficiency.

Overall, IoT links different machines, sensors, and equipment to collect real-time data for monitoring and control, also it makes remote monitoring, predictive maintenance, better energy efficiency, and higher operational visibility possible by combining data from many sources, which boosts productivity and lowers costs.

3.2.4 Green Maintenance (Sustainability)

Green maintenance in industrial settings entails using environmentally friendly procedures to maintain tools and infrastructure. This involves using sustainable energy sources to run equipment and facilities, such as solar or wind power. To prevent waste and energy use, maintenance teams use methods like vibration analysis and thermal imaging to spot probable equipment problems. Startups are also concentrating on sustainable waste management techniques and the safe disposal of dangerous materials. Manufacturers do this by utilizing eco-friendly lubricants, implementing energy-efficient lighting, and setting up water conservation measures. By implementing these procedures, they can improve productivity and cut costs while also minimizing the environmental impact of industrial maintenance operations[2]. Industries might also reduce their carbon footprint, adhere to regulations, and accomplish long-term sustainability goals by implementing green maintenance techniques.

3.2.5 Augmented Reality (Immersive Technologies)

Augmented reality (AR) is a technology that overlays digital information onto the physical world. In 2023, we can expect to see more use of AR in maintenance, such as using AR-enabled glasses to provide technicians with real-time information and guidance on how to perform maintenance tasks. In the context of maintenance, AR can be used to enhance the maintenance process by providing technicians with real-time information and guidance on equipment repairs and maintenance tasks.

AR can be used in several ways in maintenance, including:

- Remote assistance: AR can be used to provide remote assistance to technicians. For example, a technician can use AR glasses or a mobile device to connect with an expert who can provide guidance on equipment repairs and maintenance tasks.
- Training: AR can be used to provide training to maintenance teams. By overlaying digital information onto real-world equipment, maintenance teams can learn how to perform maintenance tasks more effectively and efficiently.
- Maintenance guidance: AR can also be used to provide maintenance guidance to technicians. For example, AR can provide real-time information on equipment performance and suggest maintenance tasks based on the data.

[2]https://www.startus-insights.com/innovators-guide/industrial-maintenance-trends/

- Visualization: AR can also be used to visualize equipment in 3D, allowing technicians to see inside equipment and identify potential issues that may not be visible from the outside.

AR can provide several benefits in maintenance, such as improving troubleshooting, increase safety, reduced downtime and errors, and enhance overall maintenance efficiency. However, it requires investment in AR hardware and software, as well as training for maintenance teams to ensure they are able to use the technology effectively (Gibson (2022) and Prometheus Group (2022)). Additionally, AR technology is still developing, and there may be some limitations in terms of accuracy and reliability (Davis (2022))

3.2.6 Maintenance Analytics

Predictive maintenance programs that make use of predictive maintenance analytics can forecast equipment failures by analyzing unstructured data including sensor readings, historical records, and environmental factors. Startups and scale-ups are creating analytical tools to combine and cluster data in order to facilitate this. By analyzing trends in massive datasets, big data platforms can also increase the transparency of system health issues, enable accurate modeling, and facilitate effective forecasting. These solutions' data-driven forecasts can provide useful information for quicker turnaround times and more informed business decisions (Artesis (2022)). Hence, Data analysis methods are used in maintenance analytics to find patterns, improve maintenance plans, and obtain insights into asset performance. Organizations can foresee failures, manage maintenance schedules, and increase asset reliability by studying historical data and real-time information.

3.2.7 Maintenance-as-a-Service

Large amounts of maintenance data can be gathered and processed on the cloud, which can improve maintenance services and capabilities. These services, which are increasingly offered for certain apparatus or equipment, consist of:

- Estimating a product's lifespan or giving advice on when to perform maintenance is ideal.

- Delivering context-sensitive service maintenance information, including guides, videos, virtual reality representations, and interactive support.

- Adjusting plant information technology (IT) and business information systems (such as asset management and enterprise resource planning [ERP] systems) in light of the investigation' findings.

- Supplying comprehensive statistics and reports on the machine's performance.

When and where these services are required, they can all be provided on-demand. "Maintenance-as-a-Service" is a brand-new paradigm for industrial maintenance that results from this. According to this paradigm, the equipment vendor can bill the plant operator based on how often maintenance services are actually used, as opposed to charging a set service cost for the equipment. "Maintenance-as-a-Service" (MaaS) has the potential to revolutionize industrial maintenance. It might inspire equipment suppliers to deliver the greatest support while also offering adaptable, dependable, and useful machinery. The revenue from maintenance services will probably rise in the future. It should be noted that MaaS involves merging equipment maintenance with a wider range of client services. IT suppliers (like Microsoft) are integrating maintenance operations with their CRM (Customer Relationship Management) and service platforms in this direction. Equipment suppliers currently offer early MaaS functionality. ThyssenKrupp Elevators, as an illustration, include a proactive maintenance program that foresees maintenance issues before they arise and alerts maintenance engineers accordingly. MaaS are probably going to include consumer products and goods as well. For instance, the German automaker BMW has already announced plans to provide MaaS systems that will inform car owners of the ideal times to do maintenance, repair, and service tasks on their vehicles (Prometheus Group (2022)). So, this method allows businesses to concentrate on their core strengths while assuring effective and trustworthy maintenance support. It also offers flexibility, cost savings, access to expert knowledge, and scalability.

3.2.8 Maintenance Robotics

The use of robots and automated systems to carry out maintenance duties is known as maintenance robotics. These robots are created and programmed to carry out particular maintenance tasks, like checks, fixes, cleaning, and data collection, with little assistance from humans. Robots are faster and more reliable than people in performing maintenance chores, which increases output and decreases downtime. They are able to labor nonstop and accurately do repetitious jobs. They also, can be used in potentially dangerous settings where human workers would be at risk. They can work in places with high temperatures, hazardous gases, or small spaces, exposing people to hazardous situations less. Maintenance robots are designed to carry out duties with extreme accuracy, reducing human error and raising the standard of maintenance work. They are more accurate than human hands and are able to reach difficult-to-reach places and carry out complex tasks. Although maintenance robotics may need a considerable initial investment, there may be significant long-term cost reductions. Moreover, robots may streamline maintenance schedules, cut labor costs, avoid expensive human errors, and increase productivity, all of which will result in lower maintenance costs. To gather information about asset performance, condition, and possible problems, maintenance robots can be fitted with sensors and cameras. Furthermore, to support proactive and predictive maintenance techniques, this data can be examined to find anomalies, forecast breakdowns, and improve maintenance plans. Finally, some maintenance robots may be controlled and monitored remotely, enabling professionals to manage the maintenance tasks from a central location. Even in far separated sites, this capability provides effective troubleshooting, remote help, and knowledge sharing. Robotic arms for precise repairs and replacements, autonomous vehicles for maintenance work in huge buildings or outdoors, and drones for aerial inspections of structures and pipelines are a few examples of maintenance robots. Accordingly, maintenance robotics is an emerging trend that uses automation, artificial intelligence, and robotics technology to modernize maintenance processes. It is a vital addition to contemporary industrial maintenance plans due to its many benefits, which include increased efficiency, safety, accuracy, and cost-effectiveness.

3.2.9 Human-Machine Interfaces

The technologies and systems that allow for communication and interaction between humans and machines are referred to as human-machine interfaces (HMI) in the maintenance industry. HMI significantly improves usability, accessibility, and overall user experience, which enhances maintenance operations. HMIs are implemented in factories and manufacturing facilities using a variety of tools, including specialized control panels, touchscreen displays, and mobile devices. To assist operators in managing and monitoring equipment performance, they include alarms, notifications, and data logging. HMIs increase the speed and accuracy of industrial maintenance through the provision of real-time data and diagnostic information. Additionally, the combination of cloud-based HMIs, AI, and machine language (ML) offers operators advice and insights that can be put into practice. This makes it possible to collaborate in real-time, share data among many users, and do remote maintenance[3].

HMI attempts to make interaction between people and machines as simple as possible by offering user-friendly interfaces. This includes functionalities like touchscreens, intuitive menus, iconography, and graphical user interfaces (GUIs). User-friendly interfaces save maintenance staff training periods and increase efficiency. It also enables maintenance specialists to display real-time data, including asset performance, status, alarms, and maintenance logs. Data can be shown as graphs, charts, and other visual indicators, allowing for quick and simple analysis of the data. This supports preventative maintenance methods by assisting in the identification of problems, trends, and anomalies. It makes it possible to remotely monitor and operate machinery and processes for maintenance. Maintenance teams can access and monitor assets using HMI systems from a centralized control center or via mobile devices. Real-time data collecting, analysis, and decision-making are made possible via remote monitoring, which boosts operational effectiveness and speeds up response times. HMI offers alarm and notification systems to

[3] https://www.startus-insights.com/innovators-guide/industrial-maintenance-trends/

inform maintenance staff of urgent situations or equipment failures. These alarms may be audible, visible, or even transmitted to mobile devices as notifications. By using HMI, can be ensure that maintenance specialists are quickly alerted about problems that need to be fixed, enabling early intervention and minimizing downtime. Enterprise asset management (EAM) software, maintenance management systems (MMS), and data analytics platforms are a few examples of other systems that HMI systems can integrate with. The seamless data exchange made possible by this interface gives maintenance staff extensive information and supports data-driven decision-making. HMI might be able to go beyond conventional interfaces and can be used in mobile and tablet devices as well as wearable gadgets like smart glasses or augmented reality (AR) headsets. Hands-free information access, remote help, and improved teamwork are all made possible by mobile and wearable interfaces. Maintenance employees may communicate with machines and systems thanks to speech and gesture recognition technologies that HMI can contain. Voice and gesture interfaces let users engage with maintenance equipment hands-free and more naturally, which boosts usability and productivity.

The target of HMI in maintenance is to streamline and simplify human-machine interface, enabling maintenance specialists to effectively monitor, control, and troubleshoot equipment. HMI boosts productivity, lowers errors, and increases overall maintenance effectiveness by offering user-friendly interfaces, real-time data visualization, remote monitoring capabilities, and seamless integration.

3.2.10 3D Printing

Additive manufacturing, also known as 3D printing, makes it possible to produce bespoke items fast and affordably. Startups are creating high-performance components that can resist high stress and harsh environments using materials like carbon fiber-reinforced plastics. In order to improve maintenance procedures and save downtime, this also leads to the integration of 3D printing with other maintenance technology, such as drones and sensors. Lead times and inventory costs are also decreased by on-demand replacement parts fabrication. By eliminating the need for costly downtimes and transportation for on-site emergency repairs, portable 3D printers additionally assist on-demand production[4]. By swiftly producing necessary parts or components as needed via 3D printing, maintenance teams may do away with the lengthy lead times associated with conventional manufacturing techniques. The downtime of the equipment is decreased and repairs can be completed more quickly. Complex and personalized geometries that could be difficult or expensive to build using conventional manufacturing techniques can be created with 3D printing. As a result, performance and functionality are improved. Maintenance experts can design and manufacture parts specifically adapted to their individual requirements. Employing 3D printing for maintenance enables businesses to do away with the

[4] https://www.startus-insights.com/innovators-guide/industrial-maintenance-trends/

requirement for enormous spare part inventories. Instead, they can save money on storage and reduce the risk of redundant or obsolete inventory by storing digital blueprints and manufacturing the needed parts when needed. 3D printing offers a practical alternative for sustaining legacy gear in sectors where technology is soon out of date. Maintenance teams can make replicas of original replacement parts using 3D printing to ensure continued operation and increase the lifespan of current assets when they become scarce or expensive. In order to evaluate the fit, form, and functionality of parts or components before mass manufacturing, maintenance teams can quickly prototype them using 3D printing. This iterative method aids in design improvement and lowers the possibility of mistakes occurring during actual manufacturing. By utilizing materials more effectively, 3D printing makes it possible to produce structures that are lightweight and have optimum designs. As a result, maintenance operations may use less energy, perform better, and cost less money. It is now possible to remotely communicate digital designs to 3D printers that are situated in various locations thanks to developments in connectivity and digital communication. With the use of this capability, maintenance crews can access 3D printing facilities anywhere, saving money and time on traveling. Distributed manufacturing is also made possible. While 3D printing in maintenance trends has many benefits, it's crucial to remember that not all parts or components can be printed using this technology. The viability of using 3D printing in maintenance operations should be evaluated in light of elements like material qualities, size, complexity, and structural requirements. Using this technology provides maintenance professionals with a cost-effective and efficient solution for producing spare parts and components, reducing downtime, and enabling customization. It is a valuable trend that offers increased flexibility, agility, and sustainability in maintenance practices.

3.3 Impact of the Top 10 Maintenance Trends on Industrial Maintenance

The figure 3.2 presented depicts the effects of the Top 10 Industrial Maintenance Trends projected for the year 2023. Startups and scaleups utilize Industrial Internet of Things (IIoT), predictive and preventive maintenance, and advanced analytics to proactively address potential malfunctions. In addition, corporations create maintenance analytics and human-machine interface (HMI) systems to facilitate data-driven maintenance in industrial facilities and production plants. The utilization of robotics-based automation facilitates the optimization of maintenance operations and enhances the provision of maintenance services as a service. Finally, the implementation of digital twins and immersive technologies enhances the visualization of data and facilitates worker training, whereas the adoption of green maintenance practices enhances the sustainability of maintenance operations (StartUs Insights (2023)). The significance of industrial maintenance trends lies in their ability to augment operational efficiency, curtail

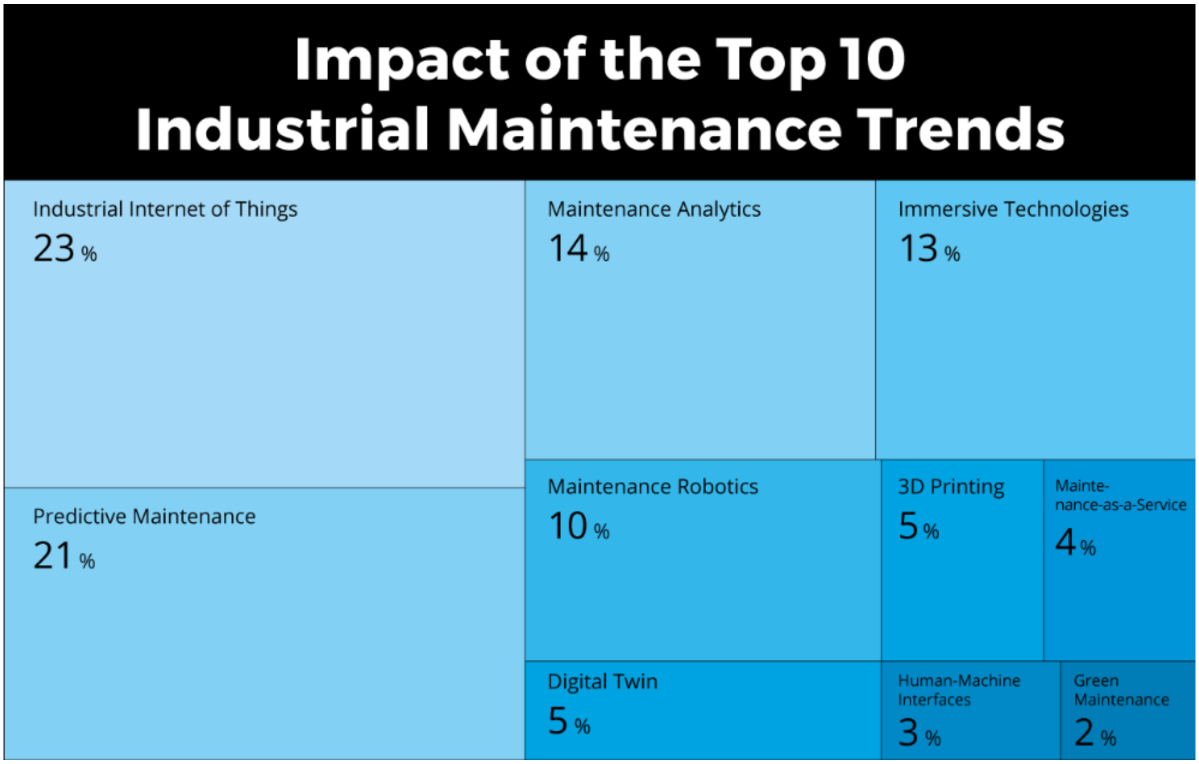

Figure 3.2: Impact of the top 10 industrial maintenance trends (StartUs Insights (2023))

expenses, enhance asset dependability, optimize resource allocation, and promote sustainable practices. By embracing these emerging patterns, enterprises can attain a strategic advantage in the ever-changing and developing industrial milieu.

3.4 Risk Level in Norwegian Petroleum Operations (RNNP)

To maintain security and environmental protection, Norwegian petroleum operations are subject to extensive risk management procedures. To reduce and manage the many hazards associated with offshore oil and gas exploration, production, and transportation, the Norwegian petroleum industry has put in place strong regulations and standards.[5]

- **Safety Risks**: The petroleum sector places a high priority on safety. To control and supervise safety in petroleum-related activities, Norway established the Petroleum Safety Authority (PSA). Before beginning operations, businesses that operate in Norwegian seas must submit safety plans and follow stringent safety standards. To prevent accidents, safeguard employees, and reduce the danger of catastrophes like well blowouts, fires, or explosions, stringent safety protocols, training programs, and emergency response procedures are in place.

[5] https://www.rnnp.no/sporreskjema/

- **Environmental Risks**: Norway places a high priority on defending its marine environment from any threats brought on by petrochemical operations. To make sure environmental laws are respected, the Norwegian Environment Agency works with the Norwegian Petroleum Directorate. There are strict controls in place to manage waste disposal, reduce pollutants, and avoid oil spills. Companies must comply with stringent drilling and production regulations, conduct environmental impact assessments, and use cutting-edge technologies for spill response and recovery.

- **Technical Risks**: Technological hazards: Since offshore activities are so complicated, there are technical risks linked to petroleum exploration, drilling, production, and transportation. A comprehensive regulatory system has been put in place in Norway to handle these issues. Through meticulous planning, risk analyses, and technical evaluations, businesses must prove the technical viability and safety of their operations. The integrity of facilities is ensured and technical failures are minimized by strict regulations for equipment, maintenance, and routine inspections.

- **Financial Risks**: Significant financial risks are associated with the petroleum industry's investments in exploration, production expenses, fluctuating oil prices, and operational uncertainty. Financial rules and requirements, such as license fees, tax duties, and decommissioning provisions, apply to businesses operating in Norway. With the help of these measures, the sector will be able to meet its financial responsibilities in the future, including well plugging and facility decommissioning.

Norway uses a cooperative strategy with industry operators, regulators, and stakeholders to effectively control these risks. To monitor compliance and find possible areas for improvement, the authorities regularly undertake inspections, audits, and risk assessments. To continuously improve safety and risk management standards, the regulatory framework also incorporates best practices from other countries and lessons acquired from incidents. In order to assure the safe and environmentally responsible exploration and production of oil and gas resources, Norway's approach to petroleum activities stresses the precautionary principle, strict restrictions, and ongoing improvement.

What is Trends in risk level in the petroleum activity (RNNP)? Since 1999, the RNNP approach has been used to track the progression of risk in Norway's oil and gas sector. The RNNP project covers both danger to persons and risk of acute discharges with the goal of generating a more comprehensive picture of accident risk. This work helps businesses, unions, and the government have a better shared knowledge of trends in risk level.

Two complementary techniques, including a quantitative tool based on incident, barrier test, and maintenance data, are used to measure trends in risk level. The alternative strategy makes use of social science analyses based on questionnaire-based research, fieldwork, interviews, and other investigations. In the end, the goal is to portray risk in a comprehensive manner that is as nuanced as feasible.

The Quantitative Section

In the quantitative section of the RNNP study, defined circumstances of hazards and accidents (DSHAs), findings from barrier testing, and maintenance data take center stage. Information on the amount of activity, including working hours, locations, wells, production volumes can also be collected in order to normalize the data.

To improve the quantitative picture of health, safety and environment (HSE) and risk, and to look deeper into the many causes of these problems, the RNNP survey can be conducted as qualitative study. We can access how different parties have interpreted the state of HSE thanks to the qualitative methodology.

Three key objectives of the survey are:

1. Describe the HSE circumstances that employees encounter in their job and point out factors that are important for variances in the work environments.
2. Provide light on underlying issues that may assist to explain other RNNP survey results.
3. It also reveals changes over time on how employees perceive HSE conditions in their own workplaces.

Scope

The description of the risk level on the Norwegian continental shelf (NCS) can be divided into the following main subjects:

- Major accidents
- Work accidents
- Working environment factors
- Acute discharges

Work on the RNNP is confined to conditions which fall within our area of authority.

Incidents

The RNNP analysis includes data on occurrences as a significant component. The businesses are required by HSE requirements to report all hazards and incidents to PSA, broken down by several DSHAs.

What are DSHAs?

The RNNP's base data includes defined hazard and accident situations (DSHAs), which are an important component. They are described as a group of potentially visible incidents that the corporations must protect themselves from in order to conduct sensible petroleum operations. They encompass events like personal injuries and work-related illnesses as well as other occurrences like hydrocarbon spills and well control issues, which have the potential to cause significant accidents.

In the quantitative section of the RNNP study, defined circumstances of hazards and accidents (DSHAs), findings from barrier testing, and maintenance data take center stage. Information on the amount of activity, including working hours, locations, wells, production volumes, and helicopter transport, can also be collected in order to normalize the data.

Personal injuries

Serious personal injuries are another key area for the RNNP. The businesses categorize them as fatalities, severe injuries, and instances involving lost time or medical treatment. All reported injuries are being reviewed and assessed based on their seriousness. The serious ones are the main concern in the RNNP.

3.5 RNNP and European Regulations

Due to Norway's adherence to international safety standards and its inclusion into the European Economic Area (EEA), the risk level in Norwegian petroleum activities is intimately tied to European rules and standards in maintenance. Firstly, Norway is a member of the European Economic Area (EEA), which guarantees the free flow of capital, labor, products, and people between Norway and other EEA EFTA (European Free Trade Association) nations. As a member of the EEA, Norway is in compliance with all EU laws and standards, including those governing upkeep in the petroleum sector. Secondly, the European Union has put in place directives and rules that give numerous businesses, notably the petroleum industry, a framework for safety and risk management. These rules frequently address matters like worker safety, environmental protection, equipment safety, and maintenance procedures. These EU directives and rules are incorporated into Norwegian law as an EEA member and put into effect. Thirdly, safety, emergency preparedness, and the working environment in the Norwegian petroleum industry are all under the control of the Norwegian Petroleum Safety Authority (PSA). The Norwegian Petroleum Act, which integrates EU rules and standards, governs how the PSA operates. This comprises specifications for upkeep procedures designed to guarantee the security and reliability of offshore installations and facilities. Furthermore, the Norwegian petroleum industry created the

NORSOK (Norwegian Continental Shelf) set of standards to define technical criteria and norms. These guidelines cover a range of petroleum operations topics, such as asset integrity and maintenance. NORSOK standards are widely accepted in the Norwegian business, even though they are not legally enforceable. They frequently coincide with European laws and industry best practices. And finally, Norway, like other countries, also adopts and implements international standards related to maintenance and risk management. For example, standards developed by organizations such as the International Organization for Standardization (ISO) and the International Electrotechnical Commission (IEC) are considered when establishing maintenance practices in the petroleum industry. Norway makes sure that its maintenance processes in the petroleum sector adhere to the necessary safety requirements by aligning with European rules, adopting EU directives, adhering to NORSOK norms, and taking into account global standards. Through effective risk management, high levels of safety, and environmental preservation, this alignment supports Norwegian petroleum activities.

3.6 Some Other European Regulations and Standards Related to Maintenance

In Europe, there are several regulations related to maintenance, which aim to ensure safety, environmental protection, and efficiency. Here are some of the most important regulations related to maintenance in Europe (The European Parliament and the Council of the European Union (2014)):

1. European Union's Machinery Directive (OSHA (2021)): This directive sets out the requirements for the design, manufacture, and maintenance of machinery in the European Union. It requires that machinery be designed and manufactured in a way that ensures its safety and that maintenance procedures be established to ensure continued safety and performance.

2. European Union's Pressure Equipment Directive (OSHA (2014)): This directive sets out the requirements for the design, manufacture, and maintenance of pressure equipment in the European Union. It requires that pressure equipment be designed and manufactured in a way that ensures its safety and that maintenance procedures be established to ensure continued safety and performance.

3. European Union's Waste Electrical and Electronic Equipment Directive (OSHA (2012a)): This directive sets out the requirements for the collection, treatment, recycling, and disposal of waste electrical and electronic equipment (WEEE) in the European Union. It requires that manufacturers ensure that WEEE is designed for easy maintenance, repair, and

upgrading.

4. European Union's Energy Efficiency Directive (OSHA (2012b)): This directive sets out the requirements for improving energy efficiency in the European Union. It requires that member states establish energy audits and energy management systems to identify energy-saving opportunities, including in maintenance processes.

5. European Union's REACH Regulation (OSHA (2023)): This regulation sets out the requirements for the registration, evaluation, authorization, and restriction of chemicals in the European Union. It requires that manufacturers and importers of chemicals provide information on the safe use, handling, and disposal of their products, including maintenance procedures.

These regulations aim to ensure that maintenance activities are carried out safely, efficiently, and with minimal impact on the environment (European Commission (2018)) . They require manufacturers and operators to establish maintenance procedures that ensure the safety and performance of equipment and to design products that are easy to maintain and repair (Andersson (2016) and OSHA (2021)).

Chapter 4

Sustainability

The significance of sustainability in maintenance lies in its ability to reduce environmental impact, optimize cost efficiency, preserve resources, augment safety and reliability, guarantee adherence to regulations, and fulfill social obligations. Through the implementation of sustainable practices, organizations have the potential to generate a favorable influence on the environment, society, and their own sustained profitability. The sustainability of systems, infrastructure, and organizations is significantly influenced by maintenance activities. Promoting sustainability in maintenance involves a holistic approach that considers the environmental impact of maintenance activities at each stage of the equipment lifecycle. By implementing sustainable practices, maintenance teams can reduce their environmental footprint while still maintaining the performance and reliability of equipment.

4.1 Contribution of Sustainability in Maintenance

Sustainability encourages asset lifetime, energy efficiency, waste reduction, environmental impact reduction, water conservation, life cycle thinking, and staff engagement. These factors all help with maintenance. Organizations can obtain long-term economic, environmental, and social benefits by incorporating sustainable practices into maintenance operations. There are several significant ways that sustainability affects maintenance:

Extended Equipment Lifespan: In order to ensure that equipment is routinely inspected, maintained, and repaired, sustainable maintenance practices emphasize preventative and predictive maintenance methods. Sustainability attempts to increase asset longevity by proactively resolving problems and keeping machinery in top shape. As a result, there will be less need for premature replacement and less environmental damage from producing new equipment.

Energy-Efficiency: Energy-efficient procedures are emphasized in sustainable maintenance. Maintenance staff can locate potential for energy savings by putting in place energy management systems, optimizing equipment settings, and performing energy audits. This can involve changing the lighting settings, improving the HVAC system, and utilizing energy-saving motors and machinery. Energy-efficient maintenance techniques limit greenhouse gas emissions while simultaneously lowering operating expenses and energy usage.

Waste Reduction: The goal of sustainable maintenance is to encourage recycling and reuse while reducing trash output. Maintenance teams can lower the amount of garbage transported to landfills by implementing procedures such efficient waste segregation, recycling initiatives, and component reconditioning. Recycling offers the possibility of generating income in addition to helping the environment and saving money by reducing the cost of garbage disposal.

Environmental Impact Reduction: Sustainability in maintenance is choosing supplies, goods, and machinery that have less of an impact on the environment. This include selecting less damaging to the environment lubricants, paints, and cleaning products. Sustainable maintenance techniques also promote proper hazardous waste disposal and adherence to environmental laws, preventing contamination and safeguarding ecosystems.

Water-Conservation: Water is frequently used in maintenance tasks like cleaning, cooling, and irrigation. Through techniques including leak detection and repair, water recycling systems, and the use of water-efficient equipment, sustainable maintenance aims to reduce water use. Conserving water eases the burden on nearby water supplies and ensures its availability for future generations.

Life Cycle Assessment: Sustainable maintenance takes into account an asset's whole life cycle, from acquisition through disposal. Organizations can evaluate the environmental impact of various maintenance practices and make wise decisions by conducting life cycle evaluations. This involves taking into account variables including energy consumption, greenhouse gas emissions, resource use, and trash generation over the course of an asset's life cycle.

Employee Engagement and Well-being: Maintenance employees must be empowered to participate in sustainability projects as part of sustainable maintenance practices. Organizations can promote a culture of environmental responsibility among their workforce by offering training and instruction on sustainable practices. Participating in sustainability initiatives can improve employee morale, foster a feeling of purpose, and foster a positive work environment.

4.2 Maintenance Trends and Sustainability in Future

Strong and mutually advantageous future connections between sustainability and maintenance trends are anticipated. The maintenance practices of businesses and industries worldwide will be vital to the success of sustainable development initiatives. Some thoughts on the relationship between sustainability and current maintenance trends are as follows.

Sustainability goals include cutting down on energy use and having less of an effect on the planet. Regular equipment inspections, parameter optimization, and proactive maintenance to prevent energy waste are all examples of maintenance practices that can greatly contribute to sustainability initiatives. Preventative maintenance helps reduce energy consumption and carbon emissions by keeping machinery running smoothly.

The use of renewable energy systems is an important part of achieving sustainability. The need of preventative maintenance for renewable energy infrastructure, such as wind turbines, solar panels, and hydropower plants, is growing. The optimal performance and prolonged life of renewable energy infrastructure is dependent on current maintenance practices adapting to meet the specific challenges and requirements of these systems as they become more widespread.

Sustainable maintenance practices advocate for a lifespan perspective, rather than the traditional "fix it when it breaks" mentality. This involves thinking about environmental impact at every stage of an asset's lifecycle (from conception to decommissioning). Sustainability goals are aided by maintenance routines that reduce equipment breakdowns, foster circular economy principles (such reusing and recycling components), and give preference to adopting environmentally friendly materials and methods.

Compliance with Environmental Regulations and Standards Maintenance practices will become more in line with regulations and standards designed to lessen their negative effects on the environment. Integrating emission control, waste management, and safe handling of hazardous materials, as well as other environmental standards, into routine maintenance procedures is a priority. This guarantees that equipment reliability is maintained alongside environmental sustainability standards.

Decisions based on empirical evidence: sustainable practices are made possible by the widespread adoption of digital technologies and data analytics in the maintenance industry. By analyzing data in real time, predictive maintenance helps find problems with machines before they happen, which cuts down on unplanned downtime and maximizes efficiency. This preventative method helps to lessen negative effects on the environment, boost operational efficiency, and promote responsible resource management.

Energy efficiency, renewable energy systems, lifecycle thinking, environmental compliance, and data-driven decision making are just some of the techniques that will strengthen the bond between sustainability and maintenance in the years to come. Organizations can improve their operational effectiveness while also making a positive impact on the world around them by adopting sustainable maintenance practices.

4.3 Sustainability and Society 5.0

Sustainability and Society 5.0 are related ideas with the same overarching objective of building a better future for society. Society 5.0 is a more expansive vision of a human-centered, technologically advanced society, whereas sustainability focuses on environmental and social responsibility. The connection between sustainability and Society 5.0 is as follows:

Sustainable Development: One of the guiding principles of Society 5.0 is sustainability. By balancing economic growth with environmental protection, social well-being, and environmental preservation, Society 5.0 aims to achieve sustainable development. It highlights the importance of using sustainable practices and cutting-edge technologies to address urgent global issues including climate change, resource depletion, and social inequity.

Technological Solutions: To build a society that is inclusive and sustainable, Society 5.0 uses cutting-edge technologies including artificial intelligence, the Internet of Things, robotics, and big data. These technologies can be used to create ground-breaking solutions in a variety of fields, including resource management, renewable energy, and sustainable transportation. Society 5.0 aspires to develop a harmonious interaction between society and the environment by using technology for sustainable reasons.

Quality of Life: Society 5.0 envisions a diverse society that enhances everyone's quality of life. In order to ensure that social and environmental aspects are taken into account, sustainability is essential to this objective. Society 5.0 wants to improve people's health and happiness by supporting sustainable practices like clean energy, effective infrastructure, sustainable agriculture, and equal access to resources.

Collaboration and Participation: Both sustainability and Society 5.0 recognize the importance of collaboration and active participation of various stakeholders. Achieving a sustainable and human-centered society requires the involvement of governments, businesses, academia, communities, and individuals. It entails fostering partnerships, knowledge sharing, and collective action to address sustainability challenges and co-create solutions that benefit society as a whole.

Ethical Considerations: Society 5.0 places a strong emphasis on ethical considerations in the development and deployment of technology. Sustainability aligns with this principle by promoting ethical and responsible practices that prioritize the long-term well-being of the planet and its inhabitants. This includes considering the environmental and social impacts of technology, promoting equity and fairness, and ensuring that technological advancements contribute to sustainable development goals. Future-oriented Approach: Sustainability and Society 5.0 both take a forward-looking stance. Both ideas acknowledge the importance of planning ahead and taking proactive steps to deal with societal and environmental concerns. Society 5.0 strives to build a future in which technology and innovation are harnessed for the benefit of society while guaranteeing the preservation of the environment for coming generations by incorporating sustainability principles into the design and implementation of technological solutions. In conclusion, the concepts of sustainability and Society 5.0 are complementary and closely related. Society 5.0 welcomes technological developments and innovation to create a human-centered society, in contrast to sustainability, which places emphasis on environmental and social responsibility. By incorporating sustainability into Society 5.0's guiding principles, we may work toward a future that is both technologically advanced and sustainable, advancing both human and environmental well-being.

4.4 Society 5.0

A strain on the current industrial, economic, and social infrastructure of the countries is caused by the overflow of information to store, the identification of the real and relevant data to analyze, and the limited scope of action due to physical capability and a lack of laws and policies. This prevents the nations from taking adequate action to address any critical issues in a timely manner. Globalization and lifespan expansion, developing economies, worldwide rivalry, social and regional inequality, and other factors are further complicating the problem. The necessity of the hour is for sustainability across industries, green energy, climate control, and social innovation (Infraspeak (2022)).

The enormous potential of the Industry 4.0 Revolution is laying the groundwork for the world to embrace Society 5.0, the imagined future that will serve as a bridge to a prosperous, data-synchronized, Super Smart, human-centered society. Combining cutting-edge technologies like IoT, AI, robotics, big data, and advanced analytics, social innovation aims to create a thriving society that balances social progress and economic growth (Cortes-Leal et al. (2022)).

By gathering big data from many sources via sensors and gadgets, Society 5.0 is being developed, merging cyberspace and physical world by connecting people, things, and systems. Big Data is examined by AI capabilities to integrate back into the real world with new values for individuals, businesses, and sectors to simultaneously advance economic growth and find answers to social issues. In Society 5.0, the new value produced by social innovation eliminates regional, age, gender, and linguistic barriers and makes it possible to provide goods and services that are specifically tailored to each customer's needs and wants. It demonstrates the capability to address a range of problems in numerous industries, including mobility, healthcare, agriculture, food, manufacturing, disaster management, and energy, among others (Hitachi (2023b)).

4.4.1 Industry 5.0 and Society 5.0

Industry 5.0 and Society 5.0 are two ideas that are closely related and that stand for various facets of a more comprehensive vision for the future of human society. A paradigm change in manufacturing known as "Industry 5.0" combines the advantages of human employees and cutting-edge automation technologies to produce a more adaptable and sustainable production system (Huang et al. (2022)).

The goal of Society 5.0, on the other hand, is to use cutting-edge technologies to address significant social issues and build a more inclusive and sustainable future. It incorporates a broader vision for the future of society as a whole. A more comprehensive and integrated approach to social and economic development, Society 5.0 aims to combine the strengths of several sectors, such as healthcare, education, energy, transportation, and communication, while Industry 5.0 is especially focused on the manufacturing industry.

The common objective of Industry 5.0 and Society 5.0 is to use cutting-edge technology to build a future that is more sustainable and focused on people. While Society 5.0 aims to solve bigger social concerns like aging populations, environmental degradation, and rising inequality by utilizing the power of technology to develop new solutions and opportunities, Industry 5.0 focuses on enhancing industrial processes and products.

4.4.2 "Hitachi" The Leading Company in Society 5.0

Hitachi, a Japanese multinational conglomerate, launched Society 5.0 in January 2016 with the goal of building a human-centered, ultra-smart, and lean society. They have a strong focus on maintenance as a key element in their business strategy. Hitachi's concept of maintenance is based on the idea of "monozukuri," which means "making things," and emphasizes the importance of creating and maintaining high-quality products and services.In Japan, the idea of Society 5.0 was put up to strike a balance between economic growth and the addressing of social issues (such as the aging population, low birth rates, and lack of competitiveness).

The Society 5.0 concept perfectly complements Hitachi's idea of a "Sustainable Society" in which everyone can lead a secure and contented life. Hitachi is prepared to collaborate with the government in achieving this reality by creating a solid framework for a smooth transition to Society 5.0 and assisting in resolving various social challenges through cutting-edge digital technologies. They have a strong and comprehensive portfolio, diversity of digital solutions, and integrated approach (Huang et al. (2022)).

They have a great focus on maintenance as a key element in their business strategy. Hitachi's concept of maintenance is based on the idea of "monozukuri," which means "making things," and emphasizes the importance of creating and maintaining high-quality products and services (Hitachi (2023a)).

Their maintenance approach involves the use of advanced technologies such as data analytics, artificial intelligence, and the Internet of Things (IoT) to achieve optimal performance, reduce downtime, and improve overall efficiency. They use a proactive maintenance approach that is based on real-time monitoring and predictive analytics to detect issues before they occur.

They also emphasize the importance of collaboration between maintenance and production teams to ensure that maintenance activities are aligned with business goals and priorities. This collaborative approach helps to minimize the impact of maintenance activities on production and helps to ensure that maintenance activities are performed at the optimal time.

They also believe in the importance of continuous improvement and has developed a "PDCA cycle" (Plan-Do-Check-Act) approach to maintenance. This approach involves continuously monitoring and analyzing maintenance activities to identify areas for improvement and implementing changes to optimize maintenance processes. Finally, Hitachi's approach to maintenance is focused on ensuring high-quality products and services, minimizing downtime, and optimizing efficiency through the use of advanced technologies, collaborative approaches, and continuous improvement (Hitachi (2023b)).

Hitachi's concept of Society 5.0 is a vision of a future society that integrates advanced technologies, such as AI, IoT, and big data, with social infrastructure to create a more sustainable and prosperous society. Within this concept, Hitachi emphasizes the importance of maintenance as a key component in achieving a sustainable society.

Hitachi's Society Maintenance 5.0 concept aims to achieve this by leveraging advanced technologies to improve maintenance processes and reduce the environmental impact of maintenance activities. This concept is based on the belief that maintenance activities can be used to create new value and contribute to the well-being of society as a whole.

In Society Maintenance 5.0, Hitachi envisions a collaborative approach between industry, government, and academia to address the challenges of sustainable maintenance. This approach includes the development of new maintenance technologies and processes, as well as the use of data analytics and AI to optimize maintenance activities.

Hitachi also emphasizes the importance of social innovation in Society Maintenance 5.0, which involves leveraging the power of technology to address social challenges such as climate change, aging populations, and urbanization. This approach involves not only improving the efficiency and effectiveness of maintenance activities but also ensuring that maintenance activities contribute to the overall well-being of society.

Hitachi's concept of Society Maintenance 5.0 is based on the belief that maintenance activities can be used to create new value and contribute to the well-being of society. This vision involves a collaborative approach to maintenance that leverages advanced technologies and social innovation to achieve a more sustainable and prosperous society (Hitachi (2023a)).

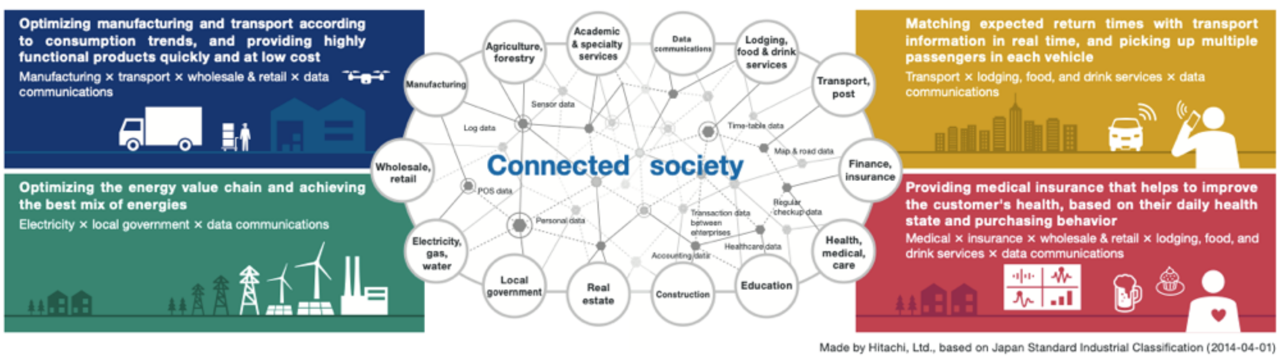

Figure 4.1: Hitachi's Approach to Society 5.0 (Hitachi (2023a))

Chapter 5

Maintenance Management

5.1 What is Maintenance Management

Maintenance management refers to the overseeing and synchronization of maintenance activities and assets in an organization to guarantee the optimal performance and durability of physical resources, including infrastructure, facilities, machinery, and equipment. The process entails formulating and executing tactics, regulations, and protocols to effectively uphold and administer these resources over the course of their existence. Some significant benefits of Maintenance Management are listed as follow:

- Increased equipment reliability and availability
- Minimized unplanned downtime and production losses
- Extended asset lifespan and reduced lifecycle costs
- Improved safety and compliance with regulations
- Enhanced productivity and operational efficiency
- Optimal allocation of maintenance resources
- Better decision-making through data analysis
- Improved customer satisfaction through reliable services

5.2 The Importance of Maintenance Management in Maintenance Trends

The significance of maintenance management lies in its ability to facilitate the integration of novel techniques, technologies, and optimal practices into an organization's maintenance strategies, thereby enabling it to remain abreast of the latest maintenance trends. The significance of maintenance management in the context of maintenance trends is noteworthy.

The maintenance trends frequently involve integrating of new technologies, including predictive analytics, Internet of Things (IoT) devices, and machine learning, in order to stay abreast of technological advancements. Competent maintenance management enables organizations to remain up-to-date with technological advancements, evaluate their potential advantages, and tactically integrate them to enhance maintenance procedures and results. Maintenance management offers a structured approach to assess and adopt novel developments that have the potential to improve the efficiency and effectiveness of maintenance activities. Organizations can enhance resource allocation, minimize downtime, and attain superior asset performance by assimilating novel practices such as condition-based maintenance or reliability-centered maintenance. Industries may encounter distinct modifications and difficulties that affect their maintenance demands, necessitating targeted measures to address these industry-specific changes. Maintenance management facilitates organizational awareness of industry-specific trends and enables the adaptation of maintenance practices in response. Organizations may need to modify their maintenance strategies to conform to new standards due to regulatory modifications or advancements in environmental sustainability. The promotion of review and analysis of maintenance trends by maintenance management fosters a culture of continuous improvement. Organizations can enhance their maintenance processes over time by identifying areas for improvement, implementing corrective actions, and evaluating emerging trends through monitoring key performance indicators and benchmarking against industry standards. The optimization of costs is a crucial aspect of business management. Maintenance trends have been identified as a potential avenue for achieving cost optimization and enhancing cost-effectiveness. The implementation of efficient maintenance management practices empowers organizations to assess the possible financial ramifications of emerging trends, such as remote diagnostics or condition monitoring, and make well-informed decisions regarding their adoption. The aforementioned outcomes may ensue from this phenomenon: decreased costs associated with upkeep, prolonged longevity of assets, and enhanced return on investment. Maintenance management aids organizations in identifying and mitigating potential risks that may arise from emerging trends. Organizations can make informed decisions and implement appropriate risk mitigation measures by conducting risk assessments, evaluating the reliability and performance of new technologies, and considering factors such as cybersecurity. The development of talent in the maintenance field may necessitate the acquisition of novel skills or competencies by maintenance personnel in response to emerging maintenance trends. The management of maintenance is of utmost importance in the identification of deficiencies in skills, provision of opportunities for training, and guaranteeing that the workforce is adequately prepared to implement and capitalize on emerging trends. Organizations can achieve higher levels of maintenance performance, optimize costs, mitigate risks, and drive continuous improvement by adopting maintenance management practices and keeping up with maintenance trends. This will enable them to align with industry advancements and changing requirements.

5.3 The Importance of Maintenance Management in Sustainability

The implementation of maintenance management is crucial for the attainment of sustainability objectives as it facilitates the enhancement of asset performance, durability, and ecological footprint of organizations. There exist multiple justifications for the significance of maintenance management in ensuring sustainability.

Efficient maintenance management is crucial in ensuring that assets are appropriately maintained and operated, thereby prolonging their lifespan and enhancing their longevity. Organizations can prevent premature asset failures and the need for replacements by implementing preventive maintenance practices, conducting regular inspections, and addressing potential issues promptly. The aforementioned practice results in a decrease in resource utilization, a reduction in the generation of waste, and the advancement of sustainable resource management.

The management of maintenance has a notable impact on the enhancement of energy efficiency. Equipment that is properly maintained tends to function with greater efficiency, resulting in a reduction of energy consumption and the corresponding emissions of greenhouse gases. Performing routine maintenance tasks such as cleansing, lubricating, and calibrating equipment can enhance its operational efficiency and maximize its performance. Organizations can contribute to sustainability goals by minimizing their environmental footprint through the maximization of energy efficiency.

The implementation of maintenance management can aid organizations in the execution of strategies aimed at reducing the generation of waste. Organizations can curtail material losses and waste generation by effectively upholding assets, detecting and rectifying leaks, and optimizing equipment performance. Furthermore, proficient management of spare parts and inventory can prevent excessive stocking, diminish obsolescence, and mitigate the wastage linked to unused or expired materials.

The practice of maintenance management is aimed at ensuring adherence to environmental regulations and standards. Through the implementation of routine inspections, maintenance personnel can promptly detect and resolve potential environmental hazards or instances of non-compliance. Compliance with regulatory mandates enables organizations to mitigate their environmental footprints, evade legal sanctions, and foster sustainable operations.

The field of maintenance management encompasses procurement operations that pertain to maintenance services, equipment, and spare parts. Through the adoption of sustainable procurement practices, entities can prioritize suppliers that exhibit eco-friendly practices, such as the utilization of sustainable materials, waste reduction, or the implementation of energy-efficient technologies. The aforementioned approach fosters sustainability across the entire supply chain and incentivizes the implementation of ecologically sound methodologies.

Effective maintenance management facilitates the regulation of emissions and pollution within organizations. The implementation of routine maintenance procedures, such as equipment calibration, filtration system cleaning, and emission control system examination, guarantees that assets function within predetermined environmental thresholds. This practice aids in the reduction of air, water, and soil pollution, thereby promoting environmental protection and facilitating sustainable methodologies.

The field of maintenance management encompasses the systematic gathering and evaluation of information pertaining to the functioning of assets, maintenance operations, and the allocation of resources. Through the utilization of this data, entities can make informed choices to enhance maintenance strategies and give precedence to sustainability goals. The process of analyzing data facilitates the identification of potential areas for improvement, monitoring of environmental metrics, and promotion of ongoing sustainability improvements.

In general, the management of maintenance offers a methodical strategy for guaranteeing the enduring utilization of resources, mitigating ecological consequences, and fostering the effectiveness of resources. The incorporation of sustainability considerations into maintenance practices can enable organizations to make a positive contribution towards environmental conservation, comply with regulatory standards, and bolster their image as entities that prioritize environmental responsibility.

5.4 Maintenance Management and Function

The importance of the maintenance function and the importance of maintenance management has increased over time. The widespread use of mechanization and automation has resulted in a decrease in the number of production workers and an increase in the amount of capital invested in infrastructure. As a result, both the percentage of workers in the maintenance department and the percentage of total operational costs attributable to maintenance have increased over time. For example, it is customary for the maintenance and operations departments to be the largest and to account for almost one third of the entire workforce in refineries. Additionally,

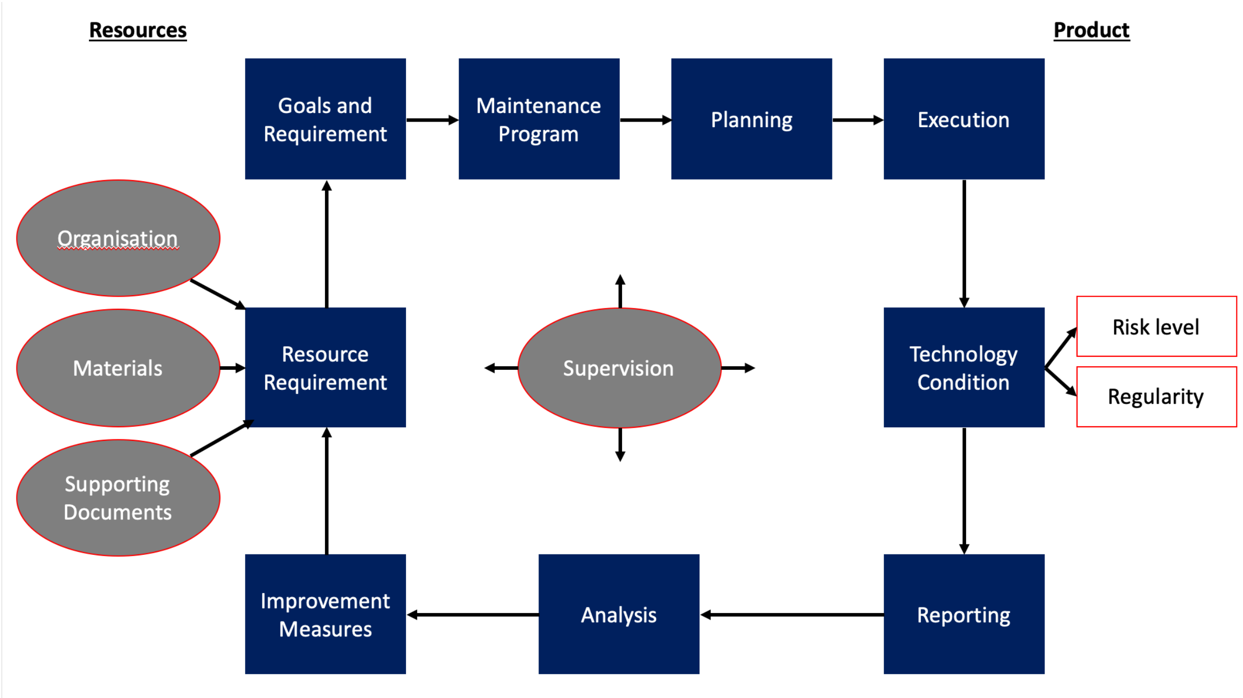

Figure 5.1: Maintenance Management adapted from The Norwegian Petroleum Directorate (1998)

maintenance expenses may make up the largest portion of any operational budget, followed by energy expenses. As is shown in figure 5.1 maintenance management figure has organisation, materials, supporting documents as resources, some practical factors such as planning, execution, reporting, analysis and ... as the supervision part and finally risk level and regularity as products.

In this section, five areas of maintenance management have been considered as follow (Gark and Deshmukh (2006)):

- Maintenance Optimization Models,
- Maintenance Types,
- Maintenance Planning,
- Maintenance Performance Measurement,
- Maintenance Information Systems.

Models and techniques for maintenance optimization might be qualitative or quantitative. Total productive maintenance (TPM), reliability-centered maintenance (RCM), and other strategies are included in the first, whereas the latter also uses a variety of deterministic and stochastic models, such as Markov Decision, Bayesian models, and other techniques. From corrective maintenance (CM) in 1940 to numerous operation research (OR) models for maintenance today, the evolution of maintenance procedures has been a long one. In this broad category, a number of contemporary techniques have been examined.

Contrary to production scheduling, when an emergency work is received, the maintenance schedule gets instantly out of line. Hence, maintenance scheduling is another difficult subject that requires further research. Any organization that wants to operate effectively must have an effective performance measurement system in place. This is because anything that is measured is more likely to be completed. Due to maintenance's complete acceptance as a crucial business activity, the first maintenance management information system (MMIS) debuted in the 1980s. The same is now a necessary part of every maintenance organization and deserves consideration under a different heading.

Similar categories can be used to categorize alternative maintenance strategies, such as age replacement policies, periodic repair policies, block repair policies, failure limit policies, etc. Each of these strategies has unique traits, benefits, and drawbacks, and requires in-depth investigation.

5.4.1 Maintenance Optimization Models

Maintenance optimization models are used to help organizations optimize their maintenance activities and make data-driven decisions in order to minimize costs and maximize system availability, reliability, and safety that improve the efficiency and effectiveness of their maintenance tasks. These models can be used to determine the optimal maintenance schedules, the optimal replacement times for equipment, and the optimal levels of inventory for spare parts. Four aspects of maintenance optimization models are covered here, firstly, a description of a technical system, its function, and importance; secondly, a model of how the system will deteriorate over time and potential consequences; thirdly, a description of the information that is currently available about the system and management actions; and finally, an objective function and optimization technique that aids in finding the best balance. There are several different types of maintenance optimization models that some of them are mentioned here, including (Fraser et al. (2015)):

Bayesian Model

A statistical framework known as the Bayesian approach is used in maintenance models to assess uncertain data and make judgments based on prior knowledge. It enhances forecasts by fusing prior assumptions with actual facts to better comprehend a system's behavior. The Bayesian technique includes a variety of information sources, including historical data and expert opinions, in maintenance models. It improves maintenance decision-making by updating these beliefs as new information becomes available. The likelihood functions connecting observed data with model parameters, posterior distributions produced by Bayes' theorem, and prior information expressed as probability distributions are important components. Decisions about maintenance, such as ideal timetables, remaining equipment life, and failure likelihood, are informed by the posterior distribution. A few benefits of the Bayesian technique include its ability to handle uncertainty, incorporate prior knowledge, and support ongoing belief changes.

Simulation and Markovian Probabilistic Models

Both of them are frequently used in maintenance models to evaluate system behavior and forecast maintenance tasks. Markovian probabilistic models examine the probabilistic transitions between states to predict reliability and availability, whereas simulation models simulate the behavior of maintenance systems to evaluate performance and optimize maintenance procedures. In terms of decision-making and maintenance modeling, both strategies are useful.

Simulation Models: Making a computer-based model that simulates the behavior of a system in the real world is known as simulation. To comprehend the dynamic nature of the system and represent various maintenance scenarios, simulations are employed in maintenance models. Simulations can provide information about system performance, ideal maintenance schedules, and resource allocation by simulating the system's operation over time and taking into account variables like failure rates, repair times, and maintenance techniques. Simulation tools can be used to evaluate the effects of different maintenance strategies and spot any potential kinks or inefficiencies in the maintenance workflow. Although they might be computationally costly, simulation models offer flexibility in modeling complex systems with various interactions and uncertainties.

Markovian Probabilistic Models: Probabilistic models called "Markovian models" are based on the idea of Markov processes. They are especially helpful for understanding systems that exhibit gradual probabilistic changes in states. Markovian models, which reflect the states of the system (such as functional, failed, and under repair) and the probabilities of switching between these states, are used in maintenance models to examine the dependability and availability of systems. Markovian models can offer insights into system performance, ideal maintenance approaches, and anticipated downtime by predicting transition probabilities based on historical data or expert knowledge. Making wise decisions about resource allocation and maintenance scheduling is made easier with the aid of these models. Markovian models offer a more formal mathematical framework for deriving probabilistic predictions and analyzing system behavior, but they may call for oversimplifying the system's assumptions.

Mixed integer linear programming (MILP) formulation

In order to minimize or maximize a certain performance measure (such as cost, downtime, or resource usage), maintenance decisions are modeled as mathematical equations and restrictions in the MILP formulation process. In this method, linear programming and integer programming both combined, where some decision variables are allowed to take only integer values. MILP can be used to optimize the scheduling of maintenance activities, considering factors like preventive maintenance, corrective maintenance, resource allocation, and constraints such as availability of maintenance crews and equipment. The goal can be to balance the workload of maintenance, maximize equipment availability, or reduce maintenance expenses. Additionally, it may optimize the amount of spare parts in stock by taking demand, lead time, ordering expenses, and stockout costs into account. Minimizing inventory carrying costs while making sure there is enough stock to meet maintenance requirements could be the goal. Furthermore, it can optimize how maintenance personnel and other resources are distributed among various projects or activities. With the aim of increasing resource utilization or reducing project completion time, it takes into account elements including skill needs, availability, and limits. Decision-makers can get optimal or nearly optimal solutions based on the specified aim and constraints by modeling maintenance problems as MILP models. However, it's crucial to note that MILP models can become computationally challenging and require specialized optimization software or algorithms to solve efficiently.

5.4.2 Maintenance Types

Preventive Maintenance

Regularly scheduled maintenance is known as preventive maintenance and takes place in accordance with original equipment manufacturer (OEM) recommendations or at another regular frequency decided upon by the organization. This kind of maintenance frequently takes place whether it is necessary or not, and as a result, it may not be cost-effective to replace machinery that is still functional.

Contrarily, preventive maintenance may cause unscheduled downtime because it cannot identify more urgent maintenance concerns. The maintenance tasks are scheduled based on time, usage, or other criteria, and are intended to catch potential problems before they occur. Preventive maintenance can include tasks such as lubrication, cleaning, inspections, and parts replacement.

Although preventative maintenance shouldn't be the only tactic employed, it does have advantages and ought to be included in the majority of organizational maintenance plans. The benefits of preventive maintenance include reduced downtime, improved equipment reliability, and extended equipment life. However, it can also be costly to perform routine maintenance tasks on equipment that may not need it, and there is a risk of overlooking potential issues that are not caught by the maintenance schedule.is done before a failure occurs and consists of maintenance types like:

Time-Based Maintenance, Failure Finding Maintenance, Risk-Based Maintenance, Condition Based Maintenance and Predictive Maintenance (Hupje (2018)).

Predictive Maintenance

Predictive maintenance differs from preventive maintenance in that it adopts a more proactive stance, relying on data, analytics, and real-time performance indicators to anticipate impending maintenance needs and schedule diagnosis and cure well in advance of unexpected downtime.

Predictive maintenance, as opposed to the previous two asset maintenance strategies, is better equipped to pinpoint the root causes of actual problems, allowing professionals to arrange treatment more successfully and at a more convenient time. Predictive maintenance can include techniques such as vibration analysis, oil analysis, and thermography to monitor equipment performance and identify potential issues. The benefits of predictive maintenance include reduced downtime, improved equipment reliability, and lower maintenance costs.

By identifying potential issues before they occur, organizations can plan and schedule maintenance activities in advance, reducing the need for unscheduled downtime and emergency repairs (Selcuk (2016) and Hupje (2018)).

Condition-Based Maintenance (CBM)

The majority of failure modes are not attributed to the aging process. Nevertheless, the majority of failure modes typically exhibit certain indications that they are presently unfolding or are on the verge of transpiring. In the event that indications of incipient failure are detected, it may be feasible to implement measures to forestall total failure and/or circumvent the ramifications of such failure.

The utilization of Condition Based Maintenance as a strategic approach involves the identification of tangible indications that a malfunction is transpiring or is on the verge of occurring. The consideration of CBM in such a manner illustrates its wider range of potential uses beyond the typical association with monitoring the condition of rotating machinery. Therefore, the PM service is predicated on the detection of readings that exceed a predetermined threshold. This involves measuring beyond a specified limit. In the event that a machine is unable to maintain a specific tolerance level, a maintenance approach based on condition is implemented.

The P-F curve, as depicted in the figure below, is a significant notion in the realm of Condition Based Maintenance.

The graphical representation illustrates that upon the onset of a failure, the equipment undergoes a gradual decline until it reaches a state where it may be feasibly identified, denoted as point "P". In the absence of timely detection and mitigation, the failure persists until the point of functional failure (referred to as "F") is reached. The P-F interval, denoting the duration between the initial occurrence of a potential failure (P) and the point of failure (F), represents a critical temporal window for conducting inspections that may enable the timely detection of impending failures and facilitate the implementation of appropriate remedial measures.

It is imperative to acknowledge that the implementation of CBM as a maintenance approach does not diminish the probability of a failure transpiring via life-renewal. Rather, its objective is to intervene before the failure transpires, based on the assumption that this approach is more cost-effective and has a lesser impact on availability.

Stated differently, the practice of condition monitoring does not serve as a means of repairing machinery nor does it serve as a preventative measure against equipment malfunctions. The practice of condition monitoring enables the identification of potential issues prior to their manifestation as a complete system failure.

It is a widely accepted heuristic that the duration between tasks of Curriculum-Based Measurement (CBM) should be either one-half or one-third of the Performance-Foundation (P-F) interval.

The relative effectiveness of condition-based maintenance in comparison to breakdown maintenance is contingent upon the duration of the P-F interval. Adequate forewarning enables the scheduling of rectification measures, procurement of necessary materials and resources, and precludes any potential breakdowns (albeit with a temporary cessation of production during the maintenance period). When the time interval between the detection of a potential failure (P) and the occurrence of the failure (F) is limited to a few days, the subsequent actions taken by the organization and workplace resemble those of a breakdown, leading to a significant loss in the effectiveness of Condition-Based Maintenance (CBM).

Early intervention is a crucial factor for the effectiveness of CBM as a maintenance strategy. An optimal approach is necessary to facilitate the collection and examination of data, the formulation of decisions, and the implementation of interventions.

In cases where the P-F interval exhibits significant variability, the implementation of condition monitoring may not prove to be a viable approach (Hupje (2018)).

Risk-Based Maintenance

Risk-Based Maintenance (RBM) is a maintenance strategy that involves utilizing a risk assessment methodology to allocate limited maintenance resources to assets that pose the highest risk in the event of a failure. It is important to note that risk is determined by the product of likelihood and consequence.

Consequently, equipment that poses a greater risk and has a significantly higher potential impact in the event of failure would necessitate more frequent maintenance and inspection.

Equipment that poses a low risk may require less frequent maintenance and a narrower scope of work.

The implementation of risk-based maintenance is a prudent approach to maintenance planning that effectively addresses two key objectives: the mitigation of potential hazards arising from unforeseen equipment failures, and the adoption of a cost-efficient maintenance strategy that results in a reduction of overall failure risk throughout the plant in a cost-effective manner.

Risk-Based Maintenance (RBM) is a form of preventive maintenance that involves the ongoing optimization of maintenance activities in terms of their frequency and scope. This optimization is based on the results of testing or inspection, as well as a comprehensive risk assessment. Instances of Risk-Based Maintenance include the implementation of Risk-Based Inspection on stationary equipment such as piping, vessels, and pressure relief valves (Hupje (2018)).

Failure Finding Maintenance (FFM)

The concept of identifying and addressing failures in a system or process, commonly referred to as "failure finding." The objective of maintenance activities is to identify concealed malfunctions that are commonly linked with safeguarding mechanisms such as pressure safety valves, trip transmitters, and similar components. This particular equipment will only be necessary for operation in the event of a prior system malfunction. Under typical operational circumstances, it is difficult to determine the functionality of the equipment due to the concealed nature of its failure modes. Given that these malfunctions are concealed, it is imperative to identify them prior to depending on the equipment for safeguarding purposes. It is imperative to acknowledge that maintenance tasks focused on identifying failures do not serve as a preventative measure, but rather serve to identify the occurrence of failure. Upon detection, it will be necessary to rectify the identified failure. The practice of Failure Finding Maintenance involves scheduled inspections that are often determined by regulatory requirements or assessments based on potential risks (Hupje (2018)).

Time-Based Maintenance (TBM)

Time-Based Maintenance refers to a maintenance approach that involves performing routine maintenance activities at predetermined intervals while the equipment is operational, with the aim of averting or minimizing the probability of equipment failure.

Preventive maintenance may be scheduled based on time intervals, such as weekly, monthly, or quarterly. Preventive maintenance protocols may also be established on the basis of utilization patterns, such as at intervals of 150 cycles, 10,000 hours, or in a manner akin to automobile maintenance, at every 10,000 kilometers (Hupje (2018)).

Corrective Maintenance (or Reactive Maintenance)

Corrective maintenance, also known as reactive maintenance or run-to-failure maintenance, involves repairing equipment after it has failed. This can include emergency repairs, as well as scheduled repairs that are performed after equipment has been taken out of service. Corrective maintenance is typically more expensive than preventive or predictive maintenance, as it often involves replacement of damaged parts or complete equipment replacement. Since maintenance only takes place at or close to a failure state, corrective maintenance as a maintenance approach is ineffective and expensive in terms of resources, spare parts, and potential downtime. Even with one of the more effective equipment maintenance strategies in place, corrective repair is nearly always required at some point during operations. This is despite the fact that it shouldn't be an organizational strategy.

The benefits of corrective maintenance include reduced downtime, improved equipment reliability, and increased safety. However, it is typically less efficient and more expensive than preventive or predictive maintenance, and can result in significant costs if equipment failure leads to damage or injury. In the chart of maintenance types 'corrective maintenance' can be divided into two sub-types (Hupje (2018)):

- **Deferred Corrective Maintenance**: It is imperative to significantly reduce the occurrence of Emergency Maintenance within our organizations. As previously stated, Emergency Maintenance is a costly endeavor. Multiple sources have indicated that Emergency Maintenance can be three to five times more expensive than routine preventive maintenance. Emergency maintenance procedures often result in extended equipment downtime and increased production impact. Furthermore, it presents a lower level of safety. When a request for corrective maintenance is initiated, it is imperative to prioritize it appropriately to ensure that, if feasible, the request is deferred, allowing the team sufficient time to effectively plan and schedule the work.

- **Emergency Maintenance**: Emergency maintenance refers to a type of corrective maintenance that is deemed so critical that it necessitates immediate attention, thereby disrupting the pre-planned frozen weekly schedule. The disruption of plans and schedules often leads to a state of disarray. Certain individuals excel in such settings and are frequently lauded as heroic figures after dedicating 16 consecutive hours to restoring production operations. However, in terms of achieving reliability, the Road to Reliability appears to be a futile endeavor. Emergency maintenance is a maintenance type that should be minimized as much as possible. World-class organizations strive to limit emergency maintenance to less than 2

5.4.3 Maintenance Planning

The process of identifying the equipment maintenance tasks that must be completed and scheduling those tasks to reduce equipment downtime and increase equipment reliability is known as maintenance scheduling. Technical know-how, management abilities, and the application of digital technology are all necessary for effective maintenance planning. The six components of a successful maintenance task, namely the mechanic(s), tools, materials/parts, availability of the unit to be maintained, information needed to execute the job, and the relevant permissions, are brought together precisely in time through scheduling (Gark and Deshmukh (2006)).

The maintenance planning process typically includes the following steps:

- **Equipment identification**: Identifying the equipment that needs maintenance is the first stage in the maintenance planning process. This could entail compiling an inventory of the equipment and evaluating each piece of equipment to ascertain what maintenance is necessary.

- **Choosing a maintenance strategy**: After identifying the equipment, the following step is to choose the best maintenance approach for each piece of equipment. Preventive, predictive, or corrective maintenance are all examples of this.

- **Maintenance task identification**: Identifying the precise maintenance tasks that must be carried out on each piece of equipment is the next step in maintenance planning. This could entail using procedures like doing a failure mode and effects analysis (FMEA), checking manufacturing documentation, or other methods.

- **Scheduling maintenance task**: The aim of these tasks is to minimize equipment downtime and operational disturbance is necessary once the repair tasks have been identified. This could entail developing a maintenance schedule depending on the availability of the equipment, production schedules, and other variables.

- **Allocating resources**: Allocating the resources required to execute the maintenance activities is the last step in maintenance planning. This could entail allocating maintenance staff, ordering equipment and supplies, and working with other departments as required.Effective maintenance planning can help organizations reduce maintenance costs, improve equipment reliability, and minimize downtime, resulting in improved operational efficiency and financial performance.

5.4.4 Maintenance Performance Measurement

The evaluation of maintenance activities within an organization is facilitated through the use of maintenance performance measurements, which are considered indispensable tools for assessing their efficiency and effectiveness. The aforementioned measurements offer significant insights relevant to the maintenance process performance, equipment reliability, resource utilization, and maintenance management holistically. The evaluation of maintenance performance entails the consideration of several crucial aspects:

Key Performance Indicators (KPIs) are measurable parameters that aid in assessing the effectiveness of maintenance operations. They offer a mechanism for monitoring advancement, recognizing opportunities for enhancement, and overseeing the attainment of maintenance objectives. Maintenance performance measurements commonly incorporate Key Performance Indicators (KPIs).

The concept of total productive maintenance (TPM), which was introduced in the 1980s, offers a quantitative measure known as overall equipment effectiveness (OEE) for assessing the productivity of manufacturing equipment. The process involves the identification and quantification of deficits in critical manufacturing domains, including availability, performance, and quality. This provides support for enhancing equipment efficiency, thereby increasing equipment productivity. The concept of Overall Equipment Effectiveness (OEE) has gained significant traction and is commonly employed as a quantitative instrument for assessing equipment performance in industrial settings. OEE metric evaluates the operational efficiency and equipment availability by taking into account various factors including but not limited to downtime, speed losses, and quality losses.

The Mean Time Between Failures (MTBF) is a metric that quantifies the average duration between equipment malfunctions, serving as an indicator of the dependability of assets.

Mean Time to Repair (MTTR) is a metric that quantifies the duration of time typically needed to restore equipment to its operational state following a malfunction. This metric is indicative of the maintenance team's level of responsiveness.

The Planned Maintenance Percentage is a key performance indicator that quantifies the proportion of planned maintenance tasks in relation to the total maintenance activities performed. This metric serves to evaluate the efficacy of preventive maintenance approaches.

The Key Performance Indicator (KPI) of Maintenance Cost as a Percentage of Asset Value evaluates the efficiency of maintenance operations by juxtaposing the expenses incurred for maintenance with the overall value of the assets.

The Key Performance Indicator (KPI) of Work Order Backlog evaluates the quantity of work orders that are yet to be completed, serving as an indicator of the maintenance department's efficiency and workload.

The precise and thorough collection of data is of paramount importance in the context of maintenance performance evaluations. Data can be acquired from diverse sources including computerized maintenance management systems (CMMS), equipment sensors, work order records, and maintenance logs. The aforementioned data is subjected to analysis for the purpose of producing performance metrics, detecting patterns, and facilitating decision-making. The utilization of data analysis techniques, including trend analysis, root cause analysis, and statistical methods, can furnish significant insights into maintenance performance and identify areas that necessitate improvement.

Benchmarking is another process that entails evaluating an organization's maintenance performance metrics in comparison to industry best practices or predetermined standards. Through the process of benchmarking, organizations can effectively pinpoint areas of performance deficiency, establish objectives for enhancement, and gain insights from the successful practices of other entities. The process of benchmarking can be carried out either internally within an organization or externally by making comparisons against industry or sector-specific standards.

The measurement of maintenance performance is a crucial factor in propelling continuous improvement endeavors. Through consistent monitoring and analysis of performance metrics, organizations can detect operational inefficiencies, bottlenecks, and opportunities for enhancement. The aforementioned observations facilitate the execution of specific enhancement tactics, such as the optimization of preemptive maintenance schedules, augmentation of equipment dependability, simplification of operational procedures, and allocation of resources towards education and proficiency advancement for maintenance staff.

The effective communication of maintenance performance measurements to pertinent stakeholders, such as maintenance managers, operations teams, and senior management, is imperative for reporting and communication purposes. Consistent reporting and effective communication promote transparency, enable well-informed decision-making, and cultivate a culture of ongoing enhancement. Effective communication of maintenance performance metrics and trends can be achieved through clear and concise reports, visualizations, and dashboards.

In short, the assessment of maintenance performance entails the utilization of Key Performance Indicators (KPIs), the gathering of data, analysis of said data, benchmarking, ongoing enhancement, and proficient reporting. The implementation of comprehensive performance measurement systems can enable organizations to enhance the efficiency, reliability, and cost-effectiveness of their maintenance operations. This, in turn, can result in improved equipment performance, reduced downtime, and an overall enhancement of the organizational performance.

5.4.5 Maintenance Information Systems

Maintenance Information Systems (MIS) refer to software applications or integrated systems that are specifically designed to facilitate the management and execution of maintenance activities within an organization. The aforementioned systems offer a centralized platform that enables the recording, analysis, and management of maintenance-related data, thereby promoting effective maintenance planning, scheduling, and execution. Organizations can boost efficiency, lower expenses, and streamline maintenance procedures with the use of maintenance information systems. These systems enable maintenance managers to make data-driven decisions and optimize maintenance procedures to increase overall equipment reliability and performance by delivering real-time data and analytics. The comprehension of Maintenance Information Systems involves the consideration of several fundamental aspects.

Functionality

MIS commonly encompasses functionalities pertaining to the generation, monitoring, and administration of work orders in the context of work order management. The documentation of maintenance tasks, commonly known as work orders, entails the recording of pertinent information such as the equipment involved, work description, priority level, personnel assigned, and scheduling details.

Asset management is a common feature of Management Information Systems (MIS), which enables organizations to monitor and manage their assets in a comprehensive manner. This includes maintaining detailed records of equipment specifications, maintenance history, warranties, and documentation.

The implementation of preventive maintenance programs is facilitated by MIS through the scheduling, tracking, and execution of routine maintenance tasks according to predetermined schedules or condition-based triggers.

Inventory management is a common feature found in Management Information Systems (MIS). This feature enables organizations to monitor and regulate their inventory of maintenance-related items, spare parts, and materials. This facilitates the effective management of stock levels, streamlining the reordering process, and optimizing inventory costs.

Management Information Systems (MIS) offer reporting and analytics functionalities that enable the generation of performance metrics and insights pertaining to maintenance operations. Reports may encompass data pertaining to the fulfillment of work orders, duration of equipment downtime, expenses incurred for maintenance, and additional KPIs.

The integration of Management Information Systems (MIS) with other enterprise systems, such as Enterprise Resource Planning (ERP) systems, asset management systems, and sensor networks, is a common practice. The process of integration facilitates the exchange of data and furnishes a comprehensive perspective of maintenance-related data throughout the entire organization.

Benefits

The implementation of Management Information Systems (MIS) can enhance operational efficiency by optimizing maintenance procedures, automating recurring tasks, and offering instantaneous monitoring of maintenance operations. The aforementioned measures enhance operational efficiency, mitigate paperwork, eliminate manual errors, and augment overall productivity.

The utilization of Management Information Systems (MIS) facilitates efficient planning and scheduling of maintenance tasks, resulting in the optimal allocation of resources, reduced equipment downtime, and minimized operational disruptions. As a result, there is an enhancement in the performance and availability of assets.

The utilization of Management Information Systems (MIS) facilitates the acquisition and examination of maintenance data, thereby enabling the process of making decisions based on data-driven insights. The system's performance metrics, trends, and insights can aid in the identification of improvement areas, optimization of maintenance strategies, and effective allocation of resources.

Maintenance activities in numerous industries are subject to specific regulatory requirements pertaining to regulatory compliance. The implementation of Management Information Systems (MIS) can aid in the fulfillment of regulatory requirements by ensuring the precision of maintenance records, monitoring maintenance operations, and producing mandatory reports.

MIS systems facilitate cost control by offering enhanced visibility into maintenance expenditures, thereby enabling organizations to effectively monitor and regulate their financial outlays. Through the optimization of maintenance activities, efficient inventory management, and identification of cost-saving opportunities, organizations can enhance their cost-effectiveness and minimize maintenance expenses.

Implementation Considerations

When selecting a Management Information System (MIS), it is recommended that organizations assess multiple options available in the market. The chosen system should be in line with the organization's specific needs, taking into account factors such as functionality, scalability, user-friendliness, and integration capabilities.

The process of data migration is of utmost importance when transitioning from a legacy system to a new Management Information System (MIS). The process entails the precise and secure transfer of pertinent information such as maintenance data, asset records, work orders, and other related data to the new system.

The proficiency of maintenance personnel and relevant stakeholders in effectively utilizing the MIS is contingent upon user training, which is deemed a crucial component. It is imperative to implement sufficient training programs in order to facilitate the adoption of a system and optimize its advantages.

The regular maintenance and updates of Management Information Systems (MIS) are imperative to guarantee its sustained functionality, data integrity, and security. It is recommended that organizations implement protocols for the maintenance, backup, and upgrade of their systems to ensure optimal system performance.

5.5 From Maintenance to Asset Management

Asset management may be summed up as a thorough and organized strategy to using physical assets as tools for the efficient and effective delivery of an enterprise's key business drivers. The process of organizing, planning, scheduling, and controlling maintenance tasks in order to maximize equipment performance, decrease equipment downtime, and cut maintenance costs is another component of maintenance management. A variety of tasks are necessary for effective maintenance management, including:

5.5.1 Asset management

The publication of IAM (2008), a specification based on the well-known BS ISO framework used in such widely embraced standards as ISO 14001 for environmental management and OHSAS 18001 for safety management, was prompted by growing international consensus on best practices for managing physical assets. There were 50 participating organizations (in 10 countries and 15 industries). Numerous international energy and transportation companies have already received certification that they adhere to the standard, and industry interest is quickly rising. Asset management is defined in the standard as: "Systematic and coordinated activities and practices through which an organisation optimally and sustainably manages its assets and asset systems, their associated performance, risks, and expenditures over their life cycle for the purpose of achieving its organisational strategic plan" (IAM (2008)).

Asset management is the process of managing an organization's physical assets, including equipment, facilities, and infrastructure, throughout their lifecycle, from acquisition to disposal. Effective asset management involves optimizing the use of assets to achieve the organization's objectives while minimizing the costs associated with owning and operating them. Simply said, it is the most effective management of assets across their entire life cycle. While managing physical assets is the main focus of publicly available specification (PAS) 55, other broad types of 'assets' like human assets, information assets, financial assets, and intangible assets (reputation, etc.) are also taken into account when doing so will directly affect the management of physical assets. It includes several key activities, including (Risktec (2010)):

- Asset acquisition include determining the assets needed to accomplish the organization's goals, choosing the best assets, and acquiring them. Activities like requirement analysis, cost analysis, vendor selection, and contract negotiation may be a part of the purchase process.

- Asset tracking entails keeping tabs on the whereabouts, state, and performance of assets throughout time. Organizations can find opportunities to improve asset utilization, lower maintenance costs, and increase asset life by using asset tracking.

- Asset availability and effective operation are ensured by maintenance management, which entails planning and scheduling maintenance tasks. Preventive, predictive, and corrective maintenance are all included in the maintenance management process.

- Asset retirement and replacement management entails overseeing the retirement and replacement of assets when their useful lives are up. Activities including asset disposition, replacement planning, and budgeting can be included in asset retirement and replacement.

- Monitoring asset performance and evaluating data to find opportunities to increase asset efficiency, lower costs, and extend asset life are all part of this process. Activities like reliability analysis, failure analysis, and root cause analysis can be a part of performance monitoring and analysis.Effective asset management requires a combination of technical knowledge, management skills, and the use of digital technologies such as asset tracking software and data analytics tools.

By implementing effective asset management practices, organizations can optimize asset use, reduce maintenance costs, and extend asset life, resulting in improved operational efficiency and financial performance.

5.5.2 Work Order Management

It is the process of overseeing the numerous activities and tasks necessary to finish maintenance work orders. Assigning tasks to maintenance employees, scheduling work, establishing work orders, monitoring work progress, and closing out finished work orders are all included in this. Technical expertise, administrative abilities, and the utilization of digital technology are all necessary for efficient work order administration. The following are some particular aspects of work order management:

- Making a work order: Making a work order entails writing down all the information about the maintenance task, such as the machinery involved, the kind of work needed, and any materials or resources needed.

- Scheduling work orders: After a work order is created, it needs to be planned to minimize operations disturbance and maximize equipment availability. To guarantee that work can be finished on schedule, this may require collaborating with other departments or stakeholders.

- Task distribution: After a work order has been planned, each task inside the work order needs to be sent to the maintenance team. This might entail distributing duties according to workload, skill level, or other considerations.

- Monitoring job progress: Monitoring work progress is crucial for ensuring that work is finished on schedule and within budget. This could entail tracking task completion, resource utilization, and other indicators using digital technologies like work order management software.

- Work order closure: After a work order is finished, it needs to be closed out in order to record the work that was completed and guarantee that maintenance records are current. This could entail updating equipment records, documenting the work that was done, and archiving the finished work order.

Effective work order management can help organizations reduce maintenance costs, improve equipment reliability, and minimize downtime, resulting in improved operational efficiency and financial performance.

5.5.3 Inventory Management

It involves maintaining and regulating the stock of materials and parts needed to support maintenance operations. In order to minimize inventory costs and waste and ensure that maintenance employees have the parts and supplies they need to accomplish maintenance activities, effective inventory management is essential. Some particular components of inventory control include:

- Inventory tracking: The first step in inventory management is to keep track of the supplies and parts used for maintenance. To keep track of inventory levels, consumption, and reorder needs, this may entail building an inventory database or employing inventory management software.

- Reordering: To ensure uninterrupted maintenance operations, parts and supplies need to be ordered again once inventory levels reach a predetermined threshold. To keep inventory levels within acceptable ranges, effective inventory management entails determining reorder points and reorder quantities.

- Inventory storage: It's important to safeguard maintenance tools and supplies from degradation and damage. To make sure that components and supplies are readily available and recognizable, this may entail using the proper storage facilities, shelving, and labeling.

- Inventory analysis: Continuous study of inventory levels, consumption, and costs is necessary for effective inventory management. This could entail performing routine inventory audits, keeping tabs on how much inventory is used and wasted, and looking for ways to save inventory expenditures.

- Supplier management: Successful inventory management includes maintaining supplier relationships in addition to inventory levels. To make sure that parts and supplies are supplied on time and at the acceptable quality level, this may involve negotiating costs, controlling lead times, and keeping an eye on supplier performance.

By lowering maintenance costs, enhancing equipment dependability, and reducing downtime, organizations can increase operational effectiveness and financial performance.

5.5.4 Performance Analysis

To discover areas for improvement and make wise decisions to enhance maintenance procedures, maintenance data must be analyzed. Maintenance managers can learn more about the effectiveness and efficiency of maintenance operations and spot areas for improvement by studying key performance indicators (KPIs). A few particular components of performance analysis are as follows:

- Data gathering: Gathering pertinent data from multiple sources, including maintenance logs, equipment monitoring systems, and work order management software, is the first step in the performance analysis process. KPIs including equipment downtime, mean time between failures (MTBF), and maintenance expenses may be included in this data.

- Data visualization: Following collection, data must be processed and presented in a form that is simple to comprehend. To present important information and spot trends, you might use data visualization tools like graphs or dashboards.

- Identification of the underlying causes of maintenance problems, such as equipment failures or excessive downtime, can be accomplished through performance analysis. Maintenance managers can take corrective action to avoid reoccurring problems by determining the source of current ones.

- Benchmarking: As part of performance analysis, maintenance operations may be compared to best practices or industry standards. This can point out chances for improvement and locations where maintenance operations could be improved (Adale (2009)).

- Continual improvement: A dedication to continual improvement is necessary for effective performance analysis. Maintenance managers may consistently enhance maintenance operations and increase operational efficiency by frequently examining performance data and making data-driven decisions.Effective performance analysis can help organizations reduce maintenance costs, improve equipment reliability, and minimize downtime, resulting in improved operational efficiency and financial performance.

Technical expertise, management abilities, and the utilization of digital technology are all necessary for efficient maintenance management. Organizations can increase equipment reliability, decrease downtime, and save maintenance costs by employing efficient maintenance management procedures.

5.6 Safety in Maintenance

The issue of safety holds utmost importance in maintenance operations across diverse industries and domains. The execution of maintenance tasks entails the handling of intricate equipment, machinery, and systems, which may pose inherent hazards if not appropriately controlled. Thus, it is imperative to establish a secure working environment and execute efficient safety protocols to safeguard personnel, avert mishaps, and preserve the authenticity of assets.

The domain of maintenance safety encompasses a broad spectrum of factors, such as the identification of hazards, evaluation of risks, implementation of safety protocols, provision of training, and continual monitoring. The process entails the execution of protocols and regulations aimed at reducing the likelihood of occurrences, harm to individuals, and impairment to machinery or physical structures.

The principal aim of safety in maintenance is to avert accidents and injuries through the detection and alleviation of hazards. The process entails performing comprehensive risk evaluations to detect plausible origins of danger, evaluating the probability and magnitude of occurrences, and executing suitable mitigation strategies to eradicate or diminish hazards. The adoption of a proactive approach empowers organizations to predict and tackle potential safety issues prior to their escalation.

The implementation of safety protocols and procedures is of utmost importance in providing guidance for maintenance activities. The protocols in question establish the requisite procedures, measures, and directives that maintenance personnel are required to adhere to in order to guarantee their own safety and that of their peers. The aforementioned topics encompass equipment lockout/tagout protocols, elevated work practices, hazardous substance management, electrical safety measures, and personal protective equipment (PPE) mandates. Compliance with these protocols serves to mitigate potential hazards and guarantees uniform safety procedures throughout maintenance operations.

The cultivation of skills and knowledge, as well as the development of proficiency, are fundamental components of ensuring safety in the field of maintenance. Adequate training is imperative to equip maintenance personnel with the essential expertise and abilities to execute their duties securely. The process involves acquainting individuals with the operation of equipment, procedures for maintenance, identification of hazards, protocols for emergency response, and appropriate utilization of safety tools and equipment. Continuous training and awareness initiatives ensure that staff members are kept abreast of the most current safety protocols, regulations, and industry benchmarks.

Systematic surveillance, examinations, and evaluations are carried out to ascertain adherence to safety standards and detect prospective opportunities for enhancement. These activities aid in the detection of any deviations from safety protocols, equipment malfunctions, or unsafe practices that may necessitate corrective measures. Through the monitoring of safety performance, organizations can consistently enhance their maintenance procedures and tackle any safety gaps or insufficiencies.

To summarize, the maintenance safety is a crucial element in guaranteeing the personnel's welfare and the assets' integrity. Through the implementation of comprehensive safety protocols, entities can mitigate the hazards inherent in maintenance operations, avert incidents, and foster a climate of safety. By implementing hazard identification, risk assessment, strict adherence to safety protocols, continuous training, and monitoring, maintenance operations can be carried out in a manner that is both safe and efficient, thereby minimizing the likelihood of incidents and fostering a healthy work environment.

5.6.1 Safety Barriers

In many industries, particularly the petroleum industry, safety barriers are crucial parts of risk management. They are created to avert, manage, or lessen the effects of probable risks and mishaps. In the context of the petroleum business, safety barriers are essential for securing assets, workers, and the environment.The efficacy of safety barriers is contingent upon their conception, execution, upkeep, and periodic evaluation. The implementation of safety audits, inspections, and drills facilitates the identification of potential vulnerabilities or deficiencies in protective measures, thereby allowing for the implementation of corrective actions. Moreover, a robust safety culture that involves active engagement and participation from all organizational levels is imperative to guarantee the appropriate utilization and efficacy of safety barriers.

The safety barriers implemented in the petroleum industry consist of both physical and operational measures that are designed to avert accidents, manage risks, and safeguard personnel, the environment, and assets. Risk management strategies incorporate them as a crucial component to guarantee secure and accountable operations. Making the distinction between what barriers are and what they do—that is, the method(s) by which they achieve their purpose—is a good place to start when developing a language. The first, referred to as the barrier functions, explains the various ways in which it is feasible to generally stop or defend against the uncontrolled transit of mass, energy, or information. The second section, titled "barrier systems," outlines the methods used to carry out the barrier functions.

Safety barriers are of paramount importance in safeguarding individuals, assets, and the environment across diverse industries and sectors. The aforementioned barriers function as protective measures that hinder or alleviate the likelihood of occurrences of incidents, accidents, and probable harm. Safety barriers are instrumental in upholding a secure working environment and mitigating the hazards associated with perilous activities by implementing multiple layers of defense.

Safety barriers can adopt diverse configurations, encompassing physical, procedural, and symbolic dimensions, each fulfilling a distinct function in mitigating or regulating hazards. Physical barriers refer to the implementation of physical structures, equipment, or devices with the purpose of establishing separation, containment, or protection. Procedural barriers encompass a set of established protocols, guidelines, and practices that serve to direct safe behaviors, operational procedures, and emergency responses. In contrast, symbolic barriers utilize communication and signage as a means of imparting safety-related warnings, instructions, and information.

The efficacy of safety barriers is contingent upon their capacity to identify and alleviate potential dangers, absorb or disperse energy, furnish timely notification, and curtail the ramifications of occurrences. The design of these systems aims to prevent unauthorized access, regulate the release of hazardous substances, provide protection against fire and explosions, reduce the impact of human error, and ensure adherence to regulations and industry standards.

Safety barriers are of utmost significance in industries such as oil and gas, transportation, manufacturing, and construction, owing to the elevated levels of risk associated with these sectors. The safety devices are incorporated within the comprehensive safety management framework and undergo routine evaluations, upkeep, and surveillance to guarantee their dependability and efficacy.

The notion of safety barriers is consistent with the "Swiss Cheese Model" of accident causation, which posits that the presence of several barriers is necessary to avert incidents. In the event of a barrier failure or weakness, supplementary layers of defense may serve to mitigate the incident's advancement.

In diverse industries, safety barriers are deemed essential components of a comprehensive safety approach. These tools are crucial for managing risks, preventing accidents, and safeguarding personnel, equipment, and the environment. Through comprehension of safety barrier principles and their implementation, entities can improve their safety culture and alleviate the potential hazards linked to their activities.

Barrier system	Barrier function	Example
Physical	Contain or protect. Prevent transporting something from the present location (release) or into another (intrusion)	Walls, doors, buildings, restricted physical access, railings, fences, filters, containers, tanks, valves, rectifiers, etc.
	Restrain or prevent movement or transportation of mass or energy	Safety belts, harnesses, fences, cages, spatial distance (gulfs, gaps), etc.
	Keep together. Cohesion, resistance	Components that do not break easily (safety glass).
	Separate, protect, block	Crumble zones, scrubbers, filters, etc.
Functional	Prevent movement or action (mechanical, hard)	Locks, equipment alignment, physical interlocking, equipment match, etc.
	Prevent movement or action (logical, soft)	Passwords, entry codes, action sequences, pre-conditions, physiological matching, etc.
	Hinder or impede actions (spatio-temporal)	Distance, persistence, delays, synchronisation, etc.
	Dampen, attenuate	Active noise reduction, active suspension
	Dissipate energy, quench, extinguish	Air bags, sprinklers, etc.
Symbolic	Counter, prevent or thwart actions (visual, tactile interface design)	Coding of functions, demarcations, labels & warnings (static), etc.
	Regulate actions	Instructions, procedures, dialogues, etc.
	Indicate system status or condition (signs, signals and symbols)	Signs (e.g., traffic signs), signals (visual, auditory), warnings, alarms, etc.
	Permission or authorisation (or the lack thereof)	Work permit, work order
	Communication, interpersonal dependency	Clearance, approval, (on-line or off-line), in the sense that the lack of clearance, etc., is a barrier
Incorporeal	Comply, conform to	Self-restraint, ethical norms, morals, social or group pressure
	Prescribing: rules, laws, guidelines, prohibitions	Rules, restrictions, laws (all either conditional or unconditional), etc.

Figure 5.2: Barrier System, Function, and Examples (Hollnagel (2007))

5.6.2 Barrier Systems

The following four kinds appear to be sufficient to characterize the potential barrier systems (Hollnagel (2007)) as seen also on Figure 5.2:

1. **Physical Barriers**: Material safeguards that physically exclude people, equipment, and the environment from potential dangers are known as physical barriers. They are intended to stop accidents from happening or lessen their effects. In the petroleum sector, some instances of physical barriers include:

    - Blast Walls: These structures are designed to withstand explosions and shield personnel and vital equipment from the effects of blast waves.
    - Containment Structures: These include bunds, dikes, or walls that are intended to contain spills or leaks, preventing them from spreading and lowering their impact on the surrounding ecosystem.
    - Fireproofing and Fire Barriers: To prevent fires from spreading and to safeguard people and property, fire-resistant materials, coatings, and fire barriers are used. Blast-resistant Modules: These modular buildings are built to withstand blast loads and offer personnel a secure haven in times of need.

2. **Functional Barriers**: Operational barriers are organizational and procedural controls meant to manage risks, stop accidents, and assure safe operations. They consist of:

    - Safety Management Systems: These systems establish thorough safety rules, practices, and protocols to direct operations and guarantee adherence to legal requirements. Risk analyses, emergency response plans, and people training programs are some of the components they contain.
    - Permit-to-Work Systems: By ensuring that work activities are appropriately permitted, managed, and monitored, these systems help to reduce the risk of snags and dangers.
    - Safety Procedures and Checklists: lay out the processes to be followed during various activities, ensuring that important safety precautions are not disregarded.
    - Safety Training and competence: Appropriate training programs and competence evaluations make sure that employees have the skills and information needed to carry out their duties in a safe and effective manner.
    - Monitoring and Alarms: Regular observation of process parameters, equipment performance, and environmental variables, along with alarm systems, offer early notification of deviations or abnormal circumstances, enabling prompt intervention.

3. **Symbolic Barrier Systems**: Systems of symbolic barriers function indirectly through their "meaning," therefore an act of interpretation by a third party is necessary. In today's world, symbolic barrier systems are pervasive, and we are constantly surrounded by a variety of signs and signals, warnings (by text or by symbol), alarms, etc. By delivering meaning through signs, signals, warnings, alarms, and other symbolic representations, symbolic barrier systems indirectly contribute to safety. These systems rely on people or other parties to read these symbols in order to comprehend the intended message and respond appropriately. Given the abundance of symbols and signals we encounter every day, symbolic barrier systems are pervasive and omnipresent in today's environment.

4. **Incorporeal Barrier Systems**: Which rely on the user's knowledge to accomplish their goals even though they are not physically present in the contexts where they are used. Organizational barriers, or standards for behavior that are imposed by the organization rather than being physically, functionally, or symbolically present in the system, are often referred to as incorporeal barrier systems in industrial environments. In addition, Human behavior and psychology play a crucial role in safety. Integral barrier systems can consider elements like risk perception, decision-making, motivation, and individual attitudes toward safety. The importance of encouraging safe conduct and fostering a culture of safety cannot be overstated. Also, Barrier systems must include clear safety policies,

procedures, and instructions. Even though they are not observable in the physical world, they offer a structure and set of guidelines for safe operations.

Safety barriers must be properly designed, put into place, maintained, and regularly tested in order to be effective. Drills, inspections, and safety audits all assist in locating weak points or gaps in the barriers and enabling necessary adjustments. For the efficient application and efficiency of safety barriers, a robust safety culture with active engagement and participation from all levels of the organization is also essential. Safety barriers are crucial for lowering the risk of accidents, as evidenced by the emphasis on their use in European regulations like the Seveso II directive (EC, 1996) and the Machinery directive (EC, 1998), national regulations like the Management regulation from the Petroleum Safety Authority Norway (PSA) (PSA, 2001), and standards like IEC (2010), IEC (2016), and ISO (2015).

5.6.3 Organizational Barriers

'Organizational barrier' is a term that is commonly used in safety discussions. Aside from the possibility that an organization could serve as a metaphorical barrier, the concept's popularity is likely due to the fact that organizations frequently start and implement barriers. However, rather than the organization as a whole, rules or procedures that are followed by people serve as the real barrier. Think about the situation of a work permit, for instance. Work is not supposed to be done if a work permit is not present. Despite this, work frequently begins before permission is granted because it is either anticipated to be granted or because it is hoped that an eventual *fait accompli* will result in the work permit being provided. This example demonstrates that a work permit is not a useful barrier system since, aside from the participants' morals, ethics, or fear of punishment, nothing about the actual system of execution precludes the acts from being carried out. A work permit in this classification is more of a symbolic barrier system because it is only a token, and its usefulness depends on how it is interpreted. Therefore, even when a work originates from an organization, classifying it as an organizational barrier is not logical (Hollnagel (2007)).

5.6.4 Composite Barrier Systems

Barrier systems frequently work together to provide effective barriers. For instance, speed bumps (physical), road signs (symbolic), and occasionally traffic police (functioning as a symbolic barrier system if they are visible and as a functional barrier system if they are unseen) can enhance the general speed limitations (incorporeal) provided by the traffic rules. Physical and functional barrier systems are typically necessary for symbolic and incorporeal barrier systems to function. Symbolic barrier systems can be used in conjunction with physical and functional barrier systems to promote their use. When it comes to physical and functional barrier systems, the system itself fulfils the necessary barrier function. When it comes to symbolic and incorporeal barrier systems, the systems themselves are unable to serve as barriers; instead, someone (or perhaps something) else must take action. The barrier function, which is given by the barrier system, is thus implemented by the action. This is not merely a play on words because it might have important repercussions to know which barrier functions a certain action serves and whether it was motivated by an instruction (a symbolic barrier system) or a sense of responsibility (an incorporeal barrier system) (Hollnagel (2007)).

5.6.5 Functions of Barrier Systems

Barrier systems' main purpose is to add additional levels of defense to prevent accidents or lessen their effects. The functions of barrier systems typically include (Paltrinieri (2022), Sklet (2005), and Liu (2020)):

- Preventive Function: Barrier systems are designed to prevent accidents or incidents before they start. This can be accomplished in a number of ways, including by creating safety procedures, educating and training staff, performing risk assessments, and utilizing the proper tools and technologies.
- Protective Function: In the case of an accident or incident, barrier systems protect people, the environment, and assets. Physical barriers that offer defense against certain risks or hazards include containment buildings and personal protective equipment.
- Control Function: Barrier systems aid in preventing the escalation or spread of accidents or incidents. For instance, blast-resistant modules or fireproof walls can contain the impacts of explosions or limit the spread of fires, preventing additional hurt or damage.
- Warning Function: Barrier systems may have alarms or warning devices that notify staff to potential risks or changes from the usual. These alerts give the chance for prompt risk mitigation and intervention.

While the primary goals of barrier systems are to provide physical and operational security, it is crucial to remember that they may also serve symbolic purposes related to safety culture and communication. Safety signs, labels, and other symbolic cues can be used to communicate safety information, remind people to follow safety procedures, or reinforce the safety culture within an organization. It is less typical, though, to refer to these components as "symbolic barrier systems."

5.7 Maintenance Effectiveness

For manufacturing factories, electrical generation and distribution systems, airline operations, as well as facilities like buildings, roads, and bridges, maintenance management (MM) is crucial. Financial performances would undoubtedly suffer from a lack of effective MM. Additionally, such could result in dangers to human safety and fatalities. Finding an efficient MM is a difficult undertaking.

Maintenance deals with situations that are highly unpredictable and irregular. It is largely beyond automation and heavily depends on human expertise and talents. It is quite difficult to do maintenance tasks satisfactorily without a thorough and organized strategy. The ability of a maintenance program to guarantee that equipment performs dependably and efficiently throughout its lifecycle is referred to as maintenance effectiveness. It is a gauge of how successfully maintenance tasks accomplish their stated purposes, such as raising uptime, lowering downtime, cutting maintenance expenses, and raising equipment performance.

An alternative approach to preventive maintenance, which does not rely on predetermined clock time or duration of operation, involves monitoring the machines' conditions and making maintenance decisions based on this information. The aforementioned practice is commonly referred to as condition-based maintenance (CBM). The surveillance of the prevailing circumstances can be carried out in a continuous manner, utilizing various instruments, or periodically through inspections.

Identifying certain indicators may be possible, however, the challenge of forecasting potential failures based on circumstances persists and holds significance in the realm of Condition-Based Maintenance (CBM).

Maintenance authors have employed various artificial intelligence techniques, such as fuzzy sets and neural networks, to develop models and facilitate decision-making in the field of maintenance. Effective implementation of models may require significant human expertise in addition to data. In certain circumstances, however, these methodologies have demonstrated considerable efficacy. Several meta-approaches have been proposed for the purpose of maintenance. Reliability centered maintenance (RCM) and total productive maintenance (TPM) are widely recognized as significant approaches in the field. The Reliability Centered Maintenance (RCM) approach places significant emphasis on the development of maintenance policies for large machinery, utilizing statistical lifetime distributions and other structured methods to ensure appropriateness and comprehensiveness. The RCM methodology is closely related to statistical modeling and optimization techniques. The concept of Total Productive Maintenance (TPM) emphasizes the significance of employee involvement in maintenance at the lower organizational levels, as well as the prevention of critical maintenance issues through the implementation of regular routine maintenance activities.

Several obstacles hinder the achievement of satisfactory maintenance management, including insufficient knowledge of plant and process, inadequate historical data, time constraints for conducting necessary analyses, insufficient support from top management, and apprehension regarding potential disruptions and interference with production and operations (Sinha (2015)).

5.7.1 Equipment Reliability

The understanding of how the machines deployed in the organization are designed, how these work, how these may fail, and how these failures may be corrected will surely be necessary for satisfactory maintenance of machines and equipment.We draw attention to the following points in particular. These should be taken into consideration by MM choices. Our recommendations in the section below are based on these findings.

Failures due to Materials Deterioration

The development of an effective maintenance strategy is contingent upon possessing sufficient comprehension of the underlying failure mechanisms and observable patterns in the failures of utilized machinery and equipment. The majority of machine structures, components, and related elements are composed primarily of metallic materials and alloys. Fatigue or creep frequently causes failure in metallic components. Fatigue pertains to the decrease in strength resulting from the repetitive application of load cycles, while creep denotes the reduction in strength due to the prolonged application of load. The intricate nature of the mechanisms responsible for these failures is contingent upon a multitude of factors. The occurrence of failure is contingent upon the loading pattern, and it is not feasible to predict failures solely based on clock time, unless there is minimal variation in the loading pattern, operational environment, and other relevant factors. The metallic composition of electrical machines, including motors, transformers, and their respective components, is a notable characteristic. Furthermore, the significance of insulating failures composed of polymer materials and other similar substances cannot be overlooked. The assemblage of integrated circuit chips, transistors, and diodes constitutes the electronic instruments utilized for the purpose of monitoring and regulating machinery. These components are produced using processing materials at a small scale, utilizing advanced techniques such as very large scale integration. Under typical circumstances, the deterioration of said components is minimal. The primary causes of component failure are attributed to manufacturing defects and overloading.

Failures due to Manufacturing Defects

An appropriate design of a component would consider the necessity for it to maintain operational integrity under "normal conditions" for an extended duration without experiencing failure. In the field of engineering, this is a customary procedure in the process of designing. Metallic components are commonly designed with a factor of safety or damage tolerance, taking into account even microscopic defects, to ensure a minimum lifespan of 25 years under assumed normal operating conditions. Nevertheless, failures may occur in such components well in advance of that timeframe. There may exist two potential explanations for this phenomenon. Either an anomalous operational circumstance has occurred, or a macroscopic manufacturing flaw has expedited the component's failure. The implementation of quality control measures in manufacturing, encompassing the assessment of raw materials and the assembly of component parts, holds significant influence over the durability of a given component and, by extension, the machinery in which it operates. This phenomenon is also relevant to electronic components. Soldering defects, such as manufacturing defects, assume significance for such commodities. Components composed of ceramics, glass, polymers, rubber, wood, paper, and other similar materials are more susceptible to failure and are subject to restrictive operating conditions. In certain instances, this may necessitate particular consideration. Frequently, a failure of said component has the potential to impede the progression of operational or production activities for a significant duration.

Failures due to Low Quality of Maintenance Repairs

The occurrence of recurrent failures can be attributed to substandard repair work. Inadequate craftsmanship during maintenance procedures has the potential to result in subsequent failures in a prompt manner. This is a common occurrence in practical scenarios. Instances of this phenomenon have been documented in various settings, such as power generation facilities, aircraft systems, and following maintenance procedures.

Failures due to Abnormal Operating Conditions

Failures frequently occur as a result of atypical operational circumstances. Aberrant operational circumstances may pertain to variations in electrical voltage, current, power, frequency, and the like. Additionally, extreme ambient temperature and humidity levels, foreign body interference, such as the infiltration of debris into the machinery, or the presence of dust, among other factors, may also contribute to such conditions. Aberrant operational circumstances may arise as a result of insufficient awareness that a specific apparatus is not designed for the prevailing conditions, or owing to an unseasoned operator. Occasionally, a circumstance may arise that is beyond one's ability to manage. It is imperative that one possesses sufficient knowledge regarding potential deviations from typical operational circumstances. It is imperative to maintain a consistent and ongoing endeavor to comprehend such aberrations to a greater extent, and enhance designs and operational protocols to mitigate their occurrence. The thermal power plant examples can be taken into consideration in this context. The reliability of power plants has exhibited a consistent upward trend due to the augmentation of knowledge and automation of plant control through sophisticated electronic devices and computer programs.

5.7.2 An Actionable Program for Effective MM

This section proposes a series of steps that, based on the preceding discussions, are deemed to be logical in attaining effectiveness and efficiency in MM. The implementation of such steps can be achieved with relative ease. The present set of procedures is referred to as an Actionable Program for Maintenance (APM). The following is a seven-point program that can be used to describe these.

Design a Routine Maintenance Program (RMP)

The RMP may encompass rudimentary visual scrutiny of the machinery, such as identifying worn-out bolts or visibly damaged belts. Additionally, it may involve lubricating bearings, periodically painting the machinery, cleaning the equipment, and covering it with a protective cover when not in use. The aforementioned activities are generally low-cost, yet yield significant advantages. TPM advocates for the implementation of regular maintenance procedures. The development of activities and schedules for the RMP ought to be grounded on the expertise of professionals, given that quantitative models may not be feasible for this objective. It is recommended that the RMP be closely implemented.

Control the Operating Conditions

It is imperative that a comprehensive and accurate understanding of the standard operational parameters of various machinery is established. Preventing failures can be achieved by ensuring the provision of suitable operating conditions. Regulating the operating conditions may entail managing the electrical power provision, regulating the ambient temperature, humidity, and other similar measures. It is imperative that an individual be sufficiently trained before being authorized to operate a machine as an operator. Sufficient measures ought to be taken to regulate the operational parameters. The expenses associated with regulating the operational parameters must be weighed against the expenses incurred due to malfunctions. Efficient control mechanisms may facilitate the prevention of numerous failures with minimal exertion. The RateMyProfessors platform may also serve as a resource in this regard. Occasionally, unforeseeable and inevitable deviations from standard operating conditions may occur. Comprehensive understanding of these anomalies is imperative, and adequate readiness must be established to effectively address such potentialities.

Determine an Optimum Maintenance and Replacement Policy for Each Major Machine

A maintenance policy aimed at preventing equipment failure can be established based on either clock time, usage, or conditions. If there exists conclusive evidence that a machine or component undergoes aging over time or usage, and if an efficient preventive maintenance policy can be established, then it is advisable to employ statistical or other relevant techniques to determine the same. When a sufficient amount of failure data pertaining to a machine is obtainable, it may be feasible to undertake the development of stochastic models. In certain instances, CBM may also be deemed suitable. The utilization of the maintenance engineers' expertise is imperative in making informed decisions. In situations where the potential benefits of a preventive maintenance policy are uncertain, a "maintain on failure only" policy may be employed. This may be applicable in numerous instances where such a policy represents the optimal solution. Simultaneously, it is imperative to establish a system that enables the effective implementation of a "maintain on failure only" approach. Adequate readiness measures, including troubleshooting tools and techniques, spare parts, and personnel, should be in place to address potential failures. In various practical scenarios, a viable approach to preventive maintenance could be referred to as the "component-level condition-based opportunistic maintenance policy." The maintenance of a complex machine, consisting of numerous components, is performed solely in response to malfunctions or as part of planned maintenance procedures. During each instance of repair or overhaul failure, it is necessary to observe the conditions of the components. Drawing from these observations, it is possible to either replace a component with a new unit or to maintain its current state. It is recommended that decisions be made utilizing an appropriate optimization model, to the extent feasible. The optimization criterion ought to be the cost incurred per unit of time, within a specified duration. In cases where precise analytical models are unattainable, simulation models can serve as a viable alternative. The process of making decisions regarding the replacement of machines is of significant importance and must be executed in an appropriate manner. It is not advisable to continue utilizing a machine beyond its designated lifespan.

Control Quality of Maintenance Actions

Sufficient provisions ought to be made for post-repair testing to ensure that the repair has been executed in accordance with the intended plan. The criticality of quality control in maintenance management cannot be overstated. It is imperative to conduct a comprehensive assessment of a machine's suitability both prior to its installation and subsequent to any repairs. It is imperative to establish a set of procedures aimed at preventing the occurrence of malfunctions resulting from manufacturing flaws in machinery. Conducting sufficient pre-launch inspections and trial runs are among the recommended measures.

Schedule Maintenance Actions

If there are insufficient resources such as manpower and maintenance equipment to carry out maintenance actions simultaneously, then it is necessary to schedule maintenance activities appropriately. It is advisable to employ optimization models to the greatest extent feasible. It is noteworthy that procrastination in executing maintenance measures can result in reduced periods of operation and other associated issues.

Plan for Resources as Spare Parts, Manpower

It is imperative to effectively strategize the aforementioned resources in order to achieve equilibrium between the expenses incurred due to insufficient supply and excess capacity. In this context, it is advisable to utilize optimization models whenever feasible. The planning of spare parts inventory can be based on demand patterns, which may be subject to approximation. Significant advantages can be achieved even in scenarios where this process is not executed systematically, as opposed to an improvised approach.

Manage Knowledge for Maintenance

It is imperative to store data pertaining to machine designs, working conditions, specifications, and other relevant information. Efficient retrieval of information can be achieved with ease and convenience as and when needed. Reliability data may be provided by manufacturers or suppliers. It is important to preserve records of instances of failure. Case studies pertaining to significant failures can be formulated and archived. The dissemination of this knowledge is intended for employees who are responsible for tasks such as troubleshooting and repairing. It is imperative to ensure sufficient provisions for employee training. The significance of providing on-the-job training should be duly acknowledged. The utilization of maintenance event case studies within an organization's training program is a viable option. The implementation of the aforementioned steps can be effectively facilitated by a maintenance management information system that operates through computer technology. Decision support systems can be designed to aid in decision-making processes that rely on optimization models. Automating decisions is a viable option, provided it is feasible.

5.7.3 Total Productive Maintenance (TPM)

The implementation of TPM has been shown to be a highly efficacious approach for enhancing industrial efficiency. TPM originated in Japan during the 1970s and demonstrated significant efficacy in improving the efficiency and financial performance of numerous Japanese enterprises. The concept of Total Productive Maintenance (TPM) has gained widespread acceptance among

Japanese industrialists and has piqued the curiosity of industrialists in various countries across the globe. According to Nakajima (1988), TPM is characterized as a form of productive maintenance that entails complete participation. This approach encompasses various elements, including:

- The primary objective of TPM is to optimize the efficiency of equipment.
- The implementation of TPM involves the establishment of a comprehensive preventive maintenance (PM) system that covers the entire lifespan of the equipment.
- The execution of TPM is carried out by multiple departments, including engineering, operations, and maintenance.
- Total Productive Maintenance (TPM) is a comprehensive approach that encompasses all members of an organization, ranging from upper-level executives to frontline workers.
- The TPM methodology is centered around the advancement of project management by means of incentivizing and overseeing self-directed team initiatives.

The final two elements are typical Japanese concepts that align with the principles of total quality management and complete employee engagement. In several foreign nations, corporations are structured such that maintenance and operations are distinct entities. As a result, the adoption of TPM by non-Japanese organizations redirects focus from "comprehensive employee engagement" to equipment efficiency. According to Hartmann (1992) introduction of TPM to multiple companies in the United States, the active participation of operators in the process results in a sustained enhancement of equipment efficiency. This improvement is said to be long-lasting in nature. TPM can be defined and characterized by two primary features, as outlined in the provided definitions. Of the two features, equipment management is deemed the most crucial. One of the most significant assets of a manufacturing company is its production equipment. The measure of return on assets is commonly assessed through the utilization of assets. Equipment utilization is frequently observed to be significantly low in numerous instances. Therefore, it is imperative for any organization to implement a robust equipment management program that focuses on enhancing asset utilization in order to remain competitive and profitable. Therefore, the emphasis of TPM is on equipment management. The second significant characteristic of TPM is the provision of authority to the workforce. The demarcation between maintenance, production, and engineering departments is frequently a cause of reduced efficiency, increased expenses, and diminished productivity. The implementation of TPM necessitates a mutual understanding between operators and mechanics, as they share a common objective and must therefore collaborate and foster a collective sense of teamwork (Ben-Daya (2000)). The goals of TPM include, but are not limited to, the following:

- improve product quality;
- reduce waste;
- improve the state of maintenance; and
- empower employees.

The attainment of these objectives is facilitated by a meticulous execution of the principles of staff empowerment and effective equipment administration. The significance of the operators' participation in the achievement of Total Productive Maintenance (TPM) cannot be overstated. One feasible strategy for attaining this objective involves adopting a methodical methodology for proficiency, whereby a qualified and accredited operator can execute a mechanical duty, and conversely. The collaboration between the operations and maintenance departments yields numerous advantages.

- The development of multiple skills among operators and mechanics results in job enrichment and enhanced flexibility of the workforce.
- The participation of operators in regular maintenance activities fosters a feeling of accountability, satisfaction, and possession.
- The reduction of delay times leads to an increase in productivity.
- Facilitating collaboration between the operations and maintenance departments to enhance teamwork.

The main emphasis of TPM is on the equipment. The initial step involves the identification of significant equipment losses. According to Nakajima (1988), there are six losses that restrict the efficiency of equipment:

1. equipment failure (breakdown);
2. setup and adjustment downtime;
3. idling and minor stoppages;
4. reduced speed;
5. process defects; and
6. reduced yield.

The primary objective of TPM, concerning machinery, is to optimize its efficiency to the maximum possible extent and sustain it at that level. The aforementioned losses can be mitigated through comprehension and implementation of strategies aimed at their elimination. The implementation of a proficient preventive maintenance (PM) regimen is necessary to ensure optimal equipment performance and efficiency. The implementation of a PM program can be significantly enhanced through the involvement of RCM. Initially, it is imperative to define the term RCM.

5.7.4 Maintenance and The Reliability Centered Maintenance (RCM)

RCM is a maintenance strategy used to determine what must be done to ensure that any physical asset continues to do what its users want it to do in its present operation context. RCM combines various types of maintenance intending to optimize efficiency and holds great significance in the maintenance field, making it crucial to address it thoroughly in this report. Consequently, comprehensive explanations have been included to provide a clear understanding of the topic. The incorporation of this concept into the industry has only recently emerged within the last decade. The maintenance efforts are focused on the parts and units that are critical for reliability.

Background and The Value of RCM

RCM is a novel approach in the American aviation industry that employs leading Net specialists and extensive damage findings to reduce the impact of technical damages on passenger planes. This method has resulted in a significant reduction of approximately 40.0.1 drops in a million. Concurrently with this advancement, the utilization of RCM logic has led to a noteworthy reduction in the duration of aircraft maintenance operations, while simultaneously enhancing their effectiveness and profitability. United Airlines allocated a total of 60,000 man-hours towards conducting significant structural assessments on their Boeing 747s, prior to the 20,000-hour threshold for the initial comprehensive structural inspection of the aircraft. According to conventional maintenance policies, the accomplishment of a heavy structural inspection of the DC-8 aircraft, which is smaller and less complex, would necessitate over four million man-hours to attain the equivalent interval. The substantial decrease in costs as mentioned herein denotes a noteworthy enhancement for any establishment that possesses a vast array of intricate machinery. It is noteworthy that cost reductions have been achieved without compromising reliability. Moreover, a deeper comprehension of the failure mechanisms in intricate machinery has been attained, leading to enhanced reliability through the facilitation of preemptive measures. The temporal manifestation of specific indicators of potential malfunction has exhibited an increase. The utilization of reliability-based net logic in the aviation sector has been paralleled by its application in various other industries. It is noteworthy that during the 1980s, South Africa was the pioneer in the widespread adoption of Reliability Centered Maintenance (RCM) in industries beyond aviation. Despite the embargo conditions prevailing in the country at that time, the implementation of this approach yielded significant advantages. Acquired by industrial entities in South Africa. Upon the determination of the efficacy of RCM in industrial settings, even under the challenging conditions of embargo, there has been a notable interest among major industries in other nations to adopt this approach.

RCM is a structured approach to determining optimal maintenance tasks. This analysis takes into consideration the risks upon failure, the failure characteristics and the cost of maintenance to evaluate whether a task is required or not. It is used to optimize a company's or facility's maintenance program. RCM assesses the most crucial business operations and then works to improve maintenance practices to reduce system failures and eventually boost equipment availability and reliability (Usman et al. (2021)).

The most important assets are those with high failure rates or serious repercussions. This maintenance approach identifies potential failure mechanisms and their effects while taking into account how the equipment will operate. Then, it is possible to decide on cost-effective maintenance strategies that reduce the likelihood of failure. The most efficient methods are then used to raise the facility's reliability. From Figure 5.3, it is showed the workflow of RCM.

RCM analysis reveals the most suitable maintenance approach preventive maintenance, predictive maintenance, reactive maintenance for each piece of equipment. In some instances, more than one approach is suitable and can be used on a particular asset. It is a maintenance strategy that provides an optimum combination of different maintenance strategies like corrective, preventive, predictive and pro-active maintenance. It considers that a single maintenance strategy is not applicable in every situation. For example, we cannot apply a predictive or pro-active strategy on the headlight of a car or similarly, we cannot use a corrective maintenance strategy for a critical pump. Hence, it is always better to select an appropriate or a combination of a suitable strategies for maintenance of critical industrial equipment (TP AIM (2020)).

The significance of Reliability-Centered Maintenance (RCM) in the field of maintenance is attributed to its capacity to optimize expenditures, enhance equipment dependability, augment safety measures, ensure adherence to regulatory standards, prolong the lifespan of assets, allocate resources efficiently, and promote knowledge management. The implementation of RCM principles and practices can enable organizations to attain elevated levels of asset reliability, availability, and performance, while simultaneously mitigating maintenance expenses and hazards.The following points illustrate why RCM is so important in maintenance:

Cost Optimization

The implementation of Reliability Centered Maintenance (RCM) enables organizations to enhance cost-effectiveness of maintenance activities by directing their resources towards crucial assets and potential failure modes. RCM methodology ensures that maintenance activities are focused on the most critical assets by identifying the optimal maintenance tasks for each asset. This approach helps to minimize ineffective or unnecessary maintenance efforts. The aforementioned methodology aims to reduce maintenance costs while simultaneously optimizing the dependability and accessibility of resources.

Improved Equipment Reliability

Reliability-centered maintenance (RCM) endeavors to avert equipment failures by taking proactive measures to identify and mitigate potential failure modes and their root causes. RCM aids organizations in devising efficient preventive maintenance plans and strategies by scrutinizing failure modes, their repercussions, and suitable maintenance actions. The aforementioned results in enhanced equipment dependability, decreased periods of inactivity, and better overall asset efficacy.

Enhanced Safety and Risk Mitigation

The Royal Conservatory of Music places significant emphasis on safety as a crucial component of maintenance. Through a methodical evaluation of potential failure modes and their corresponding risks, the Reliability Centered Maintenance (RCM) approach empowers organizations to prioritize maintenance activities aimed at mitigating safety hazards. The adoption of a proactive approach aids in the prevention of equipment failures that may result in accidents, injuries, or environmental hazards, thereby guaranteeing a safer work environment.

Regulatory Compliance

The application of RCM methodology assists organizations in fulfilling regulatory obligations and adhering to maintenance-related standards. RCM methodology guarantees adherence to regulations, industry benchmarks, and legal responsibilities by identifying crucial maintenance activities and ensuring their execution. The implementation of such measures diminishes the likelihood of incurring penalties for non-compliance and promotes a culture of responsibility and conformity to regulatory standards.

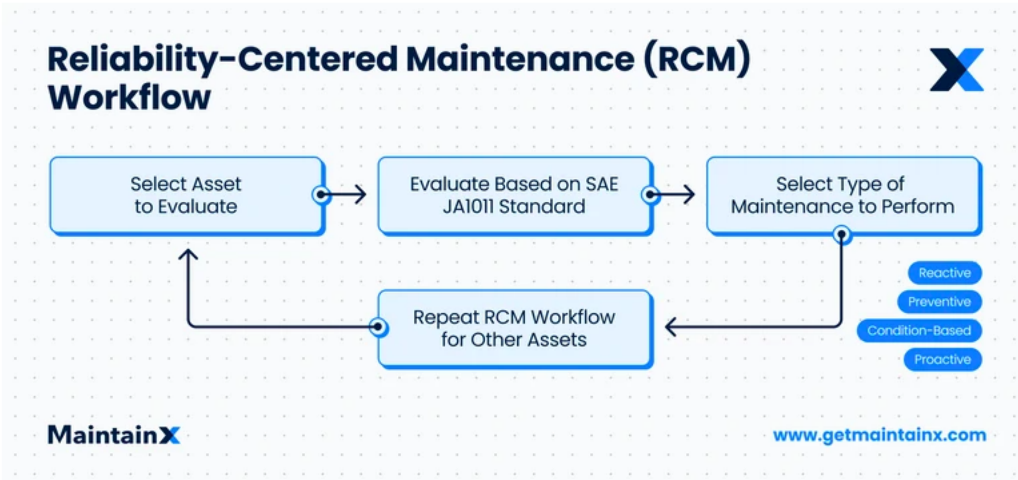

Figure 5.3: RCM Visualization from Eisner (2022)

Optimal Resource Allocation

The execution of Reliability Centered Maintenance (RCM) methodology facilitates the efficient allocation of maintenance resources within organizations. Efficient allocation of resources, including manpower, spare parts, and equipment, can be achieved by organizations that possess an understanding of asset criticality, failure consequences, and maintenance requirements. This practice guarantees that resources are allocated in a manner that maximizes their influence on the dependability and efficiency of assets.

Knowledge Management

The use of RCM methodology enables the acquisition and dissemination of knowledge within the maintenance entity. Reliability Centered Maintenance (RCM) facilitates the development of a repository of information that can be utilized by maintenance staff through the documentation of failure modes, maintenance tasks, and optimal procedures. The implementation of standardized and efficient maintenance procedures guarantees uniformity and efficacy in maintenance operations, even in the event of staff changes, ultimately resulting in enhanced maintenance results.

Drawbacks of RCM

RCM does not readily consider the total cost of owning and maintaining an asset. Additional costs of ownership, like those considered in evidence-based maintenance, are not considered, and are therefore not factored into the maintenance considerations.

The RCM Process

Although there are many different ways to apply RCM, most methods include some or all of the phases listed below. Reliability oriented maintenance can be implemented using a variety of techniques, which are condensed into the following 7 phases.

1. **Selection of equipment for RCM analysis**: The first step is to select the piece of equipment for reliability centered maintenance analysis. The equipment selected should be critical in terms of its effect on operations, its previous costs of repair, and previous costs of preventive maintenance.

2. **Define the system boundaries and functions**: The equipment belongs to a system that performs a crucial function. The system can be large or small, but the function of the system, and its inputs and outputs, should be known.

3. **Define the ways in which the system can fail (failure modes)**: In step 3 the objective is to list all of the ways that the function of the system can fail.

4. **Identification of the root causes of the failure modes**: With the help of operators, experienced technicians, RCM experts and equipment experts, the root causes of each of the failure modes can be identified.In case of a failure, there is a potential for safety hazards and adverse impact on business operations, as well as the likelihood of affecting other machinery. In order to effectively tackle this issue, it is imperative that a collective endeavor is undertaken by plant operators, equipment specialists, and technicians to ascertain the root causes of every instance of asset malfunction. Through this approach, the team can establish a hierarchy of tasks and formulate a comprehensive strategy to tackle the identified challenges.

5. **Assess the effects of failure**: In this step, the effects of each failure mode are considered. Equipment failures may affect safety, operations, and other equipment. The criticality of each of these failure modes can also be considered. There are various recommended techniques that are used to give this step a systematic approach. These include:

    - Fault Tree Analysis (FTA) The aforementioned graphical instrument facilitates the analysis of the root cause of failures occurring at the system level. The approach employed involves a deductive analysis of failure from a top-down perspective, aimed at identifying potential points of failure.
    - Failure Modes and Effects Analysis (FMEA) The present approach assesses the ramifications of prospective failures through the identification of the specific locations and mechanisms by which a given process may experience failure. As an illustration,

it can aid in identifying the variables that could potentially lead to a deceleration or cessation of operation in the conveyor belt.

- Failure, Mode, Effect, and Criticality Analysis (FMECA) This approach bears resemblance to the Failure Mode and Effects Analysis (FMEA) methodology, albeit incorporating an extra phase to establish interrelationships among failure modes, effects, and underlying causes of failure.
- Hazard and Operability Study (HAZOP) The present study involves a methodical analysis of procedures aimed at detecting potential risks that may pose a threat to individuals and resources. Typically, it provides direction for the evaluation of established protocols.
- Risk-Based Inspection (RBI) The RBI methodology is a systematic approach that aims to optimize inspection plans through a rigorous decision-making process. The primary application of this technique is the inspection of industrial machinery, specifically piping systems, pressure vessels, and heat exchangers.

Using this step, the failure modes that have a high probability of occurrence in operating conditions are given the highest importance and strategies are designed to avoid them in operation.

6. **Select a maintenance tactic for each failure mode**: At this step, the most appropriate maintenance tactic for each failure mode is determined. The maintenance tactic that is selected must be technically and economically feasible. Condition-based maintenance is selected when it is technically and economically feasible to detect the onset of the failure mode. Time or usage-based preventive maintenance is selected when it is technically and economically feasible to reduce the risk of failure using this method. For failure modes that do not have satisfactory condition-based maintenance or preventive maintenance options, then a redesign of the system to eliminate or modify the failure mode should be considered.

7. **Implementation and Continuous Improvement**: Importantly, the RCM methodology will only be useful if its maintenance recommendations are put into practice. When that has been done, it is important that the recommendations are constantly reviewed and renewed as additional information is found.

RCM Tools (FMEA/FMECA)

If the analysis is organized in accordance with the specifications of IEC-608121, the failure mode and effects analysis (FMEA) and criticality technique (FMECA) can be applied to RCM.

In order to lessen the sources of variation and failures in the production of weapons, FMEA was initially widely adopted by the defense industry in the 1940s. It has now developed into one of the most used methods for risk identification. It is a crucial instrument in the manufacturing, petrochemical, transportation, and defense sectors. Due to a particular kind of criticality evaluation, Failure Modes, Effects and Criticality Analysis (FMECA) differs from FMEA. Reliability engineers can assess each probable failure's severity level and likelihood of happening using FMECA. FMEA and FMECA are analyses that are frequently mistakenly thought to be performed independently of or in instead of RCM. Instead, the RCM process's initial steps result in an FMEA, and data from an FMECA serves as one of the process' main inputs.

Regardless of the kind or goal of the FMEA, the fundamental FMEA process entails several key processes to complete a value-added FMEA. Additionally, each of these large phases may contain a number of smaller ones. The first step after forming an FMEA team is to scope the work, which increases the possibility that it will be completed successfully.

The team then defines the concentrated FMEA effort's interfaces so that the effects can be determined. Then, using team members' experiences with the FMEA focus area as well as any available failure history, the major components of the FMEA focus are defined (and further broken down as needed), along with each of their failure modes, root causes, failure indicators, failure criticalities, failure probabilities, and effects. The more successful FMEA efforts take this analysis, add mitigation tasks and frequencies for each candidate key characteristic, and then choose which mitigation tasks to implement. This ensures that the chosen mitigation tasks add value by either identifying failure at the beginning of its failure mode or preventing a failure from occurring in the first place.

Formally recording the chosen mitigation measures once they have been chosen has proven to be essential for their effective implementation. An ideal predictive maintenance and preventative maintenance plan is built on the formal document mentioned earlier. Any maintenance chores that are already being carried out should be noted in this ideal maintenance plan because they will affect the implementation strategy. Finally, any spare parts or specialist training required for people (operations and maintenance) to carry out the maintenance plan should be included in this formal document.

Relation Between RCM and Other Maintenance Techniques

The decision of whether to apply total quality management (TQM), TPM, or RCM for world-class maintenance of their process and manufacturing plants is one of the biggest challenges maintenance managers face today. You need both strategies if you want top-notch maintenance and the high operational performance that goes along with it. Understanding how the two systems work together to provide you with the best solution is the key; it's not a "either or" situation.

Each method, including TPM and RCM, has its own advantages and disadvantages. The five

TPM pillars encourage company-wide participation in maximizing efficiency through involvement in maintenance and improvement activity, which is one of its key strengths. However, this method has a drawback. The described methodology is very simplistic and falls short of emphasizing the significance of establishing process functions and performance standards. It also fails to provide a sound methodology for identifying the most effective preventative measures and the most appropriate timing for interventions. As a result, businesses that implement TPM frequently engage in activities that have little value or, worse, may have a negative impact on the performance of equipment. On the other hand, RCM is a very thorough, scientific, and reliable methodology for determining why processes might fail to deliver the necessary functions to the necessary standard of performance and suggests the most suitable technical solution and frequency based on a thorough evaluation of the failure mechanism.

The drawback of RCM is that it necessitates the involvement of all employees, from management to operators, in the comprehension, use, and execution of the system. Unfortunately, many industries fail to see the need of incorporating the entire team and instead place an excessive emphasis on a maintenance solution including maintenance staff. They mistakenly believe that RCM is a tool for optimizing maintenance when, in fact, it is a platform for attaining Operational Excellence.

Recognizing the advantages and disadvantages of each maintenance methodology, combining all the autonomous small-group activities related to TPM/TQM and other related technologies with the reliable scientific failure prevention methods described by RCM, and using them in tandem to multiply their effects to achieve an optimal solution for system reliability, employee engagement, and autonomous maintenance is a better way to implement world-class maintenance. Below, we take a closer look at a case study emphasizing the value of combining several maintenance methods to achieve the desired machine performance and world-class maintenance (Usman et al. (2021)).

Chapter 6

Conclusion and Discussion

6.1 Summary

The effectiveness, efficiency, and sustainability of maintenance are all increasing, and we may learn more about these ways by looking at the new strategies, technologies, and procedures that are behind them. Several important key trends, including preventative maintenance, digitalization, condition-based monitoring, sustainability, and the integration of maintenance into asset management, are explored in the report. These developments are changing the approach to maintenance from reactive to proactive and data-driven. Organizations can boost operational performance by using these trends to increase asset reliability, decrease unscheduled downtime, and fine-tune maintenance plans.

The implications of maintenance trends for maintenance decision-making, resource allocation, and talent cultivation are also investigated in the research. It will stress the value of integrating maintenance teams with other stakeholders and using data analytics and cutting-edge technologies to get things done. The result from a thorough analysis of the trends that will determine the future of maintenance, empowering businesses to make smarter choices, try new approaches, and enhance maintenance operations on the fly.

Organizations that care about asset performance, downtime, and long-term sustainability would do well to devote resources to research into maintenance management and related developing trends.

6.2 Discussion

The execution of maintenance management activities is a crucial component in attaining operational excellence and maximizing the performance of assets. By implementing strategic planning, efficient execution, continuous monitoring, and evaluation, organizations can optimize maintenance effectiveness, minimize expenses, enhance reliability, and guarantee the enduring viability of their assets. Through the implementation of effective strategies and the adoption of optimal methodologies, enterprises can cultivate a proactive maintenance culture and enhance their prospects for success within a highly competitive and intricate commercial landscape.

Improving reliability requires taking steps to improve asset availability and performance. This can be achieved by proactive maintenance, thorough inspections and condition monitoring, root cause analysis, optimized maintenance schedules, and reliability-centered maintenance (RCM). Preventive maintenance, predictive analytics, and continuous improvement help firms detect hazards, mitigate them, and assure asset reliability. This may improves operational efficiency, downtime, customer happiness, and organization performance.

Optimizing maintenance performance and cost-efficiency requires techniques and procedures. This can be achieved by Preventive and predictive maintenance, data and analytics for condition monitoring and predictive analysis, robust planning and scheduling, proper resource allocation, and continuous evaluation and improvement based on performance indicators. Proactive maintenance, data-driven insights, and a culture of continuous improvement may improve maintenance effectiveness, reduce downtime, extend asset lifecycles, and maximize return on investment.

6.3 Conclusion

In conclusion, the implementation of maintenance management activities is crucial for organizations to attain operational excellence, optimize the performance of their assets, and guarantee long-term sustainability. Through the implementation of strategic planning, efficient execution, continuous monitoring, and evaluation of maintenance activities, organizations can optimize maintenance effectiveness, minimize expenses, enhance reliability, and promote ongoing improvement. The adoption of optimal methodologies and the resolution of impediments will facilitate the creation of a proactive maintenance culture within organizations, thereby enhancing their prospects of triumph in a fiercely contested commercial environment. It can be difficult to carry out efficient maintenance management tasks. Limited resources, technological constraints, organizational culture, and resistance to change are just some of the obstacles that businesses may encounter. Strong leadership, funding for technology and training, and a culture that places a premium on maintenance are all necessary to break down these barriers.

Chapter 7

Future of Maintenance

7.1 Future of Maintenance Related to Trends

As I mention about the Maintenance Trends earlier it can be said thet the future of maintenance is being shaped by industrial maintenance trends that facilitate proactive strategies, optimize maintenance activities, enhance asset reliability, and embrace sustainability. Through the utilization of these trends, entities can attain elevated levels of efficiency, efficacy, and cost reduction in their maintenance activities. The utilization of advanced analytics and machine learning algorithms to anticipate equipment failures and execute maintenance tasks in advance is deemed as the future of maintenance, also known as Predictive Maintenance. Through the real-time monitoring of asset conditions and the analysis of historical data, organizations can enhance the reliability of their assets, minimize downtime, and optimize maintenance schedules. Digital twins refer to computer-generated models that replicate physical assets, facilitating continuous monitoring, simulation, and analysis in real-time. Maintenance teams are enabled to acquire an extensive comprehension of asset performance, anticipate maintenance requirements, and enhance maintenance operations. Digital twins have been shown to improve maintenance decision-making, streamline predictive maintenance processes, and allow for simulation-based testing prior to the implementation of maintenance strategies. The Industrial Internet of Things (IIoT) pertains to the interconnection of equipment, sensors, and devices to obtain instantaneous data and facilitate maintenance practices that are based on data analysis. Through the utilization of connectivity and data analytics, maintenance teams have the ability to oversee the condition of assets, recognize deviations from normal operation, and anticipate potential malfunctions. The implementation of Industrial Internet of Things (IIoT) technology enables the adoption of condition-based maintenance strategies, leading to a reduction in unplanned downtime and an improvement in overall maintenance efficiency. The increasing emphasis on sustainability has led to a rise in the significance of green maintenance practices. This entails the adoption of maintenance strategies that prioritize energy efficiency, the implementation of environmentally friendly technologies, and the reduction of waste and emissions. The concept of green maintenance is centered on the reduction of environmental harm caused by maintenance operations, while simultaneously ensuring the highest level of asset performance and dependability. The utilization of immersive technologies, specifically augmented reality (AR) and virtual reality (VR), is revolutionizing the field of maintenance practices. Augmented Reality (AR) technology offers technicians the ability to access real-time information and instructions that are superimposed onto their field of view. This feature has the potential to improve troubleshooting and repair processes. Virtual Reality (VR) technology facilitates immersive training experiences, which enable maintenance personnel to engage in simulated environments and practice complex tasks. This approach enhances efficiency and reduces errors. The utilization of data analytics to obtain practical insights is crucial for the future of maintenance, as it pertains to Maintenance Analytics. The process of maintenance analytics entails the examination of substantial amounts of data with the aim of detecting regularities, tendencies, and deviations. Organizations can enhance maintenance strategies, boost asset performance, and facilitate data-driven decisions for resource allocation and asset management by utilizing data analytics techniques. Maintenance-as-a-Service (MaaS) is a business model that provides maintenance services to customers on a subscription basis. MaaS, or Maintenance as a Service, is a nascent phenomenon in which entities delegate their maintenance operations to expert service providers. The utilization of maintenance service providers enables companies to concentrate on their fundamental areas of expertise, while simultaneously taking advantage of the knowledge and resources offered by such providers. MaaS, or Maintenance as a Service, provides adaptable and economical maintenance alternatives customized to particular requirements, guaranteeing maximum asset efficiency and minimizing operational intricacy. The application of robotics in maintenance has been experiencing a significant surge in recent times. Robotic systems designed for maintenance purposes have the ability to execute a variety of tasks, including but not limited to, inspection, cleaning, and repairs, in environments that are considered difficult or dangerous for human workers. The implementation of automated systems has been shown to have a positive impact on safety, error reduction, and maintenance efficiency, particularly in sectors such as manufacturing, energy, and infrastructure. The field of human-machine interface is witnessing a notable transformation owing to the emergence of sophisticated technologies that facilitate interaction between humans and machines. The aforementioned comprises touchscreens, voice-activated commands, gesture recognition technology, and wearable gadgets. The aforementioned interfaces facilitate maintenance interactions that are both intuitive and efficient, leading to improved communication and increased effectiveness of maintenance tasks. The technology of 3D printing, also referred to as additive manufacturing, possesses the capability to revolutionize maintenance procedures. The technology enables the production of spare parts as per requirement, thereby minimizing lead times and inventory expenses. The prompt replacement of damaged or outdated components by maintenance teams results in reduced downtime and enhanced maintenance responsiveness.

7.2 Artificial Intelligence (AI) Predicts the Future of Maintenance

Machine learning and artificial intelligence will be used more frequently. With the aid of these technologies, it is now possible to analyze vast volumes of data in real time and spot patterns and trends that can be used to anticipate when equipment will break down. This enhances overall reliability and cuts downtime by enabling more precise and timely maintenance (Artesis (2022)).

You can collect quality data much more easily because modern maintenance management software automates so many of the processes. You enter data into the system as soon as possible, while the technicians are still on site, rather than depending on their faulty memories long after they've finished an inspection or task. With a few simple scrolls and clicks, employees can enter data into the system on their mobile device without having to wait for them to write things down when they get back to the office. Also, you may now install asset-mounted sensors to get continuous data on heat, vibration, noise, current, or air quality in places where it wouldn't make sense to have a device collecting data (Davis (2022)).

If you have carried out some work yourself you might consider to summarize the results into a dedicated result chapter.

Here you may include key results of your research without interpreting their meaning (which comes in the Discussion chapter). For empirical research you often present the result in terms of numbers, graphs, main topics addressed by your informants etc.

If you have developed a new algorithm, applied machine learning on a new type of data it will often be important to summarize the performance of your "approach". The "numbers as such" is of less importance.

If you have carried out a case study you may summarize the findings in terms of for example new maintenance intervals, improved regimes for spare part management etc. Also include the improvements you have identified.

Appendix A

Acronyms

APM Actionable program for maintenance

AR Augemented reality

BMW Bayerische Motoren Werke (Bavarian Motor Works)

BS British standards

CBM Condition-based maintenance

CM Corrective maintenance

CMMS Computerised maintenance management system

CRM Customer relationship management

DNV Det Norske Veritas

DSHAs Defined circumstances of hazards and accidents

EAM Enterprise asset management

EC European commission

ECTS European credit transfer system

EEA European economic area

EFTA European free trade association

EN Europäische norm (European standard)

ERP Enterprise resource planning

EU European union

FFM Failure finding maintenance

FM Failure mode

FMEA Failure mode and effects analysis

FMECA Failure mode and effects criticality analysis

FTA Fault tree analysis

GUI Graphical user interfaces

HMI Human-machine interfaces

HAZOP Hazard and operability study

HSE Health, safety and environment

HVAC Heating, ventilation, and air conditioning

IEC International electro-technical commission

IIoT Industrial internet of things

IoT Internet of things

IT Information technology

ISO International organization for standardization

KPI Key performance indicators

MaaS Maintenance-as-a-service

MILP Mixed integer linear programming

MIS Maintenance information systems

ML Machine language

MM Maintenance management

MMIS Maintenance management information system

MMS Maintenance management system

MTBF Mean time between failure

MTTR Mean time to repair

NCS Norwegian continental shelf

NORSOK Norsk Sokkels Konkurranseposisjon (Norwegian version of NCS)

OEE Overall equipment effectiveness

OEM Original equipment manufacturer

OR Operation research

OSHA The occupational safety and health administration

PAS Publicly available specification

PDCA Plan-do-check-act

PM Preventive maintenance

PoF Probability of failure

PSA Petroleum safety authority

RAMS Reliability, availability, maintainability, and safety

RBI Risk-based inspection

RBM Risk-based maintenance

RCFA Root cause failure analysis

RCM Reliability centered maintenance

RMP Routine maintenance program

RNNP Risikonivå i norsk petroleumsvirksomhet (Trends in risk level)

SD Standard deviation

TBM Time-based maintenance

TPM Total productive maintenance

TQM Total quality management

WEEE Waste electrical and electronic equipment

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