Predictive Maintenance Strategies for Heat Exchangers Applied in a Hybrid Project Management Framework for Oil and Gas Industries

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This study presents the development of a predictive maintenance model for heat exchangers in oil refineries, integrating agile methodologies within a structured project management framework. Conducted as a case study in an oil and gas company refinery, the research addresses challenges related to data accuracy, model reliability, and implementation. The hybrid methodology encompasses project scope definition, data collection from laboratory-scale and operational heat exchangers, and model development over 18 months. The model was validated and refined through rigorous testing, enabling the prediction of optimal cleaning schedules. Risk management strategies included applying a Risk Breakdown Structure (RBS) and SWOT analysis, resulting in optimized maintenance scheduling, cost reduction, and enhanced operational efficiency and safety. This approach provides a benchmark for improving oil and gas industry maintenance practices.
Keywords: Project Management. Predictive Maintenance. Hybrid Methods. Oil Refineries. Mathematical Models.

Project management is fundamental for successful complex ventures, particularly in the oil and gas industry, which faces significant challenges and risks. Heat exchangers are critical in this sector, ensuring facilities continuous and safe operation. These devices are essential for thermal energy exchange between fluids and are integral to oil refining and natural gas production [1,2].

The performance of heat exchangers can be severely impaired by the accumulation of deposits and fouling, which reduce heat transfer efficiency and increase operational costs [3]. Thus, strategically managing cleaning campaigns for these units requires careful planning and applying advanced predictive techniques [4].

Traditional maintenance approaches initially focused on immediate cost reduction, often neglecting long-term system reliability and availability. Maintenance practices began with Corrective Maintenance, evolving into Preventive Maintenance (PM)—a proactive approach to prevent failures. The increasing competitiveness of the oil and gas industry accelerated this transition [5]. The development of engineering concepts such as reliability, maintainability, availability, and lifecycle cost optimization emphasized the importance of minimizing equipment downtime. Consequently, preventive or scheduled maintenance became standard practice [6], eventually giving rise to modern techniques such as Condition-Based Maintenance (CBM), where maintenance decisions are driven by real-time machine condition data obtained through monitoring systems (Figure 1) [2].

In the oil and gas sector, where operations are continuous and highly complex, preventive and predictive equipment maintenance is critical [7].

Project management is vital in this context, offering significant improvements across various operational dimensions. The importance of this study can be summarized through the following contributions:

Reduction of Operational Costs: Fouling in heat exchangers increases energy consumption and necessitates frequent cleanings. An effective forecasting model can optimize maintenance schedules, yielding substantial cost savings [5].

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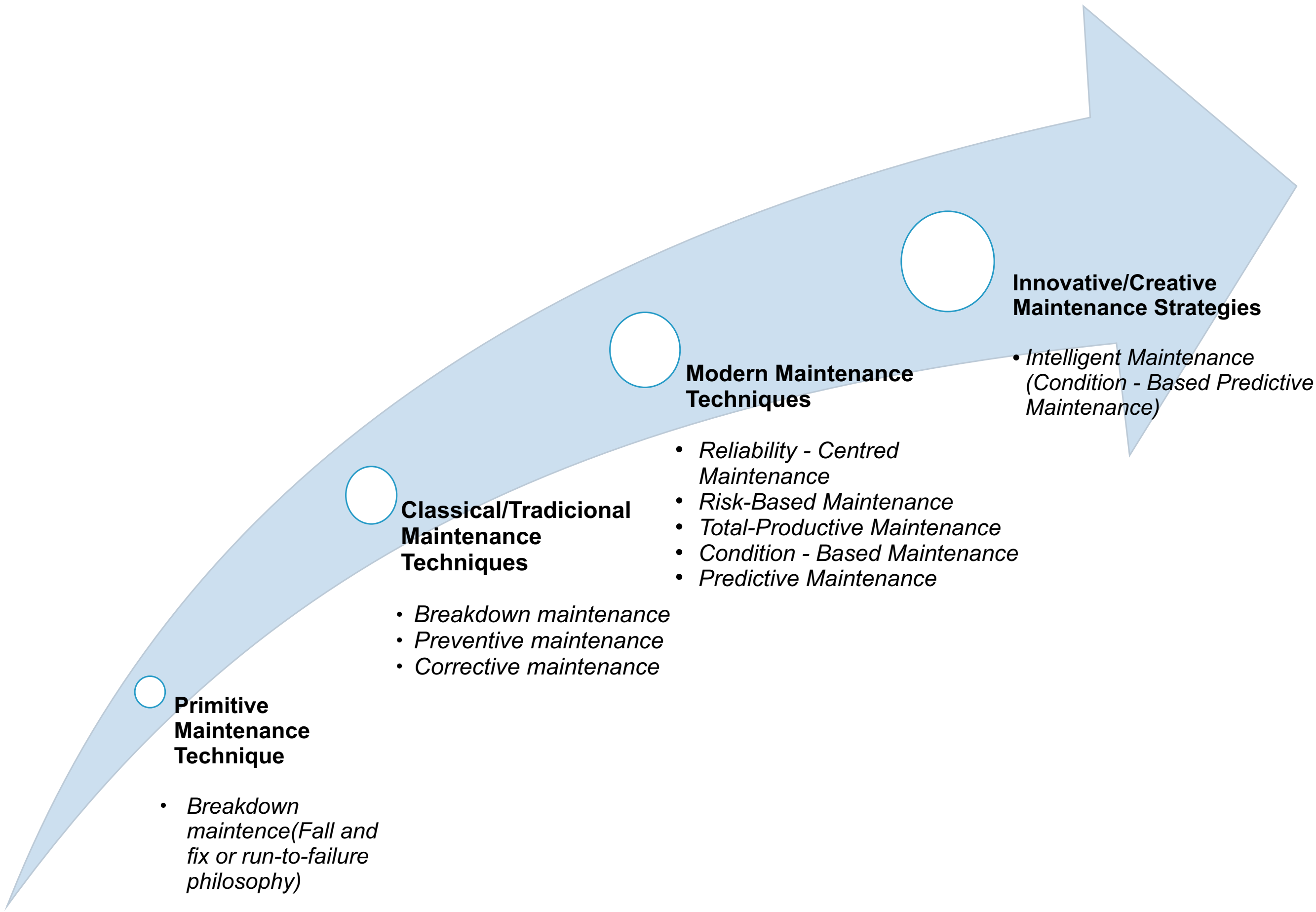
Figure 1. Evolution of industrial systems maintenance practices.



Adapted from Eyoh, & Kalawsky [2].

Extension of Equipment Lifespan: Properly managed predictive maintenance extends the operational life of heat exchangers by preventing severe degradation, thereby avoiding costly repairs or replacements [6].

Improved Operational Efficiency: Strategic project management ensures that heat exchangers operate optimally, enhancing overall process performance and contributing to the company's competitiveness [8].

Enhanced Operational Safety: Applying project management techniques to heat exchanger maintenance fosters safer industrial operations, minimizing the risk of equipment failure and associated hazards [9].

Strategic Planning Capability: Project management provides a systematic and structured approach to planning and executing cleaning campaigns, integrating technical, economic, and operational factors to achieve optimal results [3].

According to the most recent data from the Brazilian Ministry of Mines and Energy, the aggregate production of the country's oil refineries reached approximately 1.97 million barrels per day in 2020, translating to an estimated annual production of about 719 million barrels [10]. However, this output can vary significantly due to market demand, economic conditions, and refinery maintenance schedules. These fluctuations underscore the need for effective management strategies to ensure operational continuity and efficiency in Brazil's refining sector.

Therefore, the need for an effective forecasting model for heat exchanger maintenance in the oil and gas industry is evident. Such a model aims to determine the optimal timing for cleaning interventions, maximizing efficiency while minimizing maintenance costs [11]. This article explores the intersection between project management and predictive maintenance, presenting a methodological framework for developing and implementing an effective predictive model.

Materials and Methods

The method adopted in this study is grounded in applying a project proposal to a real case study conducted in 2019 at a refinery operated by an oil and gas company, as described by Souza and Marinho [12]. This practical approach was chosen to support the development of a robust mathematical model capable of predicting cleaning schedules for heat exchangers within preheat train systems.

Figure 2 illustrates the structure of the hybrid methodology, which incorporates the design of the project scope, time management, cost analysis, and risk assessment. These elements were integrated into the 18-month model development process.

Results and Discussion

A Work Breakdown Structure (WBS) is a fundamental project management tool used to define and organize a project's total scope by decomposing it into smaller, more manageable components. The WBS developed for the Cleaning Campaign Forecast Model for Heat Exchangers offers a comprehensive visual representation of the project's structure, delineating key phases such as Project Management, Acquisitions, Procurement, Development of the Mathematical Model, Testing and Certification, Project Outcome, and Closure [13].

Figure 3 presents the proposed WBS for the project. This structured approach ensures that all necessary tasks are clearly identified, appropriately assigned, and systematically executed. It facilitates effective planning, resource allocation, and monitoring of project progress.

Although the original case study adopted the Waterfall model, the current approach integrates both the Waterfall and Agile methodologies, particularly during the development and validation phases of the mathematical model for cleaning campaign prediction. This hybrid model ensures that project deliverables are aligned with the defined scope, schedule, and budget, while leveraging the flexibility of Agile practices to

Figure 2. Framework of the project.

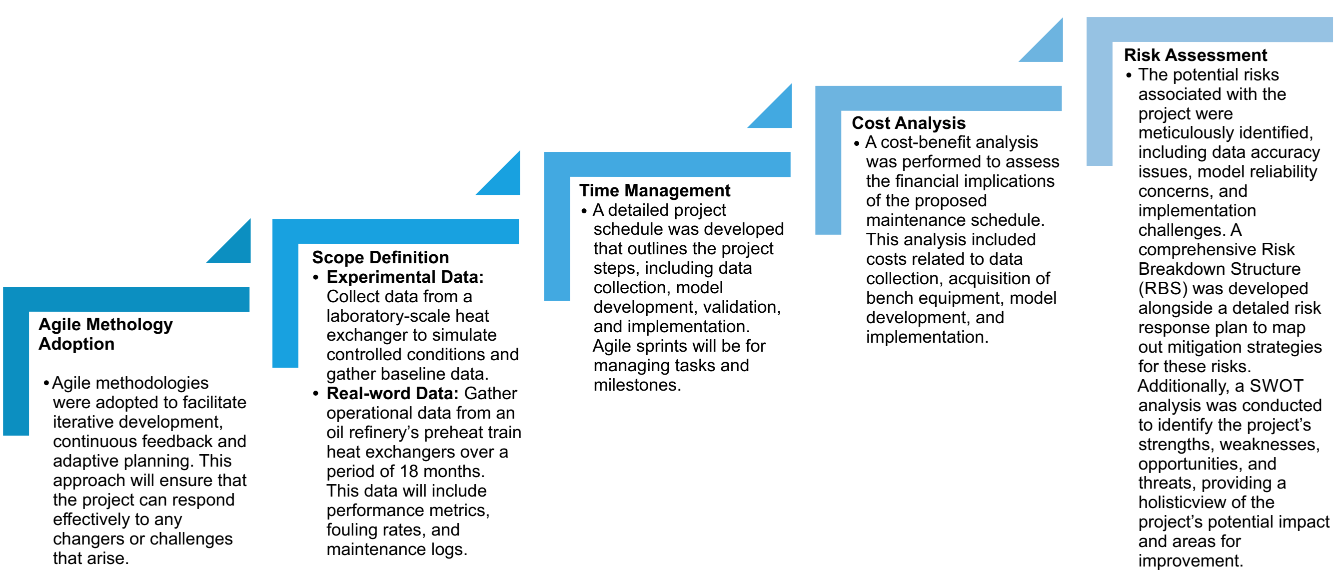
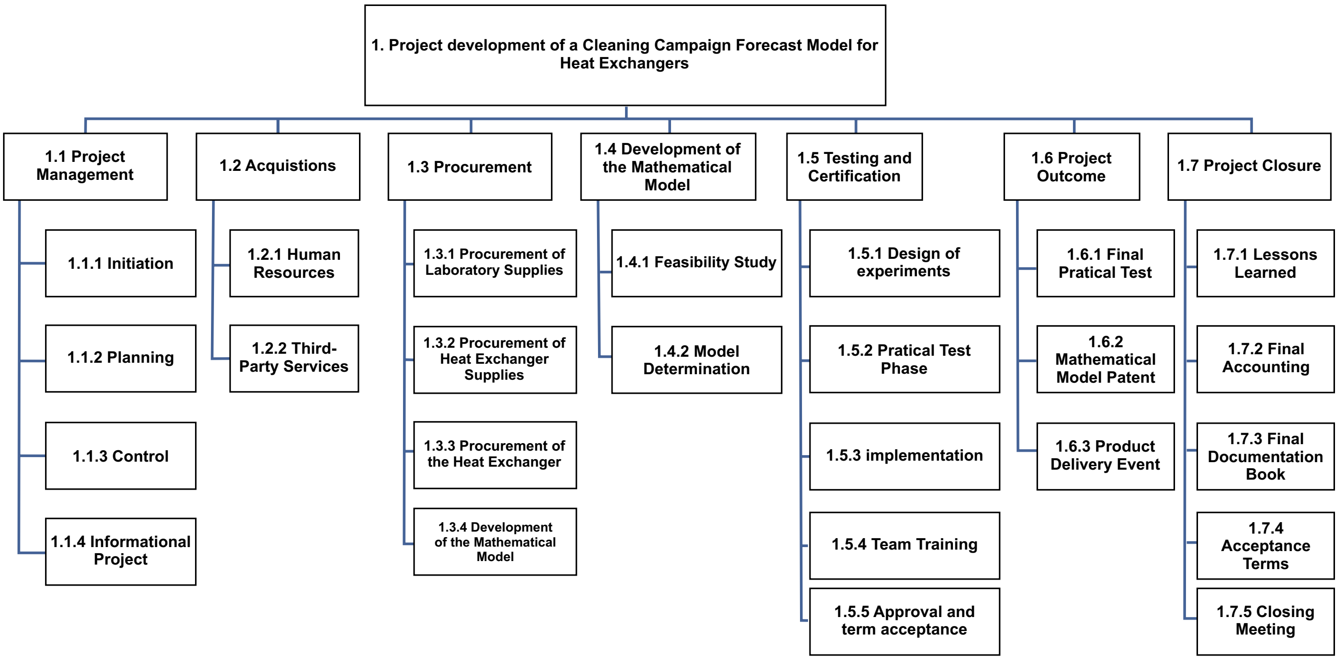


Figure 3. Project WBS.



accommodate evolving requirements and enhance the effectiveness of project execution.

In the Agile framework, the Scrum methodology organizes work into iterative cycles known as Sprints, typically lasting one month. These Sprints enable the development team to continuously refine and adapt the project as new insights and challenges emerge. The stages of the Scrum process implemented in this project include (Figure 4):

Sprint Planning: During this phase, the team defines the deliverables for the upcoming Sprint. The Product Owner prioritizes items in the Product Backlog, and the team selects tasks for the Sprint. These selected tasks are moved to the Sprint Backlog.

Daily Scrum: A short meeting is held to assess progress, discuss obstacles, and plan the day's work. This routine promotes transparency and synchrony within the team. Sprint Review: At the end of each Sprint, the team presents completed tasks to stakeholders. This stage offers an opportunity for feedback, validation, and adjustments based on practical insights.

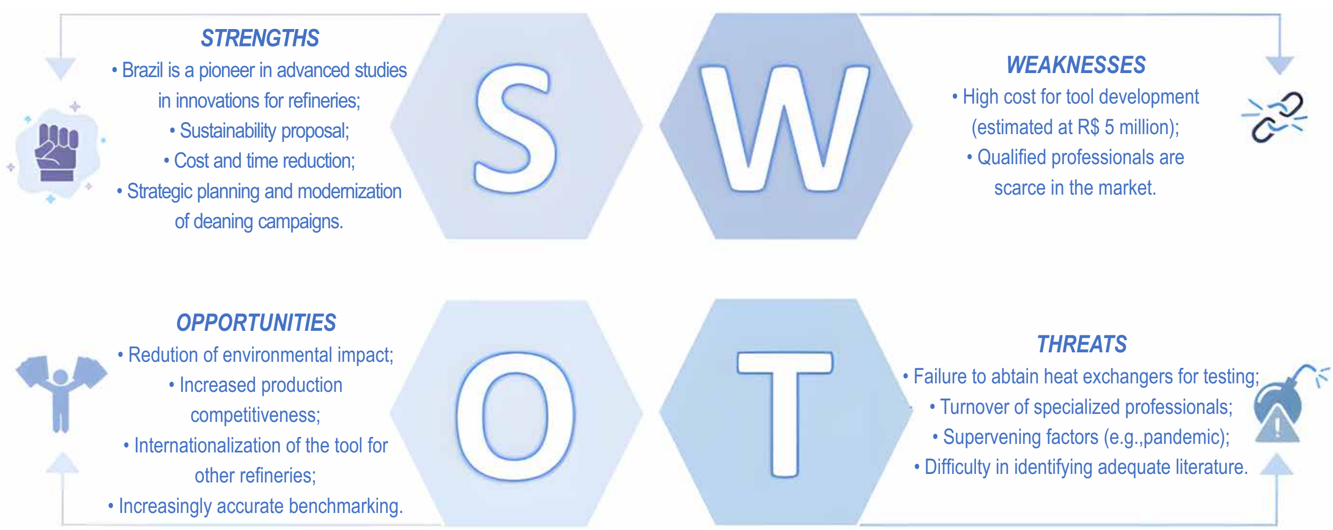
Sprint Retrospective: Following the Sprint Review, the team reflects on the Sprint process, identifying lessons learned and areas for improvement to enhance future performance.

Integrating these Scrum elements fosters a structured yet adaptable environment that supports continuous delivery of high-quality outcomes. This approach also ensures responsiveness to stakeholder feedback and evolving project dynamics. A SWOT analysis (Figure 5) and a Risk Response Plan (Table 1) were developed to complement the implementation of Agile methodology. The SWOT analysis comprehensively evaluates internal strengths and weaknesses and external opportunities and threats, providing strategic insights for decision-making. The Risk Response Plan, in turn, outlines critical risks and corresponding mitigation strategies, contributing to proactive project governance and resilience against potential disruptions.

The quality requirements for this project encompass several critical elements necessary for developing a reliable and applicable mathematical model. Central to this effort is data from both a

Figure 4. Scrum process.

Figure 5. SWOT analysis.



bench-scale shell-and-tube heat exchanger and a full-scale operational heat exchanger installed in a refinery plant. This dual-source data collection provides a robust dataset for validating and fine-tuning the model to ensure real-world applicability.

Using Microsoft Excel® VBA and MINITAB® as analytical tools is crucial in modeling. These tools offer powerful capabilities for data analysis and statistical validation. These tools support the generation of accurate, replicable outcomes, reinforcing the reliability of the predictive model. Complementing these technical components, integrating Agile methodologies—particularly Scrum—with traditional project management frameworks provided a flexible and effective structure, well-suited to the dynamic and highly regulated oil and gas sector. This hybrid management approach enabled efficient execution across all project phases, including planning, resource allocation, model development, and implementation. The iterative nature of Scrum, with recurring Sprints, supported ongoing improvements and responsiveness to emerging challenges, such as compliance requirements, environmental constraints, and rapid technological changes.

Table 1. Critical points of the risk response plan for technical execution failure.

Risk	Probability	Severity	Exposure	Response	Action Description	Responsible
Failure in the Mathematical Model Definition	Medium	Medium	Medium	Mitigate	Identify possible failures, evaluate model variables, and adjust parameters.	Technical Team
Failurein Heat Exchanger Testing	Low	Low	Low	Mitigate	Require performance and certification test reports after equipment manufacturing; If a defect is identified in the equipment, report the problem to the supplier for repair.	Supplier and Technical Team
Failure in Adapting the Obtained Data	Medium	Low	Medium	Mitigate	Identify possible failures, evaluate model variables, and adjust parameters; • Provide data through the Plant's Heat Exchanger Battery Sponsor.	Technical Team, Technical Leader, and Sponsor

Agile tools like Daily Scrums and Sprint Retrospectives promoted transparency, accountability, and continuous process optimization. Together, these elements ensured that the project maintained alignment with its technical goals while remaining adaptable to the realities of industrial environments.

As described by Pessoa and colleagues [11], the mathematical model developed for this study introduces an innovative yet simplified method for predicting fouling rates in crude oil heat exchangers within preheat systems at refineries. Fouling—a common issue in thermal systems—is affected by fluid velocity, temperature, fluid composition, and equipment configuration. This model streamlines predictions by focusing on mean fluid velocity and effective temperature, resulting in a low error margin validated against operational data from a Brazilian refinery. Its adaptability to varying operational conditions makes it a practical tool for optimizing maintenance strategies and mitigating the economic losses associated with fouling.

This technical rigor and methodological flexibility integration highlights the project's commitment to precision, efficiency, and industrial applicability in solving complex maintenance challenges.

Conclusion

As demonstrated in this study, implementing predictive maintenance strategies in preheat train heat exchangers shows substantial promise in improving operational efficiency in the oil and gas industry. The project has effectively addressed the challenges posed by fouling in heat exchangers by developing a precise and validated mathematical model using data from laboratory and operational environments and adopting a hybrid project management approach. Integrating advanced tools such as Microsoft Excel® VBA and MINITAB® enabled rigorous data handling and statistical analysis, supporting accurate modeling and decision-making. This method contributes to optimized maintenance schedules, reduced equipment downtime, and significantly minimized omic losses, affirming the strategic importance of predictive maintenance for the reliability and sustainability of refinery operations.

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