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THE EFFECT OF SCHEDULE COMPRESSION AND PREDICTIVE MAINTENANCE ON PROJECT PERFORMANCE IN THE GULF INDUSTRIAL SECTOR

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The Effect of Schedule Compression and Predictive Maintenance on Project Performance in the Gulf Industrial Sector

Abstract

Research Objectives: This study investigates the impact of schedule compression on project performance and how predictive maintenance improves equipment reliability in refineries, petrochemical plants, and oil and gas facilities. **Place of Study:** The research was conducted in Saudi Arabia and the broader Arabian Gulf region. The areas were chosen because of their extensive oil and gas operations and significant refinery and petrochemical infrastructure investment. **Methodology:** The study utilized a mixed-methods design involving quantitative surveys (N = 200) and qualitative interviews with 15 senior industry professionals. Statistical tools (SPSS, regression, and Pearson correlation analysis) were used to analyze data. Thematic coding (NVivo) was used to validate hypotheses regarding schedule compression and predictive maintenance. **Results:** Schedule Compression was found to account for 78% of the variability in project performance, demonstrating that while it can accelerate timelines, it significantly undermines quality and increases project costs. This finding has immediate relevance for project managers under pressure to deliver quickly—highlighting the hidden long-term costs of rushed execution in complex industrial settings. A strong positive correlation ($r = 0.82$, $p < 0.01$) between predictive maintenance and equipment reliability underscores the practical benefit of investing in advanced maintenance systems. Facilities that embrace AI-driven predictive tools can reduce unplanned downtime, extend equipment lifespan, and improve safety—leading to more stable, cost-effective operations. **Recommendations:** Implementing Critical Chain Project Management (CCPM) to balance speed with quality, investing in AI-driven predictive maintenance systems, promoting sector-wide digital transformation, and developing training programs for staff on new maintenance technologies and best practices.

Keywords: Schedule Compression, Predictive Maintenance, Reliability, Operational Efficiency

الملخص

أهداف البحث: تبحث هذه الدراسة في تأثير ضغط الجدول الزمني على أداء المشاريع، وكيف تُحسن الصيانة التنبؤية موثوقية المعدات في المصافي ومصانع البتروكيماويات ومنشآت النفط والغاز. مكان الدراسة: أُجري البحث في المملكة العربية السعودية ومنطقة الخليج العربي عمومًا. وقد اختيرت هذه المناطق نظرًا لعملياتها المكثفة في قطاع النفط والغاز، واستثماراتها الكبيرة في البنية التحتية للمصافي والبتروكيماويات. المنهجية: اعتمدت الدراسة تصميمًا مختلط الأساليب، تضمن مسوحات كمية (عدد المشاركين = 200) ومقابلات نوعية مع 15 من كبار المتخصصين في هذا القطاع. واستُخدمت أدوات إحصائية (برنامج للتحقق من صحة (NVivo) وتحليل الانحدار، وتحليل ارتباط بيرسون) لتحليل البيانات. واستُخدم الترميز الموضوعي، SPSS، الفرضيات المتعلقة بضغط الجدول الزمني والصيانة التنبؤية. النتائج: وُجد أن ضغط الجدول الزمني يُمثل 78% من التباين في أداء المشاريع، مما يُظهر أنه على الرغم من قدرته على تسريع الجداول الزمنية، إلا أنه يُضعف الجودة بشكل كبير ويزيد من تكاليف المشروع. لهذه النتيجة أهمية مباشرة لمديري المشاريع الذين يواجهون ضغوطًا للتسليم السريع، مما يُبرز التكاليف الخفية بين ($r = 0.82$, $p < 0.01$) طويلة الأجل للتنفيذ المُتسرع في البيئات الصناعية المُعقدة. يُؤكد وجود ارتباط إيجابي قوي الصيانة التنبؤية وموثوقية المعدات على الفائدة العملية للاستثمار في أنظمة الصيانة المُتقدمة. يُمكن للمنشآت التي تتبنى أدوات تنبؤية مُعتمدة على الذكاء الاصطناعي تقليل فترات التوقف غير المُخطط لها، وإطالة عمر المعدات، وتحسين السلامة، مما يؤدي إلى عمليات أكثر استقرارًا وفعالية من حيث التكلفة.

لتحقيق التوازن بين السرعة والجودة، والاستثمار في أنظمة الصيانة (CCPM) التوصيات: تطبيق إدارة مشاريع السلسلة الحرجة التنبؤية المُعتمدة على الذكاء الاصطناعي، وتعزيز التحول الرقمي على مستوى القطاع، وتطوير برامج تدريبية للموظفين على تقنيات الصيانة الجديدة وأفضل الممارسات.

الكلمات المفتاحية: ضغط الجدول الزمني، الصيانة التنبؤية، الموثوقية، الكفاءة التشغيلية.

I. INTRODUCTION

1.1 Background

Industrial operations involving refineries, petrochemical plants, and oil and gas facilities form the backbone of global energy production and industrial development. These facilities operate under highly regulated and technically complex conditions that demand continuous operational efficiency, equipment reliability, and strict safety protocols. In the Arabian Gulf region—particularly in Saudi Arabia—these sectors play a pivotal economic role, contributing significantly to national GDPs and global energy supply chains. For instance, Saudi Arabia alone accounts for over 12% of global crude oil production and is home to some of the world’s largest integrated refining and petrochemical complexes, such as the Ras Tanura Refinery and SATORP (Saudi Aramco, 2023). To maintain competitiveness in a globalized market, organizations in these sectors are under immense pressure to reduce downtime and optimize production schedules without compromising quality or safety. According to a 2022 report by McKinsey & Company, unplanned downtime costs the oil and gas industry approximately \$38 billion annually, with equipment failures being a primary contributor. Moreover, the increasing complexity of industrial assets and the high cost of delays—particularly in megaprojects—have amplified the need for more strategic and data-driven maintenance approaches.

Traditional preventive and corrective maintenance methods, while effective in some contexts, often fall short in high-demand environments where production timelines are compressed to meet regulatory deadlines and market expectations. In response, industries are turning toward predictive maintenance, driven by advances in Artificial Intelligence (AI) and the Internet of Things (IoT). These technologies enable real-time monitoring and data analytics, which can forecast equipment failures before they occur, thereby minimizing unplanned downtime and enhancing operational reliability (Deloitte, 2021). At the same time, many organizations resort to schedule compression

techniques—such as crashing and fast-tracking—to meet project deadlines. While these methods can accelerate delivery, they often result in increased costs, scope creep, and reduced work quality, especially when not balanced with adequate maintenance planning (Kerzner, 2022; Burke, 2020). Given these challenges, this study aims to explore how schedule compression affects project performance—specifically in terms of cost, time, and quality—and to assess how predictive maintenance can be leveraged to counteract the negative outcomes of accelerated timelines. By focusing on refineries, petrochemical plants, and oil and gas facilities in Saudi Arabia and the broader Arabian Gulf region, the research seeks to provide actionable insights into optimizing industrial operations under modern performance pressures..

1.2 Statement of the Problem

In the industrial sectors of refining, petrochemicals, and oil and gas, maintaining high productivity and safety standards while adhering to regulatory deadlines remains a complex challenge. To meet rising production demands and project milestones, many organizations compress maintenance and project schedules using techniques such as fast-tracking and crashing. While these methods may accelerate project timelines, research has shown that they often come at a significant cost to quality and budget control (Leach, 2020; PMI, 2021). Kerzner (2022) points out that schedule compression frequently results in scope creep, rework, and quality trade-offs due to overlapping tasks and insufficient lead time for proper planning and testing. Moreover, Burke (2020) emphasizes that traditional maintenance approaches—largely preventive or corrective in nature—are not adequately equipped to handle the risks and unpredictability that come with accelerated project execution. These limitations can lead to increased equipment failure rates, unplanned downtime, and higher long-term operational costs, all of which compromise safety and performance in critical infrastructure environments.

In contrast, emerging evidence suggests that predictive maintenance, powered by real-time data analytics and artificial intelligence, can reduce downtime by up to 30% and lower maintenance

costs by 20% (Deloitte, 2021; McKinsey & Company, 2022). However, there is limited research that specifically addresses how predictive maintenance can mitigate the negative effects of schedule compression in heavy industrial environments. Despite the growing adoption of predictive tools and digital maintenance systems, the intersection between schedule compression and predictive maintenance remains underexplored—particularly in high-stakes industries like oil and gas where operational efficiency and reliability are critical. This study seeks to fill that gap by investigating the extent to which schedule compression affects project performance and how predictive maintenance strategies can offset these impacts.

Main Research Question

How does schedule compression influence project performance in the oil and gas industry, and to what extent can predictive maintenance improve equipment reliability and reduce the negative consequences associated with accelerated timelines?

1.3 Literature Review and Current Gaps

Numerous studies have examined schedule compression techniques such as fast-tracking and crashing, highlighting their ability to reduce overall project duration (Kerzner, 2022; PMI, 2021; Leach, 2020). However, the cost trade-offs associated with these techniques are significant. Burke (2020) argues that compressing project timelines often leads to increased expenditures due to overlapping tasks, inefficient resource utilization, and the need for rework. While schedule acceleration might offer short-term cost savings through early project delivery, the longer-term implications—such as maintenance backlogs and equipment failures—often result in higher operational costs. Yet, these studies tend to focus solely on the immediate financial implications, overlooking the potential savings offered by integrating predictive technologies into maintenance schedules.

Fast-tracked or compressed projects frequently suffer from reduced quality due to shortened testing phases and inadequate risk analysis (Kerzner, 2022). This degradation in quality can compromise asset reliability and customer satisfaction,. The oil and gas industry operates in high-risk environments where any compromise in safety can have catastrophic consequences. Traditional reactive maintenance methods do not provide the early warning systems necessary to avoid such risks. Emerging technologies like AI, sensor networks, and IoT devices have introduced predictive maintenance systems that can detect anomalies and prevent equipment failure before it occurs. These tools, however, are rarely examined in tandem with project scheduling practices. While individual studies have addressed either schedule compression or predictive maintenance, few have evaluated their combined impact on project outcomes. Most notably, existing literature often isolates these topics rather than assessing them as interdependent variables affecting overall project performance. There is a need for a holistic framework that assesses how predictive maintenance can serve as a mitigating strategy for the adverse effects of schedule compression—particularly in cost-intensive, safety-critical industries like oil and gas and petrochemicals. A unified analysis of time, cost, quality, and safety under compressed scheduling conditions will provide both practical insights and academic contributions. Therefore, this study aims to bridge the existing gap by conducting a mixed-method investigation that quantifies the impact of schedule compression on project performance and explores the effectiveness of predictive maintenance in counterbalancing its negative consequences.

1.4 Proposed Approach

This study employs a mixed-methods approach to ensure an in-depth understanding of the effects of schedule compression on project performance. Quantitative surveys will assess the measurable impact of schedule compression on project quality, cost, and time, while qualitative interviews with industry experts will offer vital insights into the practical benefits and challenges of

integrating predictive maintenance strategies to mitigate the risks associated with accelerated scheduling. The mixed-methods framework ensures that the study addresses both the statistical relationships and the contextual factors influencing maintenance operations.

1.5 Novel Contribution and Value of the Research

The study promotes industrial maintenance by combining schedule compression and predictive maintenance. The two elements are often under-examined despite their significance in industrial settings. The research offers a new framework for operational optimization by showing that aggressive scheduling improves time efficiency but reduces quality and increases costs, thus the need for predictive maintenance to address the challenges. The study contribution is valuable scientifically since it promotes reliability and project management theories and practically due to its ability to provide industry leaders with actionable recommendations for balancing increased production demands with high-quality maintenance practices.

II. STUDY PROBLEM

2.1 Dual Nature of Compressed Schedules

Compressed project schedules increase the rate of industrial maintenance, creating a dual challenge where faster completion time can improve time efficiency but minimize quality, increase costs, and lead to potential safety hazards. Accelerating project timelines optimizes time and can help organizations to meet growing production demands. However, the urgency can compromise quality standards, inflate costs, and enhance safety risks. The study problem focuses on balancing these opposing outcomes.

2.2 Trade-Offs Between Speed, Quality, and Cost

Compressed schedules force organizations to navigate significant trade-offs. While faster completion time can reduce downtime, the urgency often leads to reduced quality of work since organizations may bypass necessary inspection and quality assurance procedures. Furthermore,

accelerated timelines usually require additional resources, such as increased labor, overtime payments, and expedited procurement, contributing to higher project costs. The pressure to meet deadlines can compromise an organization's adherence to safety protocols, leading to increased risk of accidents and operational hazards during maintenance activities.

2.3 Role of Predictive Maintenance

Predictive maintenance is a promising strategy to counterbalance the negative effects of schedule compression. Predictive maintenance in high-risk zones prevents safety threats and shut down operations involving dangerous equipment break downs (Xu et al., 2020). It uses AI, IoT, and real-time data analytics to identify equipment issues before they can cause machinery to break down, reduces unnecessary maintenance interventions to lower costs, and improves asset reliability by maintaining high maintenance standards even under tight schedules. Preventive maintenance prevents machine failures, optimizes resource allocation, and improves reliability.

2.4 Contextual Focus on Critical Infrastructure

The research study specifically examines the impact of schedule compression on project performance and how predictive maintenance improves equipment reliability in refineries, oil and gas facilities, and petrochemical plants within the critical infrastructure sectors of Saudi Arabia and the Arabian Gulf. Industries in the region have high operational stakes, increasing the risk of maintenance failures, economic recession, and safety issues. In addition, local industry practices, regulatory frameworks, and environmental conditions often create unique challenges that complicate the balance between accelerated maintenance and reliability. Insights obtained from this study can provide practical guidance for industry practitioners facing similar challenges in high-pressure industrial settings.

2.5 Research Contribution

Quantifying the trade-offs in schedule compression and assessing the mitigating potential of predictive maintenance will enable this study to provide empirical evidence demonstrating how compressed schedules affect project performance metrics such as quality, cost, and time. It will offer evidence-based recommendations for integrating predictive maintenance to enhance operational reliability. The study will provide a developed theoretical framework that bridges the gap between traditional project management methods and modern digital maintenance strategies. Addressing the study problem will establish the foundation for examining how industrial sectors can optimize maintenance processes and promote operational reliability and project performance while balancing the competing demands of speed, quality, and cost.

III. THE IMPORTANCE OF THE STUDY

- **Scientific Relevance:** This study is important from both scientific and practical perspectives. Scientifically, it promotes academic discourse by integrating traditional reliability models with contemporary predictive maintenance strategies. The integration develops the existing frameworks on project management, particularly theories on schedule compression and its impact on quality, cost, and safety. The research examines how compressed schedules affect various project outcomes to improve our understanding of time management within industrial maintenance. The knowledge promotes project management literature and supports further empirical research on this study.
- **Practical Significance:** The findings provide industry leaders with data-driven recommendations for balancing speed with quality. The research offers practical strategies to optimize maintenance processes, particularly in high-stakes environments, such as refineries, petrochemical plants, and oil and gas facilities, where maintenance failures can lead to safety issues and financial losses. Moreover, it outlines the adverse effects of compressed schedules, such as increased costs, lower quality, and safety risks, and the

benefits of predictive maintenance to help practitioners implement measures that reduce operational risks. The study's practical insights can lead organizations to promote high maintenance standards despite tight schedules.

- **Digital Transformation and AI Adoption:** The study emphasizes the role of digital transformation in maintenance reliability. It examines how organizations can utilize AI and IoT to create advanced predictive maintenance systems. Technology enables firms to enhance their traditional maintenance practices. Besides, the study integrates digital tools in maintenance management to promote industry-wide adoption of advanced technologies. Widespread digital transformation and AI adoption improve asset reliability and support a transition towards more sustainable and efficient operational practices.
- **Broader Impact:** The research offers economic benefits and fosters organizational safety and compliance. Improved maintenance strategies can significantly save costs by reducing downtime, minimizing repair expenses, and extending equipment lifespans. The economic benefits are exceptionally vital for regions with high operational costs, such as the oil and gas sectors in Saudi Arabia and the Arabian Gulf. Additionally, using predictive strategies to enhance maintenance reliability can lead organizations to maintain high safety standards and comply with regulatory standards. The measures will ensure that industrial operations perform efficiently and meet stringent safety and environmental regulations.

IV. STUDY OBJECTIVES

1. **Examine the Impact of Schedule Compression:** Evaluate how compressed project schedules affect cost, time, and quality in maintenance projects.
2. **Assess Predictive Maintenance Effectiveness:** Determine how predictive maintenance techniques like ultrasonic testing, oil analysis, thermal imaging, and vibration analysis enhance equipment reliability.

3. **Integrate Quantitative and Qualitative Insights:** Use a mixed methods approach to provide a detailed picture of the benefits and risks of accelerated maintenance schedules.
4. **Develop Practical Recommendations:** Propose various strategies to ensure maintenance reliability and operational efficiency in industrial settings.

V. THEORETICAL LITERATURE FOR THE STUDY

5.1 Project Management Theories

The study is based on established project management theories, particularly schedule compression models like fast-tracking and crashing (Kerzner, 2022; PMI, 2021). The crashing framework entails providing additional resources to reduce project duration without undermining its scope. It examines the trade-off between reduced timelines and increased costs, such as extra labor and overtime. The fast-tracking approach overlaps repetitive activities to reduce the project duration. The literature highlights risks like rework and quality issues to identify how aggressive scheduling impacts project performance. Besides, the theoretical foundation involving quality-cost-time trade-offs emphasizes the interdependent relationship between quality, cost, and time.

Accelerating project schedules may foster time efficiency but cause reduced quality and inflated costs. The trade-off is vital to understanding the influence of schedule compression on project outcomes. Project management theories offer a solid foundation for testing the study hypothesis.

5.2 Reliability Engineering Theories

Predictive maintenance models support a data-based approach to equipment maintenance.

OSO (2022) and Smith (2023) demonstrate how integrating real-time monitoring, AI, and IoT can help organizations predict and prevent equipment failures. Predictive maintenance theories are based on data analytics and fault prediction models that use current and historical data to forecast equipment malfunctions before they happen, thus minimize unplanned downtime and maintenance costs. Predictive maintenance emerged due to the failure of traditional preventive maintenance

since it offers improved precision in scheduling maintenance activities and ensures higher asset reliability. The data-driven approach of predictive maintenance frameworks can help organizations preempt equipment failures.

5.3 Theoretical Integration and Hypotheses Formation

Integrating project management and reliability engineering theories provides a detailed framework to examine how schedule compression and predictive maintenance interact. While compressed schedules may negatively affect project performance through increased costs and reduced quality, implementing predictive maintenance could mitigate the adverse effects. The theoretical integration establishes the study hypotheses:

- **H₀:** Schedule compression has no significant impact on project performance.
- **H₁:** Schedule compression significantly affects project performance.
- **H₀:** Predictive maintenance does not improve reliability.
- **H₁:** Predictive maintenance improves equipment reliability.

VI. REVIEW OF PREVIOUS STUDIES

6.1 Local Studies

Predictive Maintenance in the Saudi Oil Sector

Al-Mutairi and Khan (2021) examined the adoption of AI and IoT-driven predictive maintenance in the Saudi oil industry. They established that integrating digital technologies in maintenance processes can reduce unexpected equipment failures by 30%, enhancing scheduling efficiency. Improved scheduling efficiency fosters proactive maintenance planning and reduces unplanned downtime. This research study highlights the ability of predictive maintenance to transform operational reliability in the high-stakes oil sector.

Impact of Schedule Compression on Refinery Projects

Al-Falih et al. (2022) evaluated the effects of aggressive schedule compression on project performance in Saudi refinery expansion projects. He found that compressed schedules caused work fatigue, increased safety incidents, and undermined work quality. The negative outcomes outline the critical trade-offs between time efficiency and operational reliability and the need for balanced scheduling practices that safeguard quality and safety.

Maintenance Reliability in Arabian Gulf Petrochemical Plants

Al-Qahtani and Hassan (2023) focused on maintenance practices in petrochemical plants within the Arabian Gulf. Their research revealed that condition-based maintenance approaches could reduce operational costs by 25% by eliminating unnecessary maintenance operations. The study highlights the economic benefits of personalized maintenance strategies, suggesting that optimized maintenance routines can increase asset longevity and maintain cost-effectiveness.

6.2 Foreign Studies

Global Trends in Predictive Maintenance

Waqas et al. (2022) conducted a meta-analysis across several industries to determine the global impact of predictive maintenance. They found that predictive maintenance practices can reduce downtime by 35% and maintenance expenses by 20%, showing significant performance improvements. The study demonstrates that data-driven maintenance strategies can provide organizations with substantial financial and operational benefits, supporting their widespread adoption across industrial sectors.

Effects of Compressed Schedules on Project Outcomes

Yang et al. (2024) studied how rapid project schedules affect project performance across different industries. Despite improved time efficiency, accelerated schedules increase costs and defects. Worker burnout and suboptimal resource allocation were primarily responsible for the

adverse outcomes. The research highlights the risks of schedule compression, demonstrating the need for strategies that can mitigate its negative effects on project quality and cost efficiency.

AI in Maintenance and Reliability

Gong et al. (2020) assessed the role of AI in enhancing maintenance practices and improving equipment reliability. They found that using AI applications in maintenance can lower equipment breakdowns by 40%, thus extending asset life and reduce unplanned downtime. The study offers detailed evidence of the transformative impact of AI in maintenance by suggesting that digital transformation is essential to achieve sustainable operational efficiency.

6.3 Research Gap

While previous studies have separately examined schedule compression and predictive maintenance, there is still limited research on the connection between these factors in industrial maintenance. Existing literature lacks a unified analytical model that integrates the time-cost-quality trade-offs of schedule compression and the mitigating effects of predictive maintenance strategies. This study aims to bridge the research gap by analyzing how compressed schedules negatively influence project performance and how implementing predictive maintenance can counterbalance the adverse effects. Focusing on the high-stakes environments of Saudi Arabia and the Arabian Gulf will lead this study to offer a detailed understanding that informs academic discourse, inquiry, and practical applications in industrial maintenance.

VII. METHODOLOGY

7.1 Type of Study

This study employs a mixed-methods approach that integrates quantitative surveys and qualitative interviews. The design combines statistical analysis with in-depth expert insights to ensure an in-depth understanding of the benefits of predictive maintenance and the impact of schedule compression.

7.2 Study Design

Quantitative Component

This study used a descriptive design involving cross-sectional and longitudinal analyses. Structured questionnaires were distributed to 200 industry professionals from Saudi Aramco, SABIC, QP, and ADNOC. They covered demographics, predictive maintenance strategies, the effects of schedule compression, maintenance performance metrics, and recommendations. SPSS was employed to conduct statistical analyses. The study utilized regression analysis and Pearson correlation techniques to find the relationships between schedule compression, maintenance performance, and predictive maintenance effectiveness.

Qualitative Component

The research involved in-depth, semi-structured interviews with 15 senior professionals with significant work experience in industrial maintenance, project management, and reliability engineering. The senior professionals are specialized in the refinery and petrochemical sectors. The interviews offered contextual insights and supported survey findings. NVivo was used to thematically examine the qualitative data. The study employed triangulation to ensure the consistency and reliability of findings.

7.3 Study Population and Sample

The target population were professionals working in critical infrastructure sectors. They involved maintenance engineers, reliability engineers, project managers, operations supervisors, and quality/safety experts. Participants were selected from various refineries, petrochemical plants, and oil and gas facilities in Saudi Arabia and the Arabian Gulf region. The study used purposive sampling to ensure that only professionals with relevant expertise participated in the research. Cochran's formula for proportions was used to determine the sample size and achieve statistical significance and adequate representation.

7.4 Data Collection Tools and Procedures

Surveys

The study employed a structured questionnaire with sections on demographics, schedule compression effects, predictive maintenance strategies, maintenance performance metrics, and recommendations. The demographics covers age, experience, job role, and industry. Questions on schedule compression effects addressed the influence of schedule compression on time, cost, quality, and stakeholder satisfaction. Predictive maintenance strategies involved evaluating techniques such as ultrasonic testing, oil analysis, thermal imaging, and vibration analysis. In addition, the study used maintenance performance metrics to assess downtime, cost efficiency, and overall project performance. Recommendations were obtained after asking the participants for suggestions on improving maintenance practices. The survey was distributed electronically to reach many targeted professionals.

Interviews

Semi-structured interviews were conducted to obtain expert opinions and practical insights. They allowed flexible discussion, thus enabling respondents to elaborate on their experiences and insights regarding schedule compression and predictive maintenance. The interviews were recorded, transcribed, and coded for thematic analysis, ensuring an in-depth examination of the study findings.

Document Analysis

The study reviewed historical maintenance reports, project records, and compliance documents to provide a baseline of historical performance data and contextual information. Document analysis corroborated survey and interview findings and provided an empirical basis for the study's conclusions.

7.5 Measures and Validity/Reliability Testing

Quantitative Measures

Cronbach's alpha was calculated for the survey instrument, with a threshold of 0.7, to ensure acceptable internal consistency. SPSS was used to perform regression analysis and Pearson correlation tests to ensure the comprehensiveness of the quantitative findings. The quantitative measures ensured the reliability of the structured questionnaire findings.

Qualitative Measures

The study used NVivo software to examine interview transcripts and identify recurring patterns and themes. Furthermore, it triangulated data from surveys, interviews, and document analysis to validate findings and enhance reliability. Thematic analysis and triangulation ensured the accuracy and reliability of the qualitative outcomes.

7.6 Study Limitations

The study is geographically limited to Saudi Arabia and the Arabian Gulf, which may impact findings' generalizability to other regions. Besides, the self-reported data from surveys and interviews could be subject to respondent bias, impacting the results accuracy. Finally, the study focuses on specific industrial sectors (refineries, petrochemical plants, oil and gas), which may limit the findings' applicability to other industries.

VIII. RESULTS

8.1 Quantitative Analysis

8.1.1 Demographic Summary of Respondents

Two hundred industry professionals completed the survey, providing insights from various roles and levels of experience. The study categorizes them based on their demographic variable, which involves industry experience and job role.

Table 1: Demographic Summary of Respondents

Demographic Variable	Percentage (%)
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Industry experience	
1-5 years	20%
6-10 years	35%
11-15 years	25%
16+years	20%
Job Role	
Maintenance Engineer	30%
Reliability Engineer	25%
Project Manager	20%
Operations Supervisor	15%
Quality/Safety Expert	10%

The diverse sample provides a comprehensive foundation for assessing the influence of schedule compression and predictive maintenance across various aspects of industrial operations.

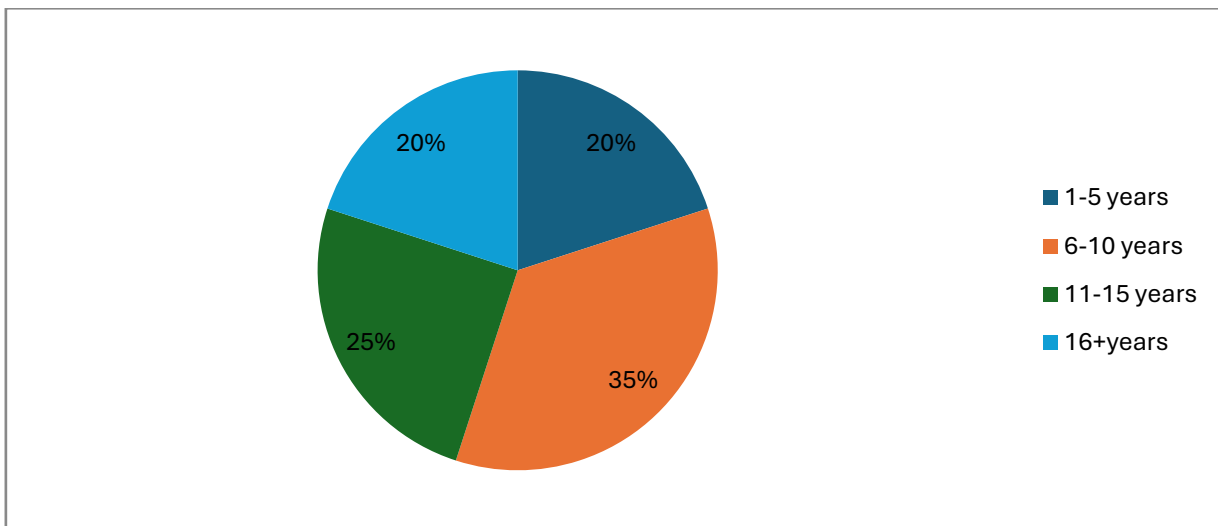


Figure 1: Demographic summary of 200 industry professionals involved in the survey based on their industry experience

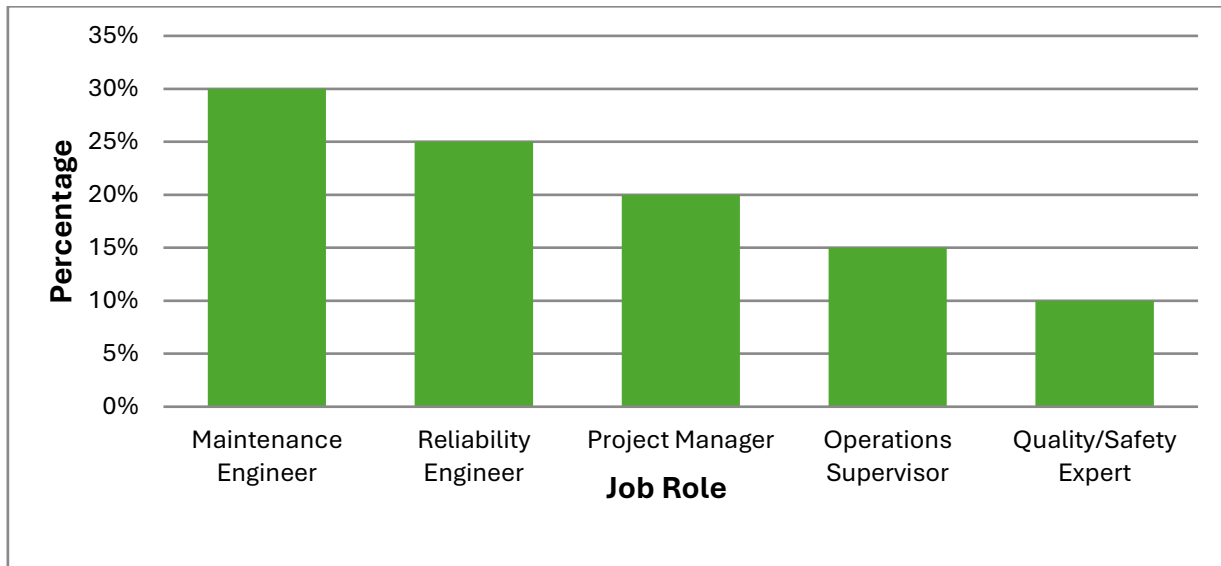


Figure 2: Demographic summary of 200 industry professionals involved in the survey based on their job role
8.1.2 Impact of Schedule Compression on Project Performance

Survey responses were analyzed to evaluate the influence of schedule compression on project performance based on cost and time efficiency, quality impact, and stakeholder satisfaction.

Table 2: Impact of Schedule Compression on Project Performance

Factor	Positive Impact (%)	Negative Impact (%)	Neutral (%)
Cost Efficiency	40%	50%	10%
Time Efficiency	55%	30%	15%
Quality Impact	35%	60%	5%
Stakeholders Satisfaction	50%	40%	10%

Key Observations:

- Time efficiency is the most positively impacted aspect (55% positive responses).
- Quality suffers significantly, with 60% of respondents reporting adverse effects since schedule compression causes multiple project errors.
- The data suggests a trade-off where improvements in time efficiency may lead to compromised quality and increased costs.

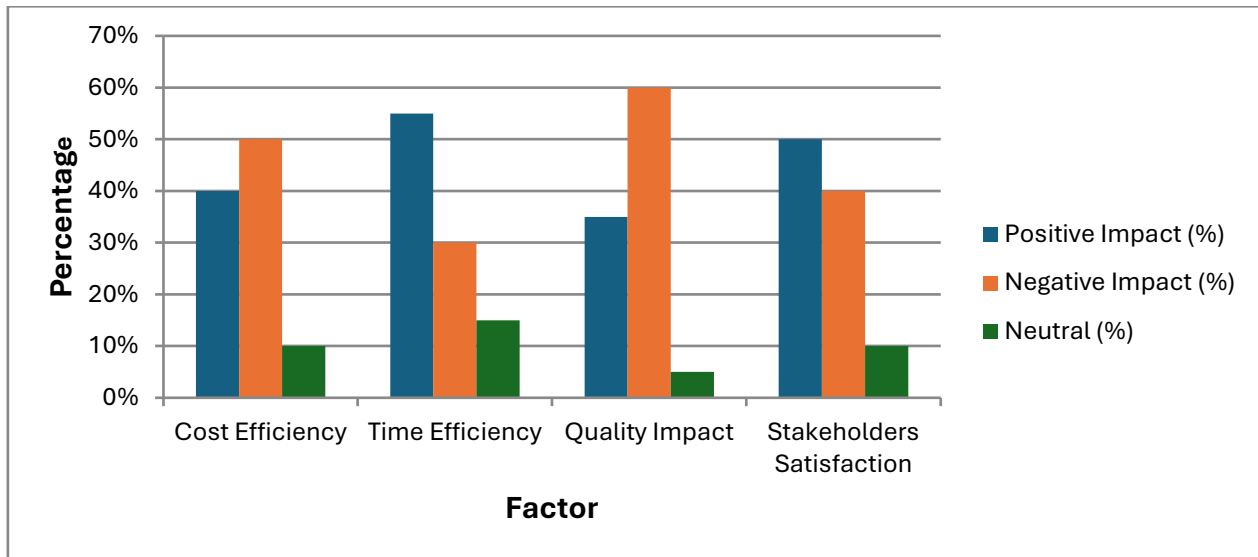


Figure 3: Impact of schedule compression on project performance

8.1.3 Effectiveness of Predictive Maintenance Strategies

Predictive maintenance (PdM) strategies significantly improve equipment reliability, minimize downtime, and optimize maintenance expenses. The effectiveness of key PdM techniques such as ultrasonic testing, oil analysis, thermal imaging, and vibration analysis can be assessed based on their impact on equipment reliability and failure prevention. The findings are illustrated in table 3 and figure 4.

Table 3: Impact of Schedule Compression on Project Performance

Predictive Maintenance Technique	High Effective (%)	Moderately Effective (%)	Ineffective (%)
Vibration Analysis	70%	25%	5%
Thermal Imaging	65%	30%	5%
Oil Analysis	60%	35%	5%
Ultrasonic Testing	55%	40%	5%

Key Findings:

- Vibration analysis is the most effective PdM strategy, with a success rate of 70%. It is particularly significant in detecting mechanical imbalances, misalignments, and bearing failures before they become major problems.
- Thermal Imaging follows closely, achieving a 65% success rate. It effectively detects overheating components, electrical faults, and insulation degradation.
- Oil analysis has a 65% success rate. It is valuable for monitoring lubrication effectiveness and detecting contaminants that may indicate wear and tear.
- Ultrasonic testing is the least effective, with a 55% success rate. However, it remains essential for identifying leaks, electrical faults, and internal component degradation in industrial machinery.

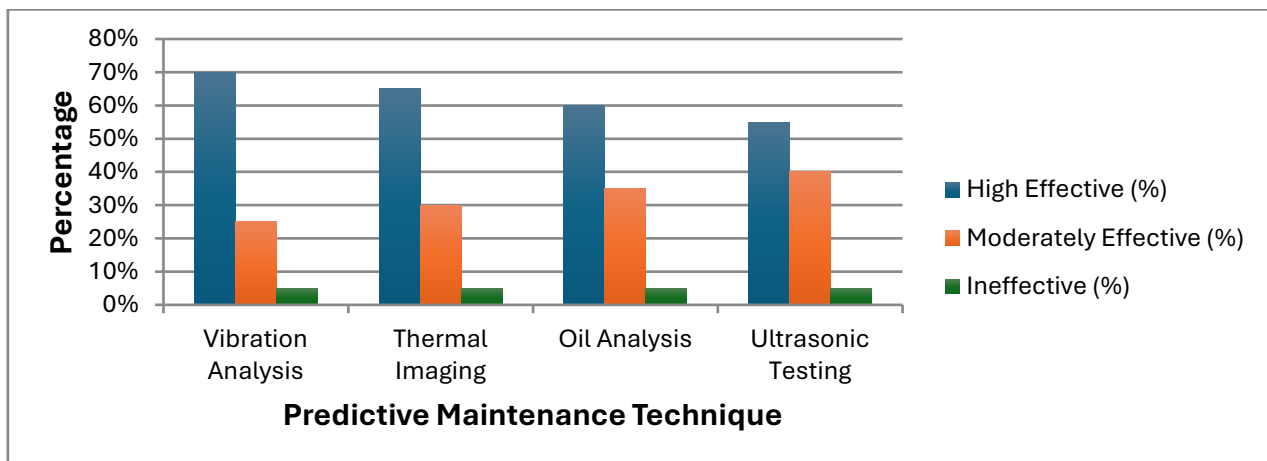


Figure 4: Impact of schedule compression on project performance

8.1.4 Regression Analysis

The study used a regression model to quantify the relationship between schedule compression and project performance. The model's formula is represented as follows:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \epsilon$$

Where:

- Y = Project Performance
- X_1 = Schedule Compression

- X_2 = Cost Impact
- X_3 = Quality Impact

Findings:

- The regression analysis produced an $R^2=0.78$, indicating that 78% of the variability in project performance is explained by schedule compression and its influence on cost and quality.
- Additionally, schedule compression was found to significantly affect quality ($p < 0.05$), confirming the adverse effects reported by survey respondents.

8.1.5 Pearson Correlation for Predictive Maintenance

A Pearson correlation analysis established the connection between predictive maintenance and equipment reliability.

Result:

- The correlation coefficient ($r=0.82$, $p < 0.01$) suggests a strong positive relationship.
- As predictive maintenance practices are more rigorously implemented, equipment reliability significantly improves.

8.2 Qualitative Analysis

8.2.1 Interview Findings

In-depth interviews with 15 senior industry professionals provided detailed qualitative data. Three main themes emerged:

i. Challenges of Schedule Compression:

- **Quality Degradation:** Rushed execution often leads to compromised work quality.
- **Safety Risks:** Accelerated schedules increase the likelihood of safety incidents.
- **Additional Costs:** Increased need for rework and overtime drives up project costs.

ii. Predictive Maintenance as a Cost-Saving Strategy:

- **Reduction in Unplanned Outages:** Proactive maintenance helps avoid unexpected breakdowns, save costs, and reduce downtime.
- **Asset Longevity:** Predictive maintenance practices extend the lifespan of equipment.
- **Improved Workforce Performance:** Fewer unnecessary maintenance tasks lead to better resource allocation and higher productivity.

iii. **Digitalization and AI in Maintenance:**

- **Technological Adoption:** AI-based systems and IoT sensors are becoming essential in modern maintenance practices.
- **Resistance to Change:** Some stakeholders are reluctant to fully adopt new technologies despite their benefits.

IX. CONCLUSION AND DISCUSSION OF RESULTS

9.1 Summary of Key Findings

The study showed that while schedule compression improves time efficiency, based on a 55% positive impact, it comes at the cost of quality and increased project expenses, with 60% of respondents indicating negative quality impacts and 50% reporting adverse cost implications. The regression model produced an R^2 of 0.78, demonstrating that schedule compression explains or is a key determinant of a significant 78% of project performance variability. The findings emphasize the role of schedule compression as a critical factor influencing project outcomes. In addition, the Pearson correlation for predictive maintenance ($r=0.82$, $p < 0.01$) confirms a strong positive relationship with equipment reliability. The findings indicate that adopting AI-driven predictive maintenance can significantly mitigate the negative impacts of aggressive scheduling.

9.2 Discussion of Results

Although compressed schedules ensure faster project completions, they often undermine essential aspects such as quality control and cost management. The findings suggest that the

benefits of rapid scheduling must be balanced with adequate quality assurance measures to avoid long-term operational issues (Ghosh & Jintanapakanont, 2021). Integrating digital technologies such as AI and IoT in predictive maintenance systems offers a promising, long-term solution. The technologies predict equipment failures and address quality issues of schedule compression, ensuring longer asset life and operational efficiency. Balancing speed with quality reduces costs by mitigating the adverse effects of accelerated project timelines.

9.3 Comparison with Previous Studies

The findings align with previous work by Al-Falih et al. (2022), Yang et al. (2024), and Gong et al. (2020), which assessed the adverse impacts of aggressive scheduling and the value of advanced maintenance strategies. Combining schedule compression and predictive maintenance within a single framework enables this study to fill a gap in the literature by providing a detailed assessment of how the two aspects interact and influence overall project performance.

9.4 Theoretical Implications

Integrating predictive maintenance into traditional reliability models promotes theoretical frameworks in project management and reliability engineering. It ensures a more comprehensive analysis of how modern maintenance strategies can be combined with conventional scheduling practices to optimize performance. Confirming the research hypotheses involving the significant influence of schedule compression and the positive role of predictive maintenance supports the validity of theoretical models underpinning this study.

9.5 Practical Implications

Industry practitioners can use these findings to balance accelerated project timelines with strategies that promote quality and reduce costs. The study recommends implementing AI-driven predictive maintenance to enhance reliability. It encourages managers to adopt advanced project management techniques like Critical Chain Project Management (CCPM) and invest in digital

transformation initiatives. Implementing the measures will promote maintenance outcomes and long-term operational sustainability. This study provides actionable insights for mitigating the risks of compressed schedules by describing the significance of integrating digital technological and traditional maintenance practices. Adopting these measures will enhance project timelines without compromising quality and raising cost.

9.6 Limitations and Future Research

This research study's focus on Saudi Arabia and the Arabian Gulf may limit its findings generalizability. Future studies should examine other regions to validate and extend the results applicability. Additionally, self-reported data from surveys and interviews may introduce biases. Subsequent studies should examine objective performance metrics and observational data to substantiate this study's findings. Future research could benefit from longitudinal studies that monitor the long-term impacts of schedule compression and predictive maintenance to provide detailed insights into their effects within a specific period.

X. RECOMMENDATIONS

10.1 Improve Schedule Management

Implementing Critical Chain Project Management (CCPM) can balance rapid project completion and rigorous quality control. This approach focuses on managing resource constraints and minimizing delays to reduce the negative influence of schedule compression on project performance. Adding time cushions into project schedules can help teams to address unforeseen delays before they happen and relieve the pressure that reduces project quality and increases costs. Contingency planning will provide predefined responses to potential issues and minimize the risks of aggressive schedule compression.

10.2 Enhance Predictive Maintenance Strategies

Increasing investment in AI-based predictive maintenance systems can reduce downtime and prevent unplanned challenges. The systems use data analytics to forecast failures and ensure timely interventions to reduce disruptions. Standardizing predictive maintenance procedures across all industrial sectors will ensure consistent application of best practices, optimize asset performance, and facilitate the integration of digital maintenance tools across organizations.

10.3 Promote Digital Transformation and Training

Designing comprehensive training programs will educate and familiarize staff members with emerging maintenance technologies like AI, IoT, and machine learning. The technologies will empower employees to learn how to use predictive maintenance tools and adapt to changing digital work practices. Creating an organizational culture that values innovation and continuous improvement by introducing pilot projects and return on investment from digital maintenance initiatives can lead to the widespread acceptance and integration of new technologies to enhance operational efficiency.

10.4 Future Research Proposals

Future studies should extend the research's geographical scope by including different regions beyond Saudi Arabia and the Arabian Gulf. The extension will enhance the findings' generalizability. Besides, conducting comparative research across various geographical regions and industrial sectors can further validate and foster the current study's conclusions. Longitudinal research studies are vital in assessing the long-term impacts of integrated maintenance strategies on overall operational efficiency. Future research should monitor changes over extended periods and offer comprehensive insights into the sustainability and evolution of predictive maintenance practices in high-pressure industrial environments.

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