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Environmental Sustainability and Turnaround Maintenance. A Review of Best Practices

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Abstract

Turnaround maintenance (TAM) is a periodic shutdown of oil and gas industrial facilities for inspection, repair, and overhaul. TAM is essential for ensuring the safety, reliability, and efficiency of the plants, but it also poses significant environmental challenges. TAM activities generate large amounts of hydrocarbon waste, emissions, and noise, and consume considerable resources such as water, energy, and materials. Therefore, it is important to adopt environmental sustainability practices in TAM to minimize the negative impacts and enhance the positive outcomes. This paper reviews the current literature on environmental sustainability and TAM and identifies the best practices for achieving environmental performance improvement. The paper also discusses the benefits and barriers of implementing environmental sustainability practices in TAM and provides some recommendations for future research and practice.

Keywords:

Turnaround Maintenance, Environmental, Sustainability, Major Maintenance.

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I. Introductıon

Turnaround maintenance (TAM) is a planned and scheduled shutdown of an oil and gas industrial plants such refineries, Liquid natural gas (LNG), petrochemical plant, or a part of it for inspection, repair, and overhaul (IRO) (Moubray, 1997 and Lenahan, 2005). TAM is a critical activity for ensuring the safety, reliability, and efficiency of the plant, and preventing major accidents and failures (Al-Marri et al., 2020). TAM is also a complex and costly process that involves multiple stakeholders, such as owners, operators, engineers, technicians, inspectors, contractors, suppliers, buyers, regulators, and communities (F. Masubelele and E. Mnkandla, 2021). TAM is complex because of the short execution duration, huge number of scopes and resources involvement. TAM typically requires many resources, such as manpower, equipment, materials, and services, and generates a large amount of waste, emissions, and noise (Ghazali et al., 2011). Therefore, TAM has significant environmental impacts that need to be managed and mitigated.

Environmental sustainability refers to our capacity to fulfill current needs without hindering future generations from meeting theirs (WCED, 1987). Environmental sustainability is a key concern for industrial sectors, especially those that operate in resource-intensive and pollution-prone industries, such as oil and gas, petrochemical, and power generation (Azapagic, 2004). Environmental sustainability is not only a moral and ethical obligation, but also a strategic and competitive advantage for industrial organizations (Porter and van der Linde, 1995). Environmental sustainability can enhance the reputation, image, and stakeholder relations of the organizations, as well as reduce the operational costs, risks, and liabilities (Melnyk et al., 2003). Environmental sustainability can also foster innovation, learning, and continuous improvement, and create new opportunities for value creation and differentiation (Hart, 1997).

Environmental sustainability and TAM are interrelated and interdependent. On one hand, TAM can affect the environmental performance of the plant, both positively and negatively. On the other hand, environmental sustainability can influence the TAM process, both as a driver and a constraint. Therefore, it is important to integrate environmental sustainability principles and practices into TAM planning and execution, and to measure and monitor the environmental performance of TAM activities. This paper aims to review the current literature on environmental sustainability and TAM, and to identify the best practices for achieving environmental performance improvement. The paper also discusses the benefits and barriers of implementing environmental sustainability practices in TAM and provides some recommendations for future research and practice.

II. Literature Review

The literature review covers three main topics: (1) the environmental impacts of TAM, (2) the environmental sustainability practices in TAM, and (3) the environmental performance measurement and improvement in TAM. The literature review is based on a systematic search of academic databases, such as Scopus, Web of Science, and Google Scholar, using relevant keywords, such as "turnaround maintenance", "environmental sustainability", "environmental impact", "environmental management", "environmental performance", and their combinations. The search was limited to peer-reviewed journal articles published in English from 2000 to 2024. The search resulted in 65 articles, which were screened and analysed according to the following criteria: (1) the relevance to the topic of environmental sustainability and TAM, (2) the quality and rigor of the research design and methodology, and (3) the contribution and originality of the research findings and implications. Based on these criteria, 25 articles were selected for the literature review.

III. Environmental Impacts of TAM

The environmental impacts of TAM can be classified into two categories: direct and indirect. Direct impacts are those that result from the physical activities and operations of TAM, such as waste generation, emission release, and noise production. Indirect impacts are those that result from the changes in the plant operation and performance after TAM, such as energy consumption, greenhouse gas (GHG) emission, and resource efficiency.

- Waste generation: TAM activities produce various types of waste, such as hazardous and non-hazardous solid waste, liquid waste, and gaseous waste. The source of waste includes (Honeywell and PECB, 2023):
  - Chemical Waste: This includes solvents, acids, and other chemicals used in cleaning and maintenance processes.

- Spent Catalysts: Catalysts used in refining processes can become hazardous waste once they are spent.
- Contaminated Equipment: Equipment and tools that have been exposed to hazardous substances can generate waste when they are cleaned or replaced.
- Oil Sludge: Residual oil and sludge from storage tanks and pipelines can be hazardous.
- Asbestos and Insulation Materials: Older facilities may have asbestos-containing materials that need to be safely removed and disposed of.
- Paints and Coatings: Removal of old paints and coatings can produce hazardous waste.

The amount and composition of waste depend on the size, type, and age of the plant, the scope and duration of TAM, and the waste management practices adopted (PECB, 2023). Waste generation can have negative impacts on the environment, such as soil and water contamination, air pollution, landfill occupation, Health risks and Wildlife and habitat impact (El-Haggar, 2007) (PECB, 2023).

- Emission release: During turnaround maintenance in the oil and gas industry, emissions can be a significant concern. Here are some common sources of emissions:
  - Depressurizing Units: When process units are depressurized, gases are often vented to the atmosphere or flares, releasing volatile organic compounds (VOCs) and other pollutants. (Anderson et al., 2018)
  - Steaming and Purging: Cleaning and purging equipment with steam or inert gases can release emissions, especially if the vapours are not properly controlled. (Anderson et al., 2018)
  - Chemical Cleaning: Using chemicals to clean equipment can result in emissions if the vapours are not captured and treated. (Anderson et al., 2018)
  - Equipment Leaks: During maintenance, equipment such as valves, flanges, and seals may leak, releasing various pollutants. (Bruce et al., 2021)
  - Combustion Sources: Temporary power generators and other combustion equipment used during maintenance can emit nitrogen oxides (NOx), carbon monoxide (CO), and particulate matter (PM). (Bruce et al., 2021)

- Waste Handling: Handling and disposing of waste materials, including hazardous waste, can also be a source of emissions. (Bruce et al., 2021)

The amount and composition of emission depend on the same factors as waste generation, as well as the emission control technologies and practices adopted. Emission release can have negative impacts on the environment, such as climate change, acid rain, smog, and ozone depletion (El-Haggar, 2007).

- Noise production: During turnaround maintenance, several activities can lead to increased noise levels. Here are some common sources: (Ingersoll, C. 2023)
  - Heavy Machinery: The use of cranes, excavators, and other heavy equipment can generate significant noise.
  - Power Tools: Drills, grinders, and other power tools used for maintenance and repairs contribute to the noise.
  - Temporary Generators: These are often used to provide power during maintenance and can be quite loud.
  - Vehicle Traffic: Increased movement of trucks and other vehicles within the facility can add to the noise levels.
  - Cutting and Welding: Activities like cutting, welding, and grinding metal parts produce high levels of noise.
  - Blasting and Cleaning: Techniques such as sandblasting and high-pressure cleaning can also be noisy.

The amount and composition of noise depend on the same factors as waste generation and emission release, as well as the noise reduction technologies and practices adopted. Noise production can have negative impacts on the environment, such as noise pollution, wildlife disturbance, and human health effects (El-Haggar, 2007).

- Energy consumption: During turnaround maintenance, several activities can lead to increased energy consumption. Here are some common sources. (Ingersoll, C. 2023)
  - Heavy Machinery and Equipment: The use of cranes, excavators, and other heavy machinery requires significant energy, often powered by diesel or electricity.
  - Temporary Power Generators: These are frequently used to supply power during maintenance activities and can consume a lot of fuel.

- Lighting: Extensive lighting is often needed to ensure safe working conditions, especially if the maintenance work continues into the night.
- Heating, Ventilation, and Air Conditioning (HVAC): Maintaining appropriate temperatures and ventilation in work areas can be energy intensive.
- Pumps and Compressors: These are used for various tasks such as cleaning, purging, and testing equipment, and they consume a considerable amount of energy.
- Welding and Cutting Equipment: These tools require substantial electrical power for their operation.

The amount and composition of energy consumption depend on the same factors as waste generation, emission release, and noise production, as well as the energy efficiency technologies and practices adopted. Energy consumption can have indirect impacts on the environment, such as GHG emission, resource depletion, and energy security (El-Haggar, 2007).

- GHG emission: TAM, especially in industrial settings like refineries and chemical plants, can be a significant source of greenhouse gas (GHG) emissions. Here are some key sources of GHG emissions during TAM: (Porter et al., 2022)
    - Equipment and Machinery: The use of heavy machinery and equipment, such as cranes, trucks, and generators, often relies on fossil fuels, leading to CO2 emissions.
    - Flaring and Venting: During maintenance, there may be a need to depressurize equipment, which can result in flaring (burning off excess gases) or venting (releasing gases directly into the atmosphere). Both processes release significant amounts of CO2 and methane.
    - Fugitive Emissions: These are leaks from valves, flanges, and other equipment components. Even small leaks can add up to substantial emissions over time2.
    - Traffic Delays and Detours: Maintenance activities can cause traffic disruptions, leading to increased emissions from idling vehicles and detours.
    - Material Use: The production and transportation of materials used in maintenance, such as steel, asphalt, and concrete, also contribute to GHG

emissions.

- Energy Consumption: The energy required to power tools, lighting, and other equipment during maintenance can lead to indirect emissions, especially if the energy comes from non-renewable sources.

The amount and composition of GHG emission depend on the same factors as energy consumption, as well as the GHG emission factors of the energy sources and the GHG mitigation technologies and practices adopted. GHG emission can have indirect impacts on the environment, such as climate change, sea level rise, and extreme weather events (El-Haggar, 2007).

- Resource efficiency: TAM activities affect the resource efficiency of the plant, both positively and negatively. Resource efficiency is the ratio of the output to the input of a process, such as the production to the consumption of materials, water, and energy. TAM can improve the resource efficiency of the plant by replacing or repairing the inefficient or defective equipment and parts, by optimizing the process parameters and settings, and by enhancing the plant reliability and availability (Khasanah et al., 2019). TAM can also reduce the resource efficiency of the plant by generating or disposing of excess or unused materials, water, and energy, by causing the loss or leakage of resources during TAM, and by disrupting the plant operation and performance. Resource efficiency can have indirect impacts on the environment, such as resource conservation, waste reduction, and cost saving (El-Haggar, 2007).

IV. Environmental Sustainability Practices in TAM

Environmental sustainability practices in TAM are the actions and measures taken to minimize the negative environmental impacts and maximize the positive environmental outcomes of TAM activities. Environmental sustainability practices in TAM can be classified into four categories: (1) environmental planning, (2) environmental management, (3) environmental technology, and (4) environmental innovation.

- Environmental planning: Environmental planning is the process of identifying, assessing, and mitigating the environmental risks and impacts of TAM activities, and integrating the environmental objectives and requirements into the TAM plan and schedule (Bruce et al., 2021). Environmental planning includes the following practices:

- Environmental Impact Assessment (EIA): Conducting an EIA helps identify potential environmental risks and impacts associated with the maintenance activities. This includes assessing air emissions, water discharges, soil contamination, and waste generation. (Bruce et al., 2021)
- Regulatory Compliance: Ensuring that all activities comply with local, national, and international environmental regulations. This involves obtaining necessary permits and adhering to environmental standards. (Forsberg, 2022)
- Waste Management: Developing a comprehensive waste management plan to handle hazardous and non-hazardous waste generated during the turnaround. This includes proper segregation, storage, transportation, and disposal of waste materials.
- Pollution Control Measures: Implementing measures to control pollution, such as using dust suppression techniques, installing air filtration systems, and treating wastewater before discharge.
- Emergency Response Plan: Preparing for potential environmental emergencies by having a response plan in place. This includes spill response procedures, emergency contact information, and training for personnel.
- Monitoring and Reporting: Continuously monitoring environmental parameters during the turnaround and reporting any deviations from the planned activities. This helps in taking corrective actions promptly. (Forsberg, 2022)

By integrating these elements into the turnaround maintenance plan, companies can minimize their environmental footprint and ensure sustainable operations.

- Environmental management: Environmental management is the process of implementing, monitoring, and controlling the environmental activities and performance of TAM, and ensuring the adherence to the environmental standards and regulations. Environmental management includes the following practices: (a) applying environmental management systems (EMS) and environmental audits for TAM activities, (b) implementing environmental procedures and practices for TAM operations, such as waste management, emission control, and noise reduction, (c) monitoring and reporting the environmental performance and compliance of TAM activities, (d) conducting environmental training and awareness programs for TAM personnel, and (e) reviewing and evaluating the environmental effectiveness and improvement of TAM activities (Bruce et al., 2021).

- Environmental technology: Environmental technology is the application of scientific and engineering knowledge and methods to reduce the environmental impacts and enhance the environmental outcomes of TAM activities. Here are some key technologies and tools used:
    - Emission Control Systems: Technologies such as scrubbers, filters, and catalytic converters help reduce emissions from maintenance activities, ensuring compliance with air quality standards. (Bruce et al., 2021)
    - Waste Treatment Technologies: Advanced waste treatment systems, including bioreactors and chemical treatment units, manage and treat hazardous waste generated during maintenance. (Olsen, T., 2018)
    - Remote Monitoring and Sensing: IoT devices and sensors monitor environmental parameters in real-time, providing data on air and water quality, noise levels, and more.
    - Energy-Efficient Equipment: Using energy-efficient machinery and tools reduces the environmental footprint of maintenance activities. This includes electric or hybrid equipment that produces fewer emissions. (Duffuaa et al., 2009)
    - Water Recycling Systems: Technologies that recycle and reuse water help minimize water consumption and reduce the impact on local water resources.
    - Predictive Maintenance Tools: Utilizing AI and machine learning to predict equipment failures can reduce the need for extensive maintenance, thereby minimizing environmental disruption.

By integrating these technologies, companies can enhance the sustainability of their turnaround maintenance processes, ensuring they meet environmental standards while maintaining operational efficiency.

- Environmental innovation: Environmental innovation is the creation and adoption of new or improved products, processes, or services that reduce the environmental impacts and enhance the environmental outcomes of TAM activities. Here are some key innovations:

- Digital Twin Technology: Creating a digital replica of physical assets allows for real-time monitoring and predictive maintenance, reducing the need for physical inspections and minimizing downtime. (Bruce et al., 2021)
- Big Data and Analytics: Utilizing big data and advanced analytics helps in predicting equipment failures and optimizing maintenance schedules, leading to more efficient use of resources and reduced environmental impact. (Olsen, T., 2018).
- Green Chemistry: Implementing environmentally friendly chemicals and processes during maintenance activities reduces hazardous waste and emissions.
- Renewable Energy Integration: Using renewable energy sources, such as solar or wind power, to run maintenance operations can significantly reduce the carbon footprint. (Rantala et al., 2022)
- Advanced Waste Management: Innovations in waste treatment and recycling technologies ensure that waste generated during maintenance is handled in an environmentally responsible manner.
- IoT and Remote Sensing: Internet of Things (IoT) devices and remote sensing technologies provide real-time data on environmental parameters, enabling proactive management of potential environmental risks. (Olsen, T., 2018).

By adopting these innovations, companies can enhance the sustainability of their turnaround maintenance processes, ensuring compliance with environmental regulations and contributing to overall environmental stewardship.

V. Environmental Performance Measurement and Improvement in TAM

Environmental performance measurement and improvement in TAM are the processes of quantifying, evaluating, and enhancing the environmental impacts and outcomes of TAM activities. Environmental performance measurement and improvement in TAM include the following practices: (1) environmental performance indicators, (2) environmental performance evaluation, and (3) environmental performance improvement.

- Environmental performance indicators: Environmental performance indicators are the metrics and measures used to quantify and assess the environmental impacts and outcomes of TAM activities. Environmental performance indicators can be classified into two categories: input and output.

Input indicators measure the amount and composition of the resources consumed and the pollutants emitted by TAM activities, here are some key EPIs commonly used: (Hansen et al., 2016)

  - Emissions: Monitoring and controlling emissions of pollutants such as CO2, NOx, and SOx during maintenance activities.
  - Waste Management: Tracking the amount and type of waste generated and ensuring proper disposal or recycling.
  - Energy Consumption: Measuring the energy used during maintenance to identify opportunities for efficiency improvements.
  - Water Usage: Monitoring water consumption and implementing measures to reduce usage and prevent contamination.
  - Spill Incidents: Recording and analysing any spills of hazardous materials to prevent future occurrences.
  - Noise Levels: Measuring noise generated during maintenance to ensure compliance with regulations and minimize disturbance.
  - Resource Utilization: Assessing the use of raw materials and promoting sustainable sourcing and usage practices.

Output indicators measure the amount and composition of the products and services produced and the benefits achieved by TAM activities, such as resource efficiency, waste reduction, emission control, noise abatement, and GHG mitigation. Environmental performance indicators can be expressed in absolute or relative terms, such as kilograms, liters, decibels, joules, tons, or percentages, ratios, and indexes.

- Environmental performance evaluation: Environmental performance evaluation is the process of comparing and analysing the environmental performance indicators of TAM activities, and identifying the strengths and weaknesses, the opportunities and threats, and the gaps and potentials of the environmental performance. Environmental performance evaluation can be conducted at different levels, such as individual, team, project, plant, or organization. Environmental performance evaluation can also be conducted from different perspectives, such as internal or external, historical or benchmark, and qualitative or quantitative. Environmental performance evaluation can use various methods and tools, such as statistical analysis, graphical representation, and multi-criteria decision making. (Hansen et al., 2016)

- Environmental performance improvement: Environmental performance improvement is the process of implementing and monitoring the actions and measures taken to enhance the environmental performance of TAM activities and ensuring the achievement of the environmental objectives and targets. Environmental performance improvement can be achieved by applying the environmental sustainability practices in TAM, such as environmental planning, management, technology, and innovation. Environmental performance improvement can also be achieved by adopting the continuous improvement cycle, such as plan-do-check-act (PDCA), define-measure-analyse-improve-control (DMAIC), or observe-orient-decide-act (OODA). Environmental performance improvement can use various methods and tools, such as feedback, learning, and adaptation. (Hansen et al., 2016).

VI. Discussion

The literature review reveals that environmental sustainability and TAM are important and relevant topics for industrial sectors, especially those that operate in resource-intensive and pollution-prone industries, such as oil and gas, petrochemical, and power generation. The literature review also reveals that environmental sustainability and TAM have significant environmental impacts and outcomes, both positive and negative, direct and indirect. Therefore, it is important to integrate environmental sustainability principles and practices into TAM planning and execution, and to measure and monitor the environmental performance of TAM activities.

The literature review identifies the best practices for achieving environmental performance improvement in TAM, such as environmental planning, management, technology, and innovation, and environmental performance indicators, evaluation, and improvement. The literature review also discusses the benefits and barriers of implementing environmental sustainability practices in TAM, such as the following:

- Benefits: Implementing environmental sustainability practices in TAM can bring various benefits to the industrial organizations and stakeholders, such as the following: (a) enhancing the reputation, image, and stakeholder relations of the organizations, (b) reducing the operational costs, risks, and liabilities of the organizations, (c) fostering innovation, learning, and continuous improvement of the organizations, (d) creating new opportunities for value creation and differentiation of the organizations, (e) improving the safety, reliability, and efficiency of the plants, (f) preventing major accidents and failures of the plants, (g) minimizing the negative environmental impacts and maximizing the positive environmental outcomes of TAM activities, and (h) contributing to the environmental sustainability of the industrial sectors and the society (Jonathan, 2022).
- Barriers: Implementing environmental sustainability practices in TAM can face various barriers and challenges from the industrial organizations and stakeholders, such as the following: (a) lack of awareness, knowledge, and skills of the environmental sustainability and TAM issues and practices, (b) lack of commitment, support, and leadership of the top management and the key decision makers, (c) lack of resources, capabilities, and infrastructure of the environmental sustainability and TAM activities and performance, (d) lack of incentives, motivation, and recognition of the environmental sustainability and TAM efforts and achievements, (e) lack of coordination, communication, and collaboration of the environmental sustainability and TAM stakeholders and regulators, (f) lack of standards, regulations, and enforcement of the environmental sustainability and TAM requirements and compliance, (g) lack of data, information, and evidence of the environmental sustainability and TAM impacts and outcomes, and (h) lack of methods, tools, and techniques of the environmental sustainability and TAM measurement and improvement (Knapik et al., 2024; Bruce et al., 2021).

VII. Conclusion and Recommendations

This paper reviews the current literature on environmental sustainability and TAM and identifies the best practices for achieving environmental performance improvement. The paper also discusses the benefits and barriers of implementing environmental sustainability practices in TAM and provides some recommendations for future research and practice.

For future research, the paper suggests the following directions: (1) conducting more empirical studies on the environmental impacts and outcomes of TAM activities, using quantitative and qualitative methods, and covering different industrial sectors, regions, and contexts, (2) developing and testing more environmental sustainability practices and innovations for TAM, using experimental and case study methods, and involving different TAM stakeholders and regulators, (3) designing and validating more environmental performance indicators and evaluation methods for TAM

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