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A Preventive Maintenance Program Evaluation Approach:
A Case Study on Gas Lift Compressors in Oil Extraction

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Abstract

This research investigates the role, impact and effectiveness of the preventive maintenance (PM) program for capital-intensive industries that require large investments in expensive physical assets as oil industry. It adopts a case study design to evaluate PM program requirements setting and implementation on gas lift compressors at X-Oil Company. It proposes that PM is one of the most important activities that maintain the production process continuity in capital-intensive industries such as oil industry. The case study investigation methods utilize maintenance records, annual plans, and employee interviews, to assess the status and effectiveness of the PM program, its implementation, its key performance indicators (KPIs), and outcomes. The findings revealed ineffective current PM program at X-Oil Company with significant adequacy/deficiencies, leading to frequent emergency shutdowns and over-reliance on corrective maintenance. The research analysis concludes that the main causes of inadequacies or deficiencies are related to underestimating the important role of PM, insufficient PM program requirements, and absence of an integrated efficient maintenance computerized management system. The study recommends a set of guidelines and solutions as suggestions to enhance PM practices, by focusing on lifecycle planning, integration of technology, and engineering asset management (EAM) training .

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Keywords: Preventive maintenance, maintenance requirement, gas lift compressors, asset performance, cost reduction, Asset reliability.

نهج تقييم برنامج الصيانة الوقائية:

دراسة حالة على ضواغط رفع الغاز في استخراج النفط

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الملخص:

هذا البحث يتحقق من دور وأثر وفعالية برنامج الصيانة الوقائية (PM) في الصناعات كثيفة رأس المال التي تتطلب استثمارات كبيرة في الأصول المادية المكلفة مثل صناعة النفط. يعتمد البحث على منهج دراسة الحالة لتقييم حالة وفعالية برنامج الصيانة الوقائية ومتطلباته وتنفيذه على ضواغط الرفع بالغاز في شركة إكس–أويل (X–Oil Company). البحث يفترض أن الصيانة الوقائية هي إحدى أهم الأنشطة التي تحافظ على استمرارية عملية الإنتاج في الصناعات كثيفة رأس المال مثل صناعة النفط. استخدمت منهجية دراسة حالة سجلات الصيانة، والخطط السنوية، ومقابلات الموظفين لتقييم حالة وفعالية تصميم وتنفيذ برنامج الصيانة الوقائية، وتحديد مؤشرات الأداء الرئيسية (KPIs)، وتحليل نتائجه وسردها بيانياً. كشفت النتائج عن عدم فعالية البرنامج الحالي في شركة إكس–أويل مع وجود قصور /نواقص كبيرة، أدت إلى عمليات إيقاف طارئة متكررة واعتماد مفرط على الصيانة الإصلاحية. خلص التحليل البحثي إلى أن الأسباب الرئيسية للقصور أو النواقص مرتبطة بالتقليل من شأن الدور الهام للصيانة الوقائية، وعدم كفاية تعريف متطلبات برنامج الصيانة الوقائية، وعدم توفير نظام متكامل وفعال لإدارة الصيانة الالي. كتوصية، تقدم الدراسة مجموعة من الإرشادات والحلول كمقترحات لتعزيز ممارسات الصيانة الوقائية، من خلال التركيز على التخطيط لدورة الحياة، ودمج التكنولوجيا، وتدريب إدارة الأصول الهندسية. يسلط البحث الضوء على الدور الاستراتيجي لمواءمة تخطيط

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الصيانة الوقائية مع الأهداف التشغيلية لتقليل تكلفة دورة حياة الأصول، وتحسين موثوقيتها، وضمان استمرارية الإنتاج لتحقيق الربحية. تساهم هذه الرؤى في تطوير أفضل الممارسات في إدارة الصيانة لمنشآت استخراج النفط على وجه الخصوص، والصناعات كثيفة الأصول بشكل عام.

الكلمات المفتاحية: الصيانة الوقائية، متطلبات الصيانة، ضواغط رفع الغاز، أداء الاصول، خفض التكاليف، موثوقية الاصول.

1. Introduction

PM has a profound effect on the efficiency of operation processes of production and service organizations that are asset-intensive like those in oil industry. The role that PM plays is related to assurance of continuity of operation, reducing emergency maintenance and optimizing the functional life of assets (El-Akruti et al., 2025, El-Akruti et al., 2016a, El-Akruti et al., 2013a), (Carvalho et al., 2015). With reference to the complexity and high investments and robust PM cost of oil assets, Aoudia et al., (2008) indicated that insufficient PM can lead to significant financial losses due to equipment failures and production interruptions of operations of critical assets in the oil and gas sector. In this respect, literature showed that PM costs account for 15% to 40% of total production costs, particularly in large industrial organizations (Bamber et al., 2004). (El-Akruti et al., 2025, El-Akruti et al., 2016b, Sigsgaard et al., 2021) highlighted that inadequate planning, insufficient resources, and misaligned objectives lead to implementing inefficient PM strategies. Kumar et al., (2013), emphasized the role of PM in enhancing productivity, operational stability and profitability by maintaining equipment reliability. Many studies have shown that effective PM can improve system availability, meet safety requirements, and optimize lifecycle costs, e.g., (El-Akruti et al., 2016a, El-Akruti et al., 2013a, Rosmaini et al., 2011). Furthermore, it shown in literature that adherence to PM schedules can prevent catastrophic accidents, unauthorized leaks, and environmental violations in oil fields (Benson et al. 2024). It was also shown that PM is considered as a strategic value-added activity (El-Akruti et al., 2016b, 2013c). PM is widely known in literature

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by its role in preventing or minimizing failures through scheduled interventions to ensure smooth operations (Jonssonl. 1999), and reduce risks (Benson et al., 2024, Martins et al., 1999). PM's implementation was widely proved to increase system reliability, enhance operator safety, extend equipment functional life, and optimizing workforce

utilization (Garner et al., 2023), to minimizes downtime, lowers repair costs (Ong et al., 2015), and improves product quality, and consequently contribute to competitive advantages in the oil industry (El-Akruti, K.O., 2012, El-Akruti et al., 2013c). IAEA, (2007) Showed that PM play a vital role in achieving objectives. Muchiri et al., (2010) showed that implementing an effective PM program poses several challenges like identifying critical equipment, prioritizing tasks, coordinating with production schedules, and managing costs. Furthermore, PM implementation requires standardized performance indicators to enhance evaluation of PM effectiveness (Swanson., 2001). Its Performance measurement was found integral to evaluate success and guiding improvements and requires clear metrics, such as Mean Time Between Failures (MTBF) and Corrective Maintenance Time as a percentage of Total Maintenance Time (Silvia et al., 2024, Elisson A., 2013, Eti M. et al., 2004 Kumar et al., (2013) showed that effective use of PM metrics enables organizations to use leading indicators for identifying gaps, address deficiencies, and enhance decision-making processes .

Despite the wide literature on PM effects on achieving success in industry, there is limited research focusing specifically on gas lift compressors in oil extraction. These compressors are pivotal in maintaining reservoir pressure and ensuring continuous oil flow, yet they face unique challenges such as wear, corrosion, and high operating stresses (Dwight., 1999). Evaluating the PM practices for gas lift compressors at X-Oil Company offers an opportunity to address this gap .

The research hypothesizes that inadequacy or deficiencies in PM activities negatively impact assets performance and results in lowering reliability, increasing downtime, inefficient operation and consequently declining profitability and loss of competitiveness.

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The study aims at identifying inadequacies/deficiencies of the PM program and propose enhancement to enable asset-intensive industries optimize assets' functional life, achieve targeted profitability and competitiveness. By providing a framework for evaluating and improving PM programs, the study contributes to reducing operational risks, enhancing asset reliability, and optimizing maintenance costs.

Moreover, the integration of advanced technologies, such as computerized maintenance management systems (CMMS), can further streamline PM processes and improve outcomes (El-Akruti et al., 2013b).

The proposed approach aligns with industry trends toward proactive asset management, emphasizing sustainability, cost-effectiveness, and regulatory compliance. The research highlights the strategic role of aligning PM planning with operational goals to reduce asset lifecycle cost, improve assets reliability, and ensure production continuity for profitability. These insights contribute to advancing best practices in maintenance management for oil extraction facilities in particular and asset-intensive industries in general.

2. Research Methodology

This research adopts a contextualist-retroductive case study design methodology that was proven by El-Akruti et al., (2010, 2018) to be well-suited for investigating complex relationships within real-world settings. The methodology considers, X-Oil Company (a pseudonym), as the case study organization and the challenges related to compressor maintenance as sub-cases or phenomenon for investigation. This organization was selected due to: (1) its operation within a complex asset and system environment suspected of significantly impacting strategic success; (2) its demonstrable support for the research and interest in its outcomes; (3) its status as a relatively new entity actively seeking to optimize asset utilization; and (4) the researcher's established familiarity with the company and the broader industry.

Data were collected from multiple sources to ensure triangulation and enhance validity:

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- Semi-structured interviews were conducted with maintenance managers and engineers to gain insights into current maintenance practices and challenges.
- Document analysis focused on reviewing PM plans, performance reports, and historical records.
- Observations were made of maintenance activities to assess the practical implementation of the PM program.

This multi-method approach, consistent with established practices for in-depth investigation (Yin, 2003), evaluated the PM program against three key dimensions :

- Inadequacy of PM activities that leads to failure
- Ineffectiveness of PM activities that impact compressor performance.
- Performance indicators that reflect rates of equipment reliability and availability alongside the ratio of PM to total maintenance work.

This methodology represent an applied approach, emphasizing real-world applicability within the oil and gas industry and integrates insights from EAM and leverages case studies to provide actionable recommendations for PM practices.

3. Case Study Organization's Gas Lift Compressors

X-Oil Company operates 26 high-pressure gas lift compressors of various types across multiple field stations as shown in Table 1. This study focuses on 4 specific units identified as the most maintenance-prone and susceptible to frequent operational disruptions. These large compressors are fundamental to X-Oil's crude oil production, directly supporting extraction from 94 oil wells. The crude output from these wells is critically dependent on the continuous and efficient operation of these gas lift compressors. Maintaining operational efficiency of these gas lift compressors requires complex, costly, and year-round maintenance; encompassing both preventive and corrective activities. Due to the specialized nature of much of this work, external expertise and dedicated trainers are frequently necessary to perform essential maintenance tasks.

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Table 1: Gas Lift Compressors in X-Oil Company (Petroleum Operations Company)

Manuf-acturer	Model	Qua-ntity	Instal-lation Year	Drive Type / Fuel	Elect. Power Consu-mption
Cooper Bessemer	CB GMVA-8	10	1967-1970	Gas Engine	-
Cooper Bessemer	CB GMVA-12	6	Not Available	Gas Engine	-
Ingersoll Rand	IR KVG	5	1968	Gas Engine	-
Ingersoll Rand	IR OFGH 14-3	2	1997	Electric Motor	2 MW per unit
Ingersoll Rand	IR RDS-TFX	1	1968	Gas Engine	-
Areal	JG H4	2	1993	Diesel Engine[1]	-
TOTAL		**26**			

*MMCFD: Million standard cubic feet of gas per day

4. Evaluation Framework for PM Program Status and Effectiveness

The Evaluation framework focus on evaluating the Status and effectiveness of PM program in the case study (at X-Oil Company), in terms of the PM program's activities; presence or sufficiency, inadequacy or deficiencies, and causes of inadequacy or shortcomings. To evaluate the status and effectiveness of a PM program, this study develops a structured framework based on EAM System's framework developed by El-Akruti et al., (2013b). The framework assesses the availability, adequacy, and causes of deficiencies in key PM elements, offering insights into enhancing PM practices. The evaluation framework focuses on three main aspects:

- Availability or Presence: Whether essential PM activities exist.
- Adequacy or Inadequacy: The extent to which these activities meet performance requirements.
- Reasons for Deficiency: Identifying root causes of inadequacies to guide corrective actions.

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The development of the PM evaluation framework is directed to evaluate the status and effectiveness of the case study company's PM program's elements/activities, focusing on achieving availability and sufficiency of necessary activities, assessing their adequacy or shortcomings, and identifying the causes of inadequacy or deficiencies. Table 2 below illustrates the key elements evaluated and outlines the evaluation criteria.

The PM framework evaluation revealed several critical gaps in the PM program:

- Spare Parts Management: A recurring issue causing delays in scheduled maintenance.
- Training Gaps: Lack of effective PM training, particularly in condition-based and predictive maintenance, stemming from senior management's limited understanding of PM's strategic role in achieving company objectives.
- Data Utilization: Inadequate systems for converting collected data into actionable insights.
- Cost Awareness: Insufficient focus on linking PM costs to lifecycle benefits.

These highlighted gaps underscore the need for integrated systems that enhance interdepartmental collaboration, improve data analytics, and prioritize training. For the oil extraction industry, addressing these gaps can significantly reduce unplanned downtime, extend equipment lifespan, and optimize operational costs.

Table 2 Evaluation Framework for PM Program Status and Effectiveness

Element of the PM Program	Availability or Presence	Adequacy or Inadequacy	Reasons for Inadequacy or Manifestations of Deficiency
Formulation of the Strategic Plan and PM Objectives	Exists: Through reducing accidents and sudden stoppages to minimize	Inadequate: The objectives require means and programs for implementation,	PM not applied at planned times; therefore, its impact on the company's

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	production downtime	which is where the deficiency lies	overall goals is not evident
PM Plan and Execution	A PM plan is available	Inadequate execution	Lack of spare parts at the specified time according to the plan
Scheduling PM Activities: Routine/Periodic, Predictive, Condition-Based, and Age-Based	Available	Routine activities are adequately executed, but others are inadequate	Insufficient training and lack of spare parts at the specified time according to the plan
Work Orders and Execution	Work orders exist	Insufficient use of CMMS; it could be adequate if given significant attention by supervisors	Insufficient use of CMMS and lack of proper requirements for execution
Information System and Integration with Other Departments (Operations, Procurement, Inventory, etc.)	Each department has its own system	Deficiency in inter-departmental integration	Primitive systems that do not support inter-departmental linking
Coordination with Other Departments	Coordination exists between departments	Insufficient	Lack of transparency, lack of responsibility integration, and deficiencies in the information system
Data Collection and Report Preparation	Data and reports are available	Deficiency in defining measurement criteria & lack	Primitive systems that lack features for processing data

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		of systems to convert data into indicators	& converting it into indicators
Monitoring and Follow-Up of PM Tasks and Problem Identification	Monitoring and data collection exist	Some data analysis occurs but not sufficiently	Lack of data analysis systems, analytical tools, and decision support
Compressor Condition Monitoring, Failure Pattern Identification, Impact Assessment, and Determination of Appropriate PM for Safety	Monitoring and data collection exist	Some data analysis occurs, but not as required to determine failure patterns and impacts	Lack of data analysis, models, and systems to base decisions on
Cost Monitoring and Determination of Economically Appropriate PM	Cost monitoring & data collection exist, but no link to costs & lifespan	Some cost monitoring exists, but not as required to create cost models for decision support	Lack of senior management support for recommendations regarding this matter
Performance Measurement and Indicator Development	Unclear if any performance measurement exists	Lack of data analysis and systems to convert data into indicators	Lack of appropriate tools and systems for measurement and indicator reporting
Use of Performance Indicators in Decision-Making to Improve PM Effectiveness	No clear evidence of performance indicators or their use	Not available	Lack of training, absence of models or frameworks to improve PM, and lack of data analysis and decision support systems
Training in PM	Stopped	Deficiency in understanding the role of PM	Senior management lacks understanding of the integrative role of PM

5. Analysis and Results

This section presents the findings of the analysis, focusing on the PM programs for gas lift compressors in oil extraction. Using

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data collected from daily records, work orders, and operational reports, technical and economic indicators were analyzed to evaluate PM effectiveness. The analysis used maintenance related key performance indicators (KPI) for evaluation as illustrated in Table 3. Due to insufficient evidence of X-Oil's effective KPI implementation, these core metrics were selected to:

- Evaluate the preventive maintenance (PM) program
- Demonstrate KPIs' critical role in performance measurement and maintenance optimization

Table 3: Maintenance Program Evaluation Core Indicators

Acronym	Indicator	Purpose	Formula
T1	Corrective Maintenance Ratio	Measures % of maintenance time spent on reactive repairs. *Lower = better PM effectiveness.*	(Corrective Maintenance Time) / (Total Maintenance Time)
T2	Preventive Maintenance Ratio	Measures % of maintenance time dedicated to PM. *Higher = fewer unplanned failures.*	(Preventive Maintenance Time) / (Total Maintenance Time)
T3	Availability	Tracks operational readiness. *Target: Maximize value.*	(Actual Operating Time) / (Total Operating Time)
T4	MTBF (Mean Time Between Failures)	Quantifies reliability between failures. *Higher = more reliable.*	(Operating Time) / (Number of Failures)
T5	Reliability Prediction	Estimates probability of failure-free operation. *Higher = fewer failures.*	$= R(t) = T_5\ e^{-\lambda t}$

The results highlight key deficiencies and their implications for operational efficiency, reliability, and cost management. Figure 1 illustrates the distribution of work orders between PM and emergency (corrective) maintenance. PM accounted for only 21.8% of total work orders (143 out of 656), while corrective maintenance dominated at 78.2% (513 out of 656). This imbalance reflects a significant gap in executing scheduled PM tasks, leading to increased downtime and reliance on emergency repairs.

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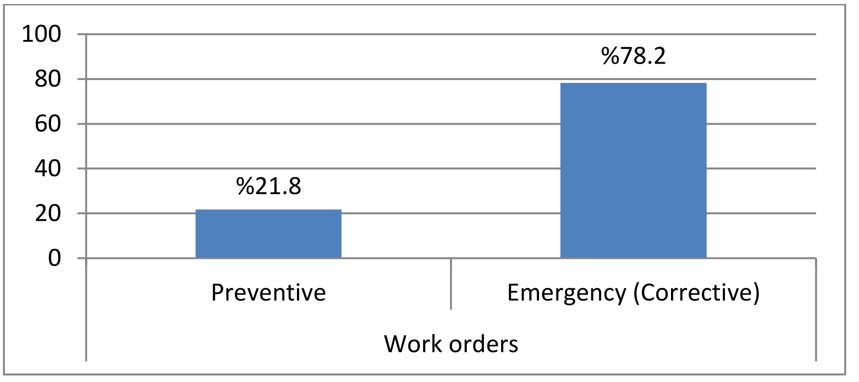

Figure 1 Percentage Proportions of Work Order Types

Key Insight: The low proportion of PM work orders indicates a lack of adherence to planned schedules, primarily due to spare parts shortages.

Comparing planned and actual PM times for four compressors showed delays in PM execution that resulted in extended periods of corrective maintenance. For example:

- Compressor (1-1): Planned at 24,000 hours but executed at 42,731 hours.
- Compressor (2-3): Planned at 24,000 hours but executed at 40,007 hours.

These delays have resulted in high correction actions for instance:

- In 2018, Compressor (1-1) had only 3.33% of its maintenance time dedicated to PM, with 96.66% spent on corrective actions.
- By 2021, after improved PM execution, corrective maintenance decreased to 16%.

Key Insight: Delayed PM significantly increases reliance on emergency repairs, reducing equipment availability and increasing costs.

Figure 2 shows the total emergency (corrective) and PM times for gas lift compressors are presented as a percentage of the total PM time. (table 4)

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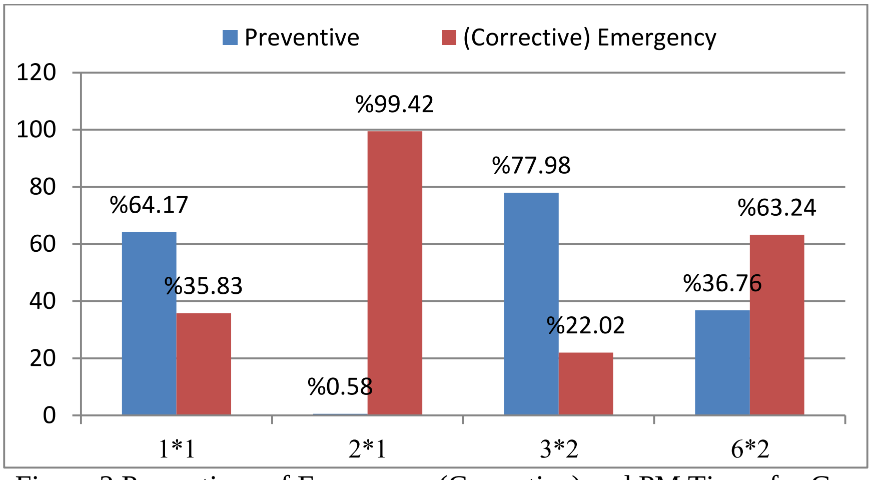

Figure 2 Proportions of Emergency (Corrective) and PM Times for Gas Lift Compressors

Table 4 Failure Rate and (MTBF) for Gas Lift Compressors

Compressor	Operating Time	Number of Failures	Failure Rate (λ)	MTBF (Hours)
1-1	30,623	177	0.00578	173
1-2	10,021	125	0.0124743	80
2-3	22,022	183	0.0083098	120
2-6	21,519	149	0.006924	144

Figure 3 shows compressor availability rates where:

- Compressor (1-1): 87.33% availability.
- Compressor (2-1): Only 28.57% availability, the lowest due to chronic spare parts shortages.

Reliability metrics in Figure 4 further highlight these issues:

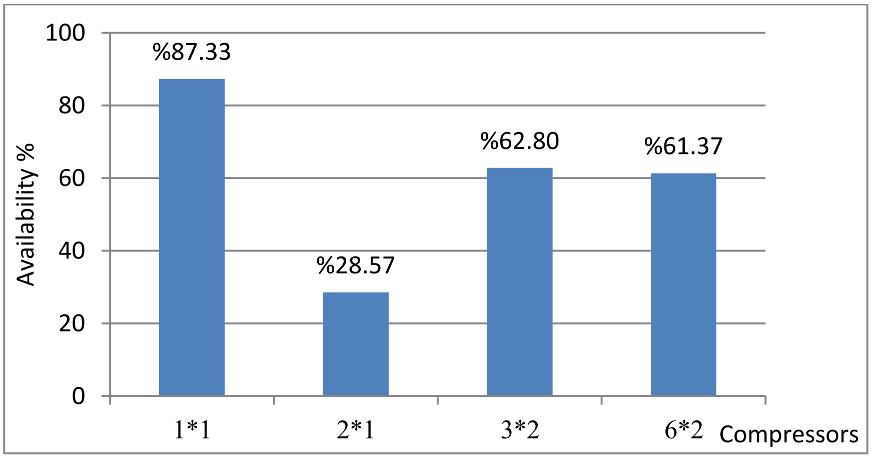

Figure 3 Availability Percentages for Gas Lift Compressors

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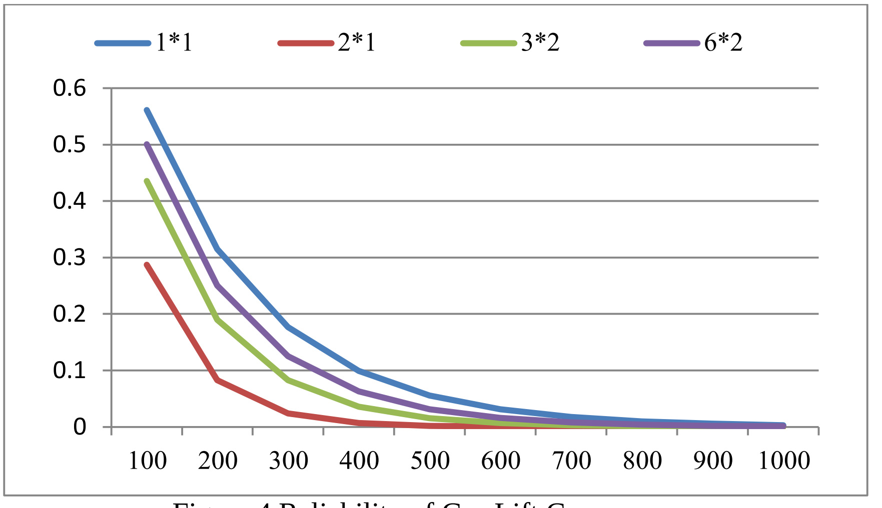

Figure 4 Reliability of Gas Lift Compressors

- Compressor (1-1): Highest Mean Time Between Failures (MTBF) at 173 hours.
- Compressor (2-1): Lowest MTBF at 80 hours, reflecting frequent breakdowns.

Key Insight: Poor PM planning and execution directly correlate with reduced availability and reliability, impacting production continuity.

The high PM cost is attributed to delayed overhauls and custom spare parts procurement. For example:

- Annual overhauls for individual compressors increased labor costs.
- Late spare parts delivery forced categorization of all costs under PM, regardless of delays.

Key Insight: Inefficient PM scheduling inflates costs, particularly for spare parts and labor, straining budgets and reducing financial efficiency.

The analysis confirms the following hypotheses:

1. Lack of PM Understanding: The organization's failure to prioritize PM led to excessive reliance on corrective maintenance, reducing operational efficiency.
2. Impact of Spare Parts Shortages: Delays in providing spare parts disrupted PM schedules, causing frequent breakdowns, reduced availability, and higher costs.

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3. Need for Integrated Systems: Absence of a computerized system linking PM with inventory, procurement, and finance departments exacerbated spare parts shortages and coordination challenges.

For the oil extraction industry, these findings underscore the importance of:

- Timely PM Execution: Adhering to scheduled maintenance reduces downtime and improves reliability.
- Integrated Asset Management: Linking PM with other departments ensures timely spare parts availability and better resource allocation.
- Cost Optimization: Streamlining PM processes minimizes unnecessary expenditures on emergency repairs and delayed overhauls.

This analysis highlights critical gaps in PM program implementation for gas lift compressors, emphasizing the need for improved planning, interdepartmental coordination, and resource management. Addressing these issues can enhance equipment availability, reduce costs, and improve operational reliability, benefiting both the case study company and the broader oil industry.

6. Conclusion:

This study demonstrated the importance of evaluating the status, effectiveness and performance of a preventive maintenance (PM) program for one of the critical assets (gas lift compressors) in the oil extraction industry. It demonstrated the important role of performing the PM program in reaching the optimal operating condition and raising the level of productivity to achieve maximum profitability for the company. The research achieved its objectives through proving the validity of its hypotheses.

The findings reflect the significant role that the PM program plays in enabling asset-intensive industries to achieve operational efficiency, assure production process continuity, optimize assets' functional life, and achieve profitability and competitiveness. The research validated its hypotheses by identifying key gaps and deficiencies in the current PM program and linking these to measurable declines in performance indicators.

The main findings are summarized as follows:

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- Implementation Gaps: There is a notable discrepancy between planned and actual PM execution, primarily due to spare parts shortages, leading to reliance on emergency maintenance.
- System Integration Deficiencies: A lack of integration between PM, inventory, procurement, and financial systems hinders timely maintenance and information sharing.
- Data Utilization Challenges: Insufficient tools and systems for data analysis prevent the conversion of collected data into actionable performance indicators.

Awareness and Training Shortfalls: Limited understanding of PM's strategic role and inadequate training in condition monitoring, cost analysis, and risk assessment further hinder program effectiveness.

Performance measurement indicators revealed:

- An increase in emergency maintenance work orders and downtime (e.g. PM accounted for only 21.8% of total work orders, while corrective maintenance dominated at 78.2%) and (e.g. in 2018, Compressor (1-1) had only 3.33% of its maintenance time dedicated to PM, with 96.66% spent on corrective actions.).
- Reduced availability and reliability of gas lift compressors, (e.g. compressor (2-1) low reliability with lowest MTBF at 80 hours, reflecting frequent breakdowns and only 28.57% availability, the lowest due to chronic spare parts shortages).
- These findings highlight the need for improved PM practices, better system integration, and enhanced awareness of PM's strategic importance.

7. Recommendations

Based on the comprehensive findings of the study recommendations are drawn to address all root causes identified in the framework (training gaps, data utilization, system integration, cost awareness), leveraging industry best practices while respecting the operational realities of oil extraction assets). The recommendation can be streamlined as :

1. Maintaining strategic alignment & leadership through :
   - Rationalization of senior management on PM's ROI using case studies (e.g., "20% PM adherence → 40% fewer breakdowns").

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- Formalize PM goals/KPIs tied to corporate objectives (e.g., "90% compressor availability → 5% production boost").

2. Maintain spare parts optimization:
   - Adopt AI-Driven Inventory system by implementing real-time tracking with automated reordering for critical spares.
   - Adopt consignment stock for high-usage parts to eliminate delays.
3. Provide training and tools:
   - Upskilling technicians by providing certifications in CBM/PdM and failure analysis
   - Train planners on KPI dashboards and cost modeling
   - Providing unified CMMS by replacing siloed systems with integrated platform (maintenance + procurement).
4. .4 Adopt performance-driven execution based on milestones of targeted KPIs with accountability, e.g. PM Ratio ≥40%, Availability ≥85%, Reliability ≥95%
5. .5 Adopt process discipline by enforce PM deadlines, e.g. using ±5% tolerance for scheduled maintenance, RCM implementation, e.g. prioritize PM tasks using failure impact analysis, lifecycle cost tracking, e.g. using models to justify PM spend

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