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Quality and Reliability-Centered Maintenance Best Practices in the Petroleum Industry

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Abstract

Oil and gas is a crucial industry and has the highest profit value in the modern economy. This sector faces many challenges between workplace safety, asset management, facility upkeep and environmental and legal regulations.
The industry plays a crucial role in powering global economies, supplying energy for transportation, heating, and industrial processes. However, the industry faces numerous quality challenges that can impact safety, environmental sustainability, and operational efficiency. The market value of an individual crude stream reflects its quality characteristics. Two of the most important quality characteristics are density and sulfur content. Density ranges from light to heavy, while sulfur content is characterized as sweet or sour. A strong quality management system is vital in the oil and gas industry. It ensures consistent process quality, prevents serious consequences, and aids in identifying improvements through regular audits. flexibility, ease, and precision are guaranteed. The oil and gas industry is also a complex and capital-intensive sector, where maintenance is a critical aspect of ensuring the reliability and efficiency of operations. Effective maintenance practices are crucial for minimizing downtime, improving safety, environmental performance, reducing costs, and improving overall profitability. One key factor in achieving these goals is strategizing maintenance activities and tracking maintenance performance and costs. As a former engineer in the oil and gas industry, the author understand the critical role quality management systems, best-in-class reliability maintenance, and international standards and codes of practice play in ensuring safe and efficient operations in the oil and gas industry. In this IEOM Singapore 2025, the author will talk about the globally accepted quality and reliability-centered maintenance best practices in the petroleum industry.

Keywords
Oil and Gas Industry, Quality Characteristics, Quality Management Systems and Reliability-Centered Maintenance

1. Introduction
The petroleum industry, also known as the oil and gas industry, encompasses the activities of exploring, extracting, refining, transporting, and marketing crude oils, natural gases, and petroleum products. It plays a crucial role in various sectors and significantly contributes to the global economy. Many economist view crude oil as the single most important commodity in the world, and it is currently the primary source of energy production. The petroleum industry is enormous and its activities extend over all regions of the world. Given the wide ranging nature of this industry, it is important to achieve the highest possible level of quality it deserves both in its basic product (crude oil), and the sophisticated equipment that continuously operate to ensure they can perform their intended functions effectively to meet the daily demand of crude oil in the world market.

Last November 7, 2024, the U.S. Energy Information Administration (EIA) completed its forecast of global production and consumption of petroleum and other liquid fuels for the year 2025 to be 104.7 million barrels per day from 102.6 million barrels per day in 2024 and 104.4 million barrels per day from 103.1 million barrels per day in 2024 respectively (refer to Table 3 for Global Petroleum and Other Liquid Fuels for 2022 – 2025 forecast). These increases will put additional pressure on crude oil extractions and utilization of critical equipment in the oil and gas industry. Additionally, the more oil we extract, the more sulfur we will have in the environment. Sulfur in crude oil can negatively impact the atmosphere in several ways. Air pollution, respiratory problems, atmospheric deposition, corrosion to name a few. Hence, a more aggressive strategies must be put in place to improve the quality of crude oil and reliability of the equipment that are associated with the production and processing of oil.

The quality characteristics of crude oil are density and sulfur content. Density ranges from light to heavy and it is measured according to the American Petroleum Institute gravity or simply called API gravity, while sulfur, a contaminant that is present to a greater or lesser extent in all crude oils, is characterized as sweet or sour. The API gravity of crude oil varies typically between 10 and 50, with most falling in the range of 20-45. The higher the rating, the lighter the crude oil. Lighter crude oils are normally deemed more valuable as they contain greater quantities of hydrocarbons that can be converted into gasoline. Sulfur content on the other hand is expressed as weight percent of sulfur in crude oil. Those with less than 0.5% sulfur by weight are typically referred to as low sulfur or "sweet." High-sulfur crude oils have a sulfur content greater than 2% and are referred to as "sour." Crude oils with sulfur content between these two values are referred to as medium-sulfur.

Prices of critical assets or equipment that keeps the petroleum industry alive are ranging from hundreds of thousands of dollars to even millions of dollars. Their functions are to ensure continuous production of oil and gas, effective operations, and the safety of the plants and their workers. Hence, intelligent maintenance strategies must be put in place to ensure their reliability, and long service life.

The control of maintenance functions is a complex problem. The time scales and functions vary, as does the complexity of decision-making. The complexity caused by numerous output factors, such as safety, availability, reliability, quality and longevity. Each of these factors is in turn influenced by numerous input factors. Using a strategy based on a Reliability-Centered Maintenance optimized maintenance program.

Through a comprehensive review of existing literatures, oil and gas journals, interview with the industry professionals, and empirical knowledge of the author in the oil and gas industry, this research examines the industry best practices in enhancing the quality of crude oil and the ongoing innovation and maintenance best practices of its assets that keeps the oil flowing.

1.1 Objectives

The objective of this research is to help spread awareness to industrial engineering societies and other engineering societies the globally accepted quality and reliability-centered maintenance best practices in the petroleum industry.

Specifically, it aimed to provide readers a deeper understanding of the petroleum industry from the standpoint of quality and maintenance reliability by providing them answers to the following research questions:

- Research Question 1: What is the value of quality in the petroleum industry?
- Research Question 2: What is the difference between maintenance and reliability?

2. Literature Review

The U.S. Energy Information Administration published on July 16, 2012 and re-published on June 26, 2013 reported that many types of crude oil are produced around the world. The market value of an individual crude stream reflects its quality characteristics. Two of the most important quality characteristics are density and sulfur content. Density ranges from light to heavy, while sulfur content is characterized as sweet or sour. Ruairi O' Donnellan, of *Intuition* (2023) on the other hand, explained that there are some crude oils both below and above the API gravity. The chemical nature of a crude oil is assessed from an assay. As crude oil has become more openly marketed and traded, many companies publish assay details publicly.

John A. Dutton, of the Institute for Teaching and Learning Excellence, PennState, College of Earth and Mineral Sciences in 2023 described that sulfur content of crude oils is the second most important property of crude oils, next to API gravity. Sulfur content is expressed as weight percent of sulfur in oil and typically varies in the range from 0.1 to 5.0%wt. The standard methods that are used to measure the sulfur content are ASTM D129, D1552, and D2622, depending on the sulfur level. Crude oils with more than 0.5%wt sulfur need to be treated extensively during petroleum

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refining. Crude oils that are light (higher degrees of API gravity, or lower density) and sweet (low sulfur content) are usually priced higher than heavy, sour crude oils.

Edo et al. (2024) explained that the oil and gas industry stands as a pillar of modern civilization, providing the energy resources necessary for economic growth and development. At the heart of this industry lies a vast network of infrastructure and equipment, meticulously engineered to extract, process, and transport hydrocarbons from deep within the earth to end-users around the world. Yet according to Adefemi et al. (2023), amid this complexity, ensuring the reliability and integrity of these assets remains a paramount concern for operators and stakeholders alike.

Xia (2024) argued that traditionally, maintenance practices within the oil and gas sector have followed reactive or preventive approaches. Reactive maintenance, characterized by addressing equipment failures as they occur, often results in unplanned downtime, costly repairs, and safety hazards. Additionally, However, Usiagu et al. (2024) articulated that similarly, preventive maintenance, while scheduled at regular intervals, may lead to unnecessary servicing of equipment that remains fully operational, contributing to increased maintenance costs and inefficiencies. Abrahams et al. (2024) articulated that in the midst of these challenges, a new paradigm has emerged – predictive maintenance. Fueled by advancements in artificial intelligence (AI) and machine learning, predictive maintenance represents a transformative shift in how oil and gas facilities manage their critical infrastructure.

Oroy and Anderson (2024) from their side, explained that by harnessing the power of data analytics and predictive algorithms, operators can anticipate equipment failures before they occur, proactively addressing issues and optimizing maintenance schedules to minimize downtime and maximize asset performance.

The oil and gas utility industry presents its own set of challenges when it comes to maintaining equipment performance and personnel safety. Effective oil and gas asset management strategies can help improve and mitigate some of these challenges according to James Chan, Limble (2024).

Implementing Quality Management System (QMS) in the oil and gas industry is crucial due to the sector's high-risk nature, complex operations, and stringent regulatory environment. A robust QMS ensures that all processes, from exploration to production, adhere to the highest quality, safety, and efficiency standards. This is essential in mitigating risks associated with operational hazards such as equipment failures, environmental incidents, and health and safety issues that could lead to catastrophic consequences. ComplianceQuest 2024.

Quality control and assurance are critical in the oil and gas industry, where substandard equipment or materials can have disastrous consequences. These practices cover a wide range of activities aimed at ensuring that equipment and materials meet stringent quality standards and specifications. Companies can reduce the risk of accidents, improve operational efficiency, and maintain a strong reputation in the industry by implementing robust quality control measures. Syed Fadzil Syed Mohamed, Fellow of the Institute of Engineers, Malaysia (FIEM). June 8, 2023.

The oil and gas industry relies heavily on complex infrastructure and equipment to extract, process, and transport hydrocarbons (Patidar et al., 2024). Ensuring the reliability and integrity of these assets is paramount for efficiency and safety. Traditionally, maintenance strategies in the oil and gas sector have been reactive or preventive, often leading to unexpected downtime, increased maintenance costs, and safety risks. However, with advancements in AI and machine learning, predictive maintenance has emerged as a proactive approach to asset management, revolutionizing how oil and gas facilities maintain their critical infrastructure (Adegbite, et al 2023)

3. Methods

- Extensive review of related literatures
- Review of global annual forecast for petroleum and other liquid fuels
- Extensive review of articles featured on oil and gas journals and world energy reports
- Thematic analysis and investigative approach
- Empirical knowledge of the author derived from his extensive experience in the petroleum industry

4. Data Collection

- Crude production by Quality
- Crude production quality by Gravity and by Sulfur Content
- Global petroleum and other liquid fuels forecast for 2022 - 2025
- Maintenance strategies being utilized in the oil and gas industry
- Expected reliability and maintenance Key Performance Indices

5. Results and Discussion

Crude oil extracted from onshore and offshore wells in various countries have different quality characteristics in terms of their lightness and heaviness, and how much sulfur content has in them. Light crudes generally exceed 38 degrees API and heavy crudes are commonly labeled as all crudes with an API gravity of 22 degrees or below. Bitumen is the heaviest, thickest form of petroleum.

The lighter the crude oil, the higher the price it attracts in the market. Lighter crude oils are normally deemed more valuable as they contain greater quantities of hydrocarbons that can be converted into gasoline. Heavy oil on the other is very viscous and does not flow easily. The common characteristic properties (relative to conventional crude oil) are high specific gravity, low hydrogen-to-carbon ratios, high carbon residues, and high contents of asphaltenes, heavy metal, sulfur, and nitrogen.

Libya and Algeria produce the most desirable crude: light, with a high potential gasoline content, and with a low content of undesirable sulfur while large heavy oil deposits are found in Canada. Table 1 below shows World Crude Production by Gravity as of 2022.

Table 1. World Crude Production by Gravity as of 2022
Source: 2023 World Energy Review, Eni

Crude Production by Gravity(*)
(thousand barrels/day)

	2010	2015	2016	2017	2018	2019	2020	2021	2022	Share of total 2010	Share of total 2022
World	74,227	80,681	80,559	80,617	82,372	82,194	75,811	76,790	80,515		
Light	21,754	24,427	23,724	24,161	26,438	27,900	25,345	25,372	25,976	29.3%	32.3%
Medium	41,658	44,935	45,554	45,383	44,982	44,017	41,083	41,739	44,160	56.1%	54.8%
Heavy	9,604	10,651	10,672	10,479	10,363	9,705	8,846	9,145	9,887	12.9%	12.3%
Unassigned production	1,211	668	609	595	588	572	537	533	493	1.6%	0.6%

What are the common processes used to convert heavy crude oil to lighter fractions or quality characteristic?
Thermal cracking is a non-catalytic process that breaks heavy hydrocarbons down into smaller molecules by simply heating them to a high temperature. Take a heavy oil that there is limited market, pump it into a very large furnace that heats it up to about 960 degrees Fahrenheit (325 degrees Centigrade), keep it at that temperature for 20 seconds to a couple of minutes, and then cool it back to room temperature. The heavy oil is converted into a mixture of that is about 60% lighter products like gasoline and 40% unconverted. Recycle most of the unconverted oil back to the furnace until all but about 5% of it remains as a heavy tar (Figure 1- Figure 2).

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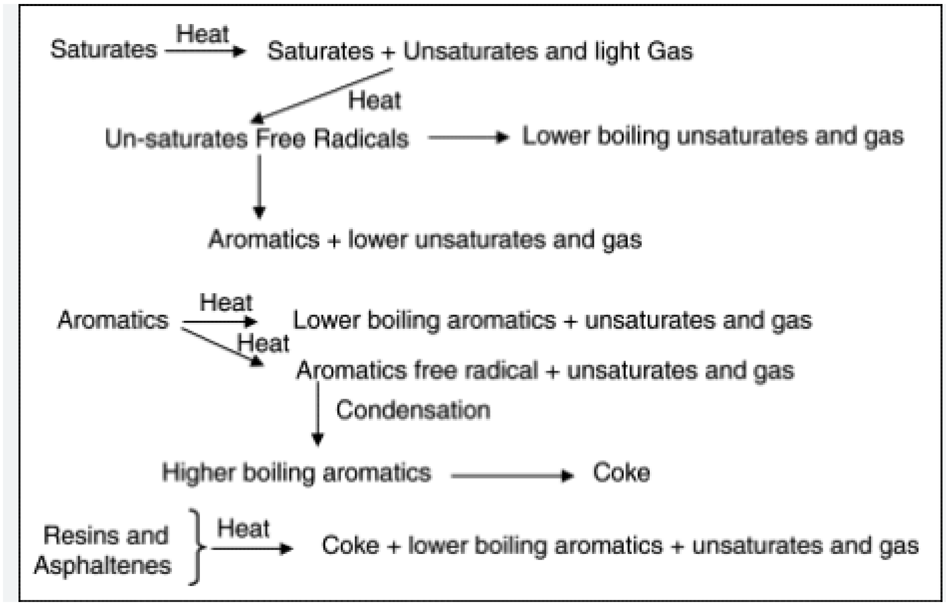

Figure 1. Thermal Cracking

Crude oil blending involves the mixing of multiple types of crude oils to achieve a desired blend that meets specific requirements. These requirements can vary depending on factors such as market demand, refinery capabilities, and transportation logistics. Diluent is a light hydrocarbon mixture used to blend with heavy crude petroleum to reduce its viscosity to make it more fluid (thinner) which makes it more efficient to transport oil by pipeline. Diluent can come from refineries or natural gas production wells.

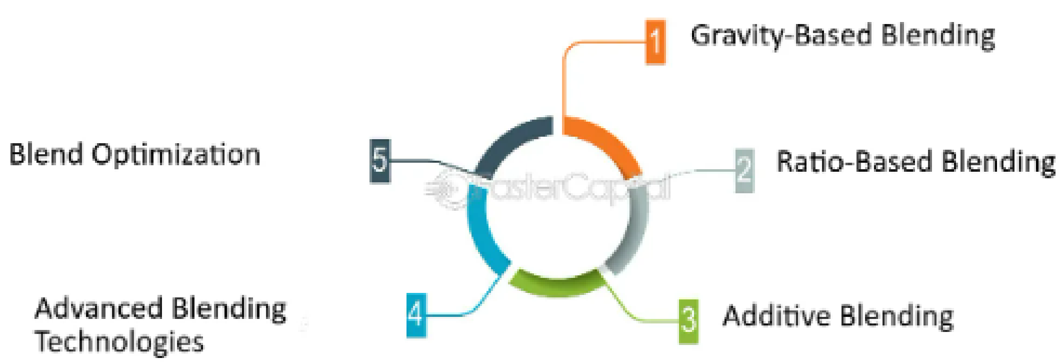

Figure 2. Techniques and Technologies Used in Crude Oil Blending

Pipelines are typically used to transfer heavy oil from the location of production to ports or refineries, where it can then be delivered to other locations. The main challenge for heavy oil pipeline transport technology is the high viscosity of oil. Oil carriers seek extremely cost-effective and efficient solutions to reduce excessive prices. Using core annular flow (CAF), is a good strategy for coping with the challenges brought on by the high viscous oil.

Sulfur, is a contaminant that is present to a greater or lesser extent in all crude oils, is characterized as sweet or sour and it is measured using X-Ray spectroscopy. Sulfur content on the other hand is expressed as weight percent of sulfur in crude oil. Those with less than 0.5% sulfur by weight are typically referred to as low sulfur or "sweet." High-sulfur crude oils have a sulfur content greater than 2% and are referred to as "sour." Crude oils with sulfur content between these two values are referred to as medium-sulfur.

High sulfur levels can also damage machinery, fast-track corrosion and compromise the efficacy of catalysts used during the refining process. The average oil and gas reservoir contains sulfur concentrations ranging from between 1 to 5%, making sulfur extraction methods fundamental to the oil and gas sector. The concentration of hydrogen sulfide (H2S) in the crude rises with overall sulfur content. Furthermore, inhalation of high concentrations of H2S can produce extremely rapid unconsciousness and even death. Table 2 below shows World Crude Production by Sulfur content as of 2022.

Table 2. World Crude Production by Sulfur Content as of 2022
Source: 2023 World Energy Review by Eni

Crude Production by Sulphur Content (*)
(thousand barrels/day)

	2010	2015	2016	2017	2018	2019	2020	2021	2022	Share of total 2010	Share of total 2022
World	74,227	80,681	80,559	80,617	82,372	82,194	75,811	76,790	80,515		
Sweet	25,746	28,245	26,921	27,286	28,929	30,636	28,695	28,771	28,705	34.7%	35.7%
Medium Sour	8,846	9,534	9,296	9,553	9,954	9,776	9,492	9,473	10,266	11.9%	12.8%
Sour	38,424	42,234	43,732	43,184	42,901	41,211	37,086	38,012	41,050	51.8%	51.0%
Unassigned production	1,211	668	609	595	588	572	537	533	493	1.6%	0.6%

Standard Test Method for Sulfur in Petroleum Products by Wavelength Dispersive X-ray Fluorescence Spectrometry. ASTM D2622 covers the determination of total sulfur content in liquid petroleum and petroleum products. Liquefiable at ambient conditions or solubilized in hydrocarbon solvents can be also be samples.

Sulfur removal from crude oil and hydrocarbons

The poor quality of crude oil currently can obviously result in the high sulfur contents of oil products, which can lead to corrosion, catalyst poisoning, environmental pollution and other negative consequences. The treatment of high-sulfur crude oil is becoming the focus of research in China's oil refining industry. The conventional equipment cannot deal with the high-sulfur crude oil during petroleum refining processes.

The increasing sulfur content of crude oil also results in an increase in sulfur content in automotive gasoline, diesel fuel, and jet fuel. To meet the needs for producing clean fuels, decreasing the sulfur content of crude oil becomes an urgent task. Studying new desulfurization technology and raising the efficiency of desulfurization processes are keys to bringing increasing quality of crude oils and more profits to the oil refining companies.

Caustic washing method for oil desulfurization

Caustic washing method is mainly aimed at removing the sulfides from the crude oil by using the caustic solution. At present, this method is widely used in the oil industry. The advantage of this method is that the process is simple and the cost is lower, but this method contains many defects such as the poor quality of oil products and lower efficiency of desulfurization. However, this method cannot remove all sulfur compounds from the crude oil, especially the organic sulfides. At the same time, it brings too much sulfide-containing wastewater, which greatly pollutes the environment. So, it is urgent to improve this method or find a better way to reduce the sulfur contents in petroleum products.

Dry gas desulfurization method

According to the report, the first equipment in China for treating heavy crude oil through dry gas desulfurization method has been used in the No.3 joint oil gathering station at Tahe Oilfield of the Northwest Oilfield Branch Company. The cost of this equipment is about 500 million RMB, and it is the first time in China to use this dry gas treatment method at the crude oil desulfurization system in reality.

Hydrodesulfurization (HDS)
Hydrodesulfurization is one of the catalytic desulfurization processes, which aims at turning organic sulfur compounds into H2S using H2 as the reactant in the presence of metal catalysts operating at high temperature and pressure. The resultant hydrogen sulfide is then removed from the system. This method is widely used in oil industry in China since 1955. However, the HDS process features a complicated procedure, high production cost and high materials consumption. With an increasing ratio of heavy crude oil supply to the oil refinery, the sulfur content in crude slate is growing, which leads to a shortened catalyst life at the refinery. Furthermore, the HDS process needs more H2, so the production cost will increase a lot.

Biodesulfurization (BDS)
BDS is a new bio-catalytic desulfurization method, which has been applied since the 1980s. According to the principle of enzyme catalysis for implementing the specific reaction for C—S bonds cleavage performed by micro biological flora, sulfides in crude oil can be turned into elemental sulfur that can be removed. In the process of desulfurization, the sulfur containing pollutants are transformed into sulfides and H2S by biological reduction, and the elemental sulfur can be removed via the process of biological oxidation.

Merox Sweetening Process
Merox sweetening processes are reserved for heavier hydrocarbons such as kerosene, aviation fuels, and diesel. These fuels contain longer-chain mercaptans which are not soluble in caustic. They require the conversion of mercaptans to disulfides in a single fixed-bed reactor in the presences of oxygen, caustic, and Merox catalyst.

Asset Management
As for the incoming **crude oil** and the outgoing final products, sophisticated machines, systems, and techniques are needed to ensure continuity of production and delivery to the downstream customers. Hence, their regular maintenance is critical for operational safety and reliability in the oil and gas industry. It involves frequent inspections and timely interventions to mitigate risks and extend the equipment's lifespan, making maintenance cost-effective in high-risk environments.

The oil and gas industry has complex, large-scale assets. These include pipelines, drilling vehicles, refineries, storage facilities, pumps, compressors, turbines, valves, vessels, and more. To keep up with the complexity of these assets, a well-organized maintenance strategy is required.

Exploring the Spectrum of Maintenance Strategies in Oil and Gas
Managing complex machinery and extensive infrastructure requires well-planned strategic measures in the oil and gas industry. This not only entails fixing what has malfunctioned but also involves proactively preventing issues before they arise and skillfully handling unforeseen events as they occur.

With the intricate nature of assets, strict regulatory standards to follow, and inherent safety hazards present, it is critical for oil and gas companies to recognize the importance of effective maintenance in upholding operational efficiency.

Maintenance within this sector balances planned inspections, regular servicing routines, and astute data analysis—all designed to improve operational efficiency and productivity.

Consistent maintenance ensures that equipment performance remains at its peak while reducing incidents that could lead to shutdowns. Proactive strategies are mainly focused on countering wear-and-tear impacts on equipment over time.

Equipment maintenance is not just a must, but it is also a significant economic opportunity. When done well, companies can obtain the operational efficiency needed to navigate through volatile oil markets by extending the life of their equipment.

Reliability-Centered Maintenance (RCM)
Reliability-Centered Maintenance (RCM) is a structured framework used in the petroleum industry to ensure the reliability, safety, and efficiency of critical equipment. It focuses on identifying potential failures, understanding their consequences, and implementing tailored maintenance strategies to address these issues. The following outlines how RCM is administered in the petroleum industry:

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1. System Selection

- **Criticality Analysis:** Identify and prioritize equipment based on their importance to operations, safety, and environmental impact.
- **Focus on Key Assets:** Emphasize systems like pumps, compressors, pipelines, storage tanks, and offshore platforms that have the highest operational significance.

2. Functional Analysis

- **Define Equipment Functions:** Clearly state the primary and secondary functions of each piece of equipment (e.g., maintaining flow rates, pressure levels, or temperature controls).
- **Performance Standards:** Establish performance benchmarks to identify acceptable operating conditions.

3. Failure Modes and Effects Analysis (FMEA)

- **Identify Failure Modes:** Examine how each system or component can fail (e.g., leaks, blockages, mechanical wear, or electrical faults).
- **Assess Consequences:** Evaluate the impact of each failure on operations, safety, environment, and maintenance costs.
- **Categorize Failures:** Differentiate between failures with safety implications, production downtime risks, or environmental hazards.

4. Determine Maintenance Strategies

Based on the analysis, RCM recommends appropriate maintenance tasks:

- **Predictive Maintenance (PdM):** Use technologies like vibration analysis, thermal imaging, and oil analysis to predict failures.
- **Preventive Maintenance (PM):** Schedule regular inspections, cleaning, and component replacements to prevent failures.
- **Run-to-Failure (RTF):** Allow non-critical components to operate until failure, minimizing unnecessary maintenance costs.
- **Condition-Based Maintenance (CBM):** Monitor equipment condition in real time to trigger maintenance only when necessary.

5. Implementation of RCM Tasks

- **Develop Task Lists:** Create specific maintenance tasks for each failure mode.
- **Resource Allocation:** Assign qualified personnel, tools, and spare parts to execute tasks efficiently.
- **Maintenance Scheduling:** Incorporate RCM tasks into the overall maintenance schedule, optimizing plant downtime.

6. Monitoring and Continuous Improvement

- **Performance Metrics:** Track metrics like Mean Time Between Failures (MTBF), Mean Time to Repair (MTTR), and maintenance costs.
- **Feedback Loops:** Use operational data to refine maintenance strategies and improve reliability.
- **Root Cause Analysis (RCA):** Investigate failures to identify underlying issues and prevent recurrence.

7. Training and Capacity Building

- **Employee Training:** Train maintenance teams on RCM principles, tools, and techniques.
- **Cross-Functional Collaboration:** Involve operations, maintenance, and engineering teams in the RCM process.

8. Use of Technology

- **RCM Software:** Utilize specialized software to document, analyze, and implement RCM processes.
- **Digital Twin Models:** Create virtual replicas of equipment to simulate performance and optimize maintenance strategies.
- **IoT Integration:** Leverage real-time data from sensors for condition monitoring and predictive analytics.

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9. Compliance and Documentation

- **Regulatory Standards:** Ensure RCM practices comply with industry standards like API 580/581 (Risk-Based Inspection) and ISO 55000 (Asset Management).
- **Documentation:** Maintain detailed records of maintenance activities, equipment history, and reliability studies for audits and future planning.

10. Benefits of RCM in the Petroleum Industry

- **Increased Equipment Availability:** Minimizes downtime by addressing critical failures proactively.
- **Cost Efficiency:** Reduces maintenance costs by focusing resources on high-impact areas.
- **Enhanced Safety:** Mitigates risks associated with equipment failures, ensuring compliance with safety regulations.
- **Improved Sustainability:** Reduces environmental impacts by preventing leaks, spills, and emissions.

By adopting RCM, the petroleum industry ensures a systematic, data-driven approach to maintenance, ultimately enhancing operational efficiency and extending the lifecycle of critical assets.

According to the O&M Best Practices Guide, Release 3.0 https://www1.eere.energy.gov/femp/pdfs/OM_5.pdf, top-performing facilities, on average, divide their maintenance efforts into the following categories based on RCM:

- <10% Reactive Maintenance
- 25% to 35% Preventive Maintenance
- 45% to 55% Predictive Maintenance

RCM emphasizes newer predictive maintenance technologies—such as infrared, acoustic (partial discharge and airborne ultrasonic), corona detection, vibration analysis, sound-level measurements, and oil analysis.

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

Below are the evaluation criteria for RCM, as described by the Society of Automotive Engineers (SAE). Assess each piece of equipment, organized by phase, by asking:

Decision

- What functions does it perform, and what are the desired performance standards?
- In what ways could the asset fail to fulfill its functions?
- What are the causes of each possible failure scenario?

Analysis

- What happens when each type of failure occurs?
- What consequences would we suffer as a result of each failure?
- How could we predict or prevent each potential failure?

Action

- What should we do if we cannot determine a suitable proactive task?

How to run a reliability-centered maintenance program

The best way to implement an RCM program–which can be daunting–is to take a logical approach and handle one step at a time. While there are different ways of implementing RCM, these eight basic steps are a great place to start:

Step 1: Select an asset for RCM analysis
Choose an asset on which to perform the RCM analysis. What criteria should you use to select the asset? Some factors to consider include how critical the asset is to operations, its repair costs in the past, and its previous preventive maintenance costs.

Step 2: Outline the functions of the system for the selected asset
It is important to know the functions of the system, including its inputs and outputs, no matter how small. This helps to define the requirements for the maintenance of the system or equipment. For example, the inputs of a conveyor belt are the goods and the mechanical energy that powers the belt.

Step 3: Define the system or equipment failure modes
Understand the different ways in which the system can fail. For example, the conveyor belt may not transport the goods fast enough or completely fail to transport them from one end to the other.

This helps to prioritize maintenance activities based on the potential impact of each failure on the overall performance of the system or equipment. Functional failure is the inability of an asset or system to meet acceptable standards of performance.

Failure Mode and Effects Analysis (FMEA) is the process of assessing the potential causes and impacts of equipment failures. It is a proactive, data-driven, and team-oriented method for identifying the relative effect of various failure modes on productivity goals.

Step 4: Assess the consequences of failure
What will happen in the event of a failure? Asset failure can result in safety concerns and poor business performance. It also can affect other equipment. Plant operators, equipment experts, and technicians should work together to identify the root causes of individual asset failure. This process helps determine how to prioritize tasks.

The process can be organized using many methods, including:

- **Failure Modes and Effects Analysis (FMEA):** This is a method of evaluating the impact of a failure by identifying where and how a process might fail. For example, what would make the conveyor belt slow down or stop working?
- **Failure, Mode, Effect, and Criticality Analysis (FMECA):** This is the same as FMEA. However, it goes one step further and creates linkages between failure modes, the effects, and the causes of failure.
- **Hazard and Operability Studies (HAZOPS):** HAZOPS is a systematic examination of processes to identify issues that may result in risks for your personnel and assets. In most cases, it guides the review of standard operating procedures.
- **Fault Tree Analysis (FTA):** The FTA is a graphic tool used to examine the cause of system-level failure. It employs a top-down deductive analysis of failure.
- **Risk-based Inspection (RBI):** RBI is a decision-making process used to optimize inspection plans. It is primarily used to examine industrial equipment, such as piping, pressure vessels, and heat exchangers.

Always prioritize the more critical failure modes for additional analysis. Retain the failure modes that can occur in real-life operating environments.

Step 5: Determine a maintenance strategy for each failure mode
The probability of each failure mode occurring should be assessed, taking into account factors such as the system's operating environment, maintenance history, and the reliability of its components.

Step 6: Implement the strategy and perform regular reviews
For your RCM program to be effective, you need to implement the maintenance recommendations identified in Step 5. After implementation, regular reviews will help to improve the systems and performance. Whichever maintenance strategy you decide to use for each asset, you will be able to generate additional data that will improve your systems.

Step 7: Determine a maintenance strategy for each failure mode
At this point, select a maintenance strategy for each critical failure mode. It should be both economically and technically feasible. You can use condition-based maintenance (CBM), preventive maintenance, corrective maintenance, or predictive maintenance (PdM). If you are unable to implement a given strategy for a particular failure

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mode, consider redesigning the system to modify or eliminate the failure mode completely in all your maintenance planning.

Non-critical failure modes can be considered for a run-to-failure maintenance strategy. At this stage, you are looking to answer the question, "What is the principle of an effective maintenance strategy?"

Step 8: Implement the strategy and perform regular reviews
For your RCM program to be effective, you need to implement the maintenance recommendations identified in Step 5. After implementation, regular reviews will help to improve the systems and performance. Whichever maintenance strategy you decide to use for each asset, you will be able to generate additional data that will improve your systems.

The final component of RCM is choosing and scheduling appropriate maintenance tasks. A computerized maintenance management system (CMMS) can schedule, assign, and oversee work orders. As expected, different techniques are suitable for different asset situations. Some machinery may require proactive tasks, including preventive and predictive maintenance. Conversely, reactive maintenance may be the most financially prudent course of action for other low-importance pieces.

CMMS and RCM

- With CMMS software, manufacturers can easily track and record all information related to the maintenance activities of their assets. This, in turn, helps identify situations that could lead to equipment failure or downtime. In addition, by using RCM as part of their overall maintenance strategy, manufacturers can ensure that all necessary preventive measures are taken to minimize the risk of mechanical breakdowns or downtime.
- CMMS software also helps manufacturers keep their equipment running at its peak operating efficiency.
- By providing detailed data on how each piece of machinery is performing, CMMS software allows manufacturers to identify areas where they can optimize performance and extend the lifespan of their assets. In addition, manufacturers can use this data to identify potential issues before they cause problems and quickly determine when equipment needs to be serviced or upgraded to maintain optimal performance levels.

Overall, RCM, combined with the convenience of CMMS software, provides an effective preventative maintenance strategy for reducing unplanned downtime, improving reliability, and ensuring that all machinery runs at peak efficiency. With an effective preventative plan in place, manufacturers can achieve maximum production rates while keeping operational costs low. As a result, businesses can increase their competitive advantage by eliminating or minimizing mechanical failures. This reduces long-term repair costs associated with emergency maintenance activities.

Advantages and disadvantages of reliability-centered maintenance
Successfully implementing RCM benefits organizations that can afford it. The framework takes the guesswork out of maintenance prioritization and helps organizations maintain assets in a consistent, structured, and cost-effective manner. Because RCM heavily relies on predictive maintenance (PdM) technologies, its program advantages and disadvantages mirror those of it. However, RCM allows facilities to match resources to equipment needs more closely while improving reliability and decreasing cost—more than any singular PdM strategy.

RCM advantages
The advantages of reliability-centered maintenance include:

- **Cost effectiveness.** RCM helps reduce costs by minimizing unnecessary routine maintenance tasks. When combined with preventive maintenance, RCM has been shown to reduce workloads by 70 percent.
- **Better teamwork.** RCM takes a group approach to maintenance tasks. Communication and cooperation among departments and teams improve when everyone is involved in problem analysis and decision-making.
- **Improved asset performance.** It also eliminates unnecessary overhauls and, therefore, reduces shutdowns. RCM also helps to diagnose failure more quickly.
- **Improved employee motivation.** When employees are involved in the application of RCM, they get a better understanding of the assets in their operating contexts. This motivates them to take ownership of maintenance problems and solutions.
- **Better safety and environmental integrity.** RCM seeks to understand the implications of every failure mode and takes proactive steps to prevent them. Besides limiting failures, the maintenance prioritization process promotes the availability of necessary protective devices.

Here is an example of RCM's benefits: The NASA Marshall Flight Center saved more than $300,000 in costs by implementing an RCM strategy that reduced maintenance costs, improved workplace safety, and extended the lifespan of aging assets. The program also enabled the Center to minimize its energy consumption and reduce its environmental impact.

RCM disadvantages
RCM also has its drawbacks. The initial costs of implementing RCM are high. Performing RCM analysis requires maintenance teams to invest significant time, finances, and resources to get started. ROI may be slower than executives prefer. The second major disadvantage of RCM is that it simultaneously incorporates all of the other types of maintenance strategies, including some of their drawbacks. For instance, say you choose a run-to-failure approach for a given asset. You simultaneously run the risk of an unplanned failure. For this reason, RCM is sometimes seen as expensive compared to running predictive or preventive maintenance programs alone. However, most experts agree that RCM is more cost-effective in the long run.

5.1 Numerical Results

The U.S. Energy Information Administration (EIA) has forecasted an increase of 2.1 million barrels per day in production and 1.3 million barrels per day in consumption for global petroleum and other liquid fuels for 2025. These increases will naturally put more pressure in the oil extractions and utilization of critical equipment in the oil industry. Table 3 below shows the Global Petroleum and Other Liquid Fuels 2022 – 2025 forecast.

Table 3. Global Petroleum and Other Liquid Fuels 2022 – 2025 Forecast

Global Petroleum and Other Liquids	2022	2023	2024	2025
Brent crude oil spot price (dollars per barrel)	101	82	*81*	*76*
Global liquid fuels production (million barrels per day)	100.2	102.0	*102.6*	*104.7*
OPEC liquid fuels production (million barrels per day)	32.9	32.2	*32.1*	*32.5*
Non-OPEC liquid fuels production (million barrels per day)	67.3	69.8	*70.5*	*72.2*
Global liquid fuels consumption (million barrels per day)	100.0	102.1	*103.1*	*104.4*
Global GDP (percentage change)	3.4	3.3	*3.1*	*3.2*

Note: Values in this table are rounded and may not match values in other tables in this report.

Expected KPIs for Maintenance in Petroleum Industry:
The following are some expected KPIs for maintenance in the petroleum industry:

1. **Total Productive Maintenance (TPM) Efficiency**: 70% - 85%
2. **Maintenance Cost as a Percentage of RAV**: 3%
3. **Maintenance Scheduling Effectiveness**: 80% - 90%

4. **Equipment Reliability**: 90% - 95%
5. **Maintenance Labor Productivity**: 5 - 8 hours per technician per day
6. **Inventory Turnover**: 4 - 6 times per year
7. **Maintenance Backlog**: 5% - 10% of total work orders
8. **Work Order Completion Rate**: 85% - 95%
9. **First-Time Fix Rate**: 70% - 80%
10. **Corrective Maintenance Cost as Percentage of Total Maintenance Costs**: 30% - 50%
11. **Preventive Maintenance Cost as Percentage of Total Maintenance Costs**: 50% - 70%
12. **Maintenance Labor Utilization**: 60% - 80%

Benchmarking Opportunities
By tracking these KPIs, petrochemical organizations can benchmark their performance against industry standards and best practices. For example:

- TPM efficiency: Compare your TPM efficiency to industry benchmarks to identify areas for improvement.
- Maintenance cost as a percentage of revenue: Benchmark your maintenance costs against industry averages to identify opportunities for cost reduction.
- MTBF: Compare your MTBF to industry standards to identify areas where equipment reliability can be improved.

By implementing a comprehensive maintenance management system, using standardized cost codes, monitoring equipment performance, and conducting regular audits, petrochemical organizations can achieve these KPIs and benchmark their performance against industry standards.

5.2 Graphical Results
As mentioned earlier, two of the most important quality characteristics of crude oil are density and sulfur content. Density ranges from light to heavy, while sulfur content is characterized as sweet or sour. Figure 3 below shows the relationships of gravities and sulfur contents of the world crude oil production from 2005 to 2022.

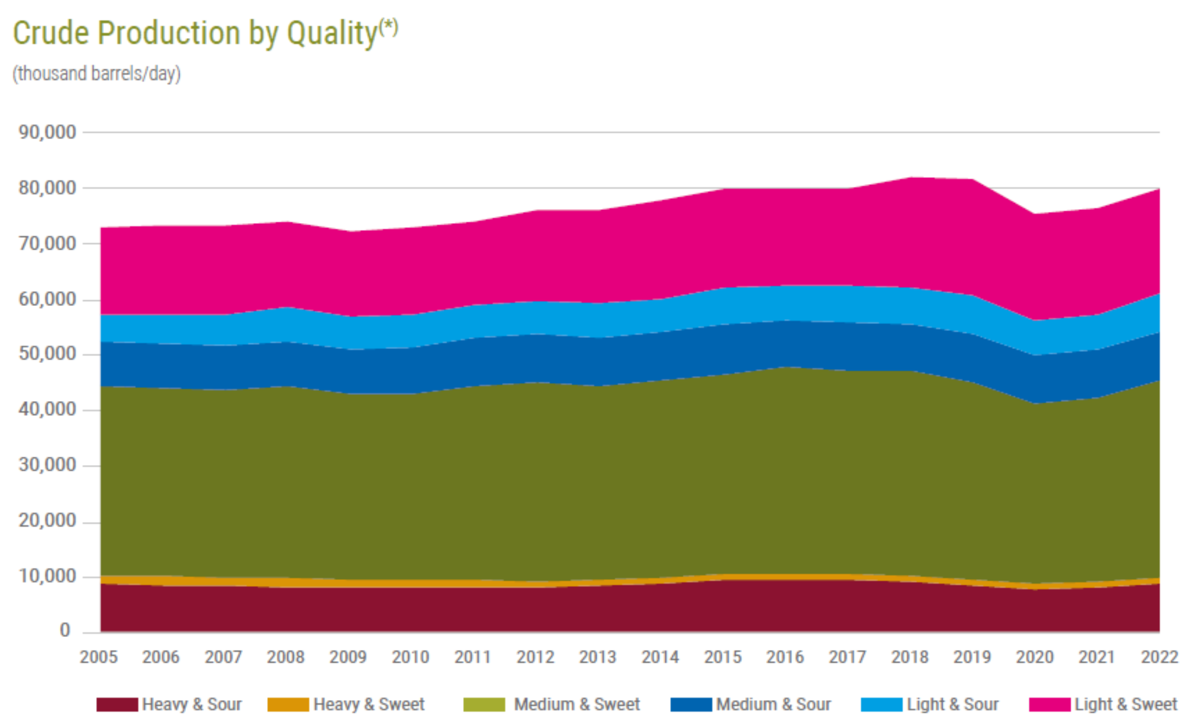

Figure 3. World Crude Production by Quality

The Figure 4 below shows the density and sulfur content of selected oil producing countries.

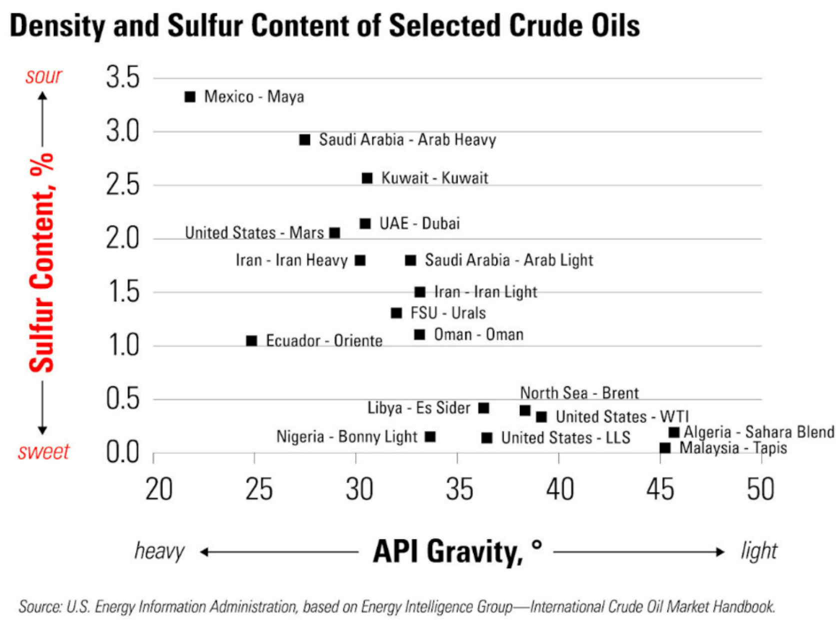

Figure 4. Density and Sulfur Content of Selected Oil Producing Countries

The Figure 5 bathtub curve below is a graphical representation tool in reliability maintenance that shows the three stages of failures, infant mortality period, normal life period, and wear-out period. It allows maintenance managers to tailor their strategies according to the life cycle phase of their assets, ensuring optimal performance and reliability throughout their lifespan.

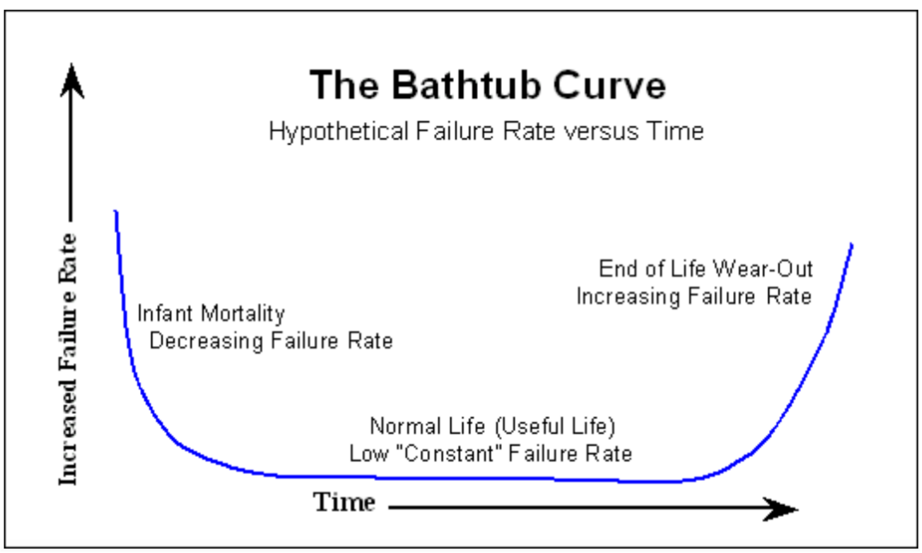

Figure 5. The Bathtub Curve

5.3 Proposed Improvements

- Conduct a more aggressive experimental research in improving the quality of crude oil refining
- Implement a stricter regulation that limits sulfur emission in petroleum products

- Enhance collection of reliability and maintenance data including key performance indices from oil producing countries and include them in the statistics on energy information and world energy reviews
- Continually investigate and invest in new technologies to augment the accuracy and efficiency of reliability-centered maintenance approaches. These include machine learning, advanced analytics, and artificial intelligence (AI) to build predictive models that can better forecast equipment failures.

5.4 Validation

This research was conducted using the following sources that validates its authenticity:

- ISO 14224:2016 is an international standard that provides guidelines for the collection and exchange of information about reliability and maintenance of equipment, including reliability data in the petroleum industry. It also help organizations gather data on the performance and breakdowns of their assets, such as machinery or systems
- Annual reporting of world crude oil quality by Eni (Ente Nazionale Idrocarburi), an Italian energy company that contributes to the industrial development
- Benefits of applying Reliability-Centered Maintenance as described by PetroSync™. An international petroleum conference and training organization that also provides consultancy and news reports on global petroleum developments

6. Conclusion

This investigative research was concluded with the examination of the quality and maintenance aspects in the oil and gas industry. The author highlighted various strategies that can revolutionize operational practices. Combining proactive preventive maintenance, predictive analytics, and strategic reactive measures creates a comprehensive and essential framework for sustaining this sector.

As a result in completing this research, we must acknowledge the critical lessons learned: Quality and Maintenance are not just routine work; they are key factors in ensuring safety, improving efficiency, and extending the lifespan of assets in the oil and gas sector. By adopting these strategies, oil and gas companies can elevate their operational practices and foster a more efficient and sustainable energy production environment. Consequently, answers to the research questions outlined in the Objectives, sub-section 1.1 are provided below.

Research Question 1: What is the value of quality in the petroleum industry?
Quality in the petroleum industry is essential for ensuring safe, reliable, sustainable operation and compliant with the industry standards, codes and best practices.

Research Question 2: What is the difference between maintenance and reliability?
Maintenance ensures optimal equipment performance through proactive actions, preventing breakdowns and reducing downtime. Reliability measures equipment's ability to consistently function without unexpected failures. In the petroleum industry, design, manufacturing and maintenance practices extremely influence reliability and safety. Metrics like MTBF and MTTR quantify reliability. Maintenance and reliability are interrelated, with maintenance enhancing reliability by preventing failures, while reliability focuses on consistent performance through design and manufacturing considerations.

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Biography

Ricardo Pablo Rabang is a graduate of B.S. Industrial Engineering, has completed a master of science degree in Management Engineering at Adamson University, and a PhD candidate in Engineering Management. Aside from being a professional industrial engineer, he is also a certified Lean Six Sigma Master Blackbelt, a certified Business Continuity Professional, a certified ISO 9001 Internal Auditor, and a certified Emergency Management Specialist. He has over 40 years of experience in various industries. Thirty-six of them were with the petroleum industry as an engineer and later became a senior supervisor of planning and reliability engineering section at Saudi Aramco in Saudi Arabia. Aside from engineering and management activities, he was also involved in numerous lean six sigma projects such as, improving turnaround time in overhauling class A and B critical equipment, reducing breakdowns of motor operated valves, improving cycle time of periodic testing and inspection of a gas and oil separator plant, minimizing structural defects in construction of low and medium-rise buildings, improving cycle time in periodic maintenance servicing of Toyota vehicles, and enhancing process yield in supply chain just to name a few. Additionally, he has participated in the investigation of plant equipment failures and unplanned shutdowns including safety-related incidents. He has participated in various local and international conferences including business assignments in the Middle East, Europe and USA and has been a plenary speaker at the 13th IEOM international conference in Manila. He is currently a university lecturer in the college of engineering and graduate school at the Adamson University in Manila, Philippines.