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ENHANCING MAINTENANCE PERFORMANCE IN A SELECTED SOUTH AFRICAN COAL-FIRED POWER GENERATION PLANT: A QUALITY-DRIVEN APPROACH

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Abstract

Maintenance performance is critical for ensuring operational efficiency and reliability in power generation facilities. At a South African coal-fired power generation plant (PGP), various factors influence maintenance effectiveness, including the integration of quality tools, management principles, and the role of external service providers. This study investigates these factors to identify opportunities for improvement and enhanced performance.

The study employed a quantitative cross-sectional research approach to collect empirical data through surveys at the selected PGP. Participants were selected using a stratified sampling technique to capture diverse perspectives across different roles and responsibilities. Data analysis included both descriptive and inferential statistics.

The findings reveal significant gaps in the application of quality tools, contributing to increased downtime and reduced system reliability. Although the plant demonstrates a strong commitment to quality objectives, continuous improvement initiatives are not sufficiently embedded in daily operations. Key challenges include inefficient workforce management, substandard workmanship, inadequate spare parts inventory practices, and communication gaps with external service providers.

To address these challenges, this study proposes an Operational Quality Maintenance Framework, integrating quality tools and principles with best practices in supplier management, waste reduction, and improved documentation. A notable feature of the framework is the introduction of a "Hit Squad" approach, that deploys specialized teams to critical areas, enabling them to promptly address urgent maintenance issues and normalize operations. This strategy enhances collaboration between departments and ultimately leads to improved maintenance performance.

The proposed framework offers a practical model for integrating quality management into maintenance processes, providing a pathway for improved reliability and efficiency in coal-fired power generation. The insights from this study contribute to the broader understanding of maintenance optimization and offer scalable solutions applicable to similar industrial contexts, emphasizing the importance of structured quality management for sustainable operations.

Keywords

Maintenance, Quality Management, Coal-Fired Power Generation, Operational Efficiency, Continuous Improvement, Supply Chain Management

1. Introduction

Maintenance stands as a cornerstone of industrial production processes, playing a pivotal role in optimizing equipment performance, enhancing operational efficiency, and prolonging the lifespan of machinery and equipment (Molęda et al., 2023). By seamlessly integrating maintenance practices into production and quality management frameworks, manufacturers have established robust control policies and guided decision-making processes within manufacturing operations (Hajej et al., 2021; Farahani & Tohidi, 2021). This integration does not only prevent equipment breakdowns but also ensures the unified operation of production processes, thereby boosting overall productivity, minimizing equipment downtime through proactive maintenance strategies, and upholding product quality to meet customer expectations (Modgil & Sharma, 2016; Kurniati et al., 2015).

Similarly, in sectors like South Africa's critical electricity infrastructure that drives the economic growth, robust maintenance practices are essential. For instance, the state-owned power utility Eskom, which relies heavily on coal-fired power plants faces significant challenges of electricity margin shortages and operational inefficiencies (Mditshwa et al., 2023; Nkosi, 2023; Bah & Azam, 2017). The ageing infrastructure of these power plants has led to escalating routine maintenance requirements, posing significant threats to energy security and reliability (Modiba & Telukdarie, 2021, Mathews et al., 2020). Despite Eskom having an established Quality Management System (QMS) and Business Excellence Program, along with proactive maintenance efforts, several factors, such as poor planning, substandard execution of tasks, deficiencies in quality management processes, and skills shortages, have hindered the successful execution of their reliability maintenance initiatives (Mashilo, 2023; Eskom, 2023; Solomon et al., 2017).

This study aims to identify factors that can enhance maintenance performance at a selected coal-fired power generation plant (PGP) in South Africa. It will assess the integration of quality tools and ISO 9000:2015 Quality Management Principles (QMP) into maintenance activities while exploring how operational inefficiencies and external service providers contribute to the backlog of corrective maintenance. The study intends to provide valuable insights into the challenges faced by Eskom and similar organizations in maintaining critical infrastructure.

1.1 Context of Study

Eskom is the largest producer of electricity in South Africa and although their mandate is to provide stable, efficient, and sustainable electricity supply, their aging infrastructure and lack of timely investments have exacerbated the challenges faced by the utility company. Electricity demand grew significantly over the years, with insufficient capacity being planned and added to the electricity sector (Eskom, 2023). Furthermore, the increase in population, urbanization and income brackets drive up electricity demand and put more strain on the already insufficient generating capacity resulting in devastating economic impact on regional, national and global levels (Moyo et al., 2021). This resulted in Eskom experiencing many challenges in maintaining a constant electricity supply to meet the required demand of the country and therefore forced to implement load shedding (Mditshwa et al., 2023; Mashilo, 2023; Modiba & Telukdarie, 2021; Moyo et al., 2021). The majority of South Africa's electricity is generated from its 15 coal-fired power plants, with minimal design improvements undertaken to alleviate growing electricity margin shortages (Mathews et al., 2020; Bah & Azam, 2017). The selected coal-fired PGP situated in the Free State province of South Africa is a critical component of the country's electricity grid, contributing approximately 8% of the total power output (Eskom, 2023). However, the Energy Availability Factor (EAF) for the PGP demonstrated a downward trend in the 2023 Financial Year, dropping to 75.10%, as shown in Figure 1. This decline is largely attributed to maintenance targets not being consistently met, despite the selected PGP's maintenance being performed to good standards.

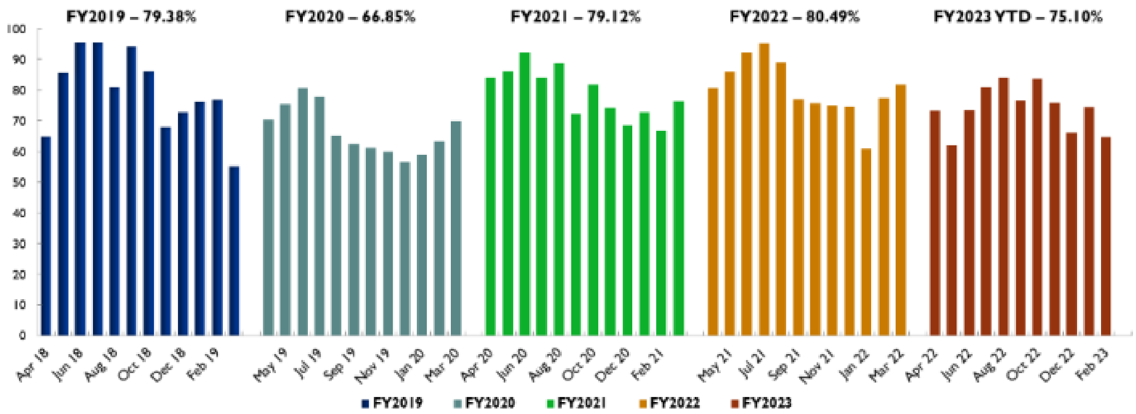


Figure 1 – Selected Plant EAF Performance Trend

Source: Adapted from Opera Assessment Report (2023)

2. Literature Review

2.1 Maintenance

Maintenance encompasses a diverse range of activities aimed at restoring and repairing the functionality of equipment, machinery, infrastructure, and systems (Al-Refaie & Almowas, 2023; Ferreira et al., 2020). Optimization of maintenance operations is pivotal in enhancing organizational efficiency and subsequently contributes significantly to improving economic performance (Krupitzer et al., 2020; Ran et al., 2019). These activities often involve Reliability, Availability, and Maintainability (RAM) analysis to inform decision-making regarding design adjustments, compliance with standards, optimization of maintenance schedules, inventory management, and overall lifecycle expenses (Barbieri & Hernandez, 2024; Al-Refaie & Almowas, 2023; Nunes et al., 2023; Ferreira et al., 2020; Zlatic, 2019). The two prevalent maintenance categories are Corrective Maintenance (CM) and Preventive Maintenance (PM), with the former promptly addressing equipment failures to restore functionality after breakdowns, and the latter employing proactive measures to prevent breakdowns and prolong equipment lifespan (Al-Refaie & Almowas, 2023; Molęda et al., 2023; Ferreira et al., 2020; Farahani & Tohidi, 2021).

2.1.1 Corrective Maintenance

CM is a reactive approach to maintenance to restore equipment to its operational state after a failure has occurred (Al-Refaie & Almowas, 2023; Krupitzer et al., 2020; Ferreira et al., 2020; Ran et al., 2019). This method, often referred to "run-to-failure", involves replacing or repairing components only after they have malfunctioned and the equipment is unable to operate without intervention (Nunes et al., 2023; Asadi et al., 2023; Krupitzer et al., 2020). The reactive nature of CM incurs substantial costs, including production disruption, equipment downtime, immediate spare part procurement, and production losses (Molęda et al., 2023; Krupitzer et al., 2020; Erkoyuncu et al., 2017). Despite these challenges, CM is still widely used in industry (Achouch et al., 2022). For example, Ran et al. (2019) emphasize that CM ensures maximum equipment utilization and production value before any intervention, thereby minimizing prevention costs. Additionally, Molęda et al. (2023) highlight that CM can reduce immediate servicing costs and extend maintenance intervals, making it particularly suitable for non-critical, easily repairable equipment. While CM is essential for addressing unexpected breakdowns and minimizing downtime, organizations also strive to implement preventive maintenance measures to proactively mitigate failures and optimize asset performance (Ferreira et al., 2020). Thus, it becomes imperative to supplement corrective measures with preventive maintenance strategies to mitigate adverse impacts and ensure sustained operational resilience.

2.1.2 Preventative Maintenance

PM is a proactive maintenance approach aimed at preventing equipment failure through regular inspections, servicing, and repairs (Nunes et al., 2023; Achouch et al., 2022; Modgil & Sharma, 2016). These activities are scheduled at regular intervals or after a specified number of operational cycles, guided by factors such as equipment usage, manufacturer guidelines, and industry best practices (Molęda et al., 2023; Krupitzer et al., 2020). PM plays a crucial role in maintaining equipment health, minimizing failure costs, and reducing machine downtime, thereby enhancing productivity (Ran et al., 2019). Despite its benefits, PM presents several challenges, including meticulous planning, budgeting, unexpected failures, premature replacements, and difficulties in machine selection and timing (Molęda et al., 2023; Al-Refaie & Almowas, 2023; Nunes et al., 2023; Asadi et al., 2023; Ran et al., 2019). Addressing these challenges is essential for minimizing resource wastage, expenses, and production delays. Alhourani et al. (2023) advocate for analyzing machine failures and maintenance needs within a plant to optimize PM strategies, emphasizing the grouping of machines with similar maintenance requirements to streamline processes and reduce costs. Additionally, Al-Refaie and Almowas (2023) highlight the increasing importance of PM in preventing potential machine breakdowns within modern manufacturing systems. Alhourani et al. (2023) suggest that a thorough evaluation of machine failures and maintenance needs within a facility can enhance PM strategies. They recommend grouping machines with similar maintenance needs to simplify processes and lower costs. Similarly, Al-Refaie and Almowas (2023) emphasize the critical role of PM in preventing possible equipment failures in contemporary manufacturing environments, highlighting the need for continuous improvement and strategic adaptation into maintenance practices.

2.2 Quality Management Systems in Maintenance

2.2.1 ISO 9001:2015 QMS

A QMS is a clearly defined set of business processes that are geared to consistently deliver products or services at a high standard while satisfying customer needs (Benzaquen & Narro, 2023). The ISO 9001:2015 standard serves as a globally recognized benchmark that applies to a QMS, devised to facilitate business improvement and certification (Abuazza et al., 2020). Pursuing ISO 9001:2015 certification is voluntary for businesses and demands significant commitment, yet organizations willingly choose to pursue it (Kartha, 2022). This decision is consistently driven by the challenges they encounter, such as cost reduction, process simplification, managing shorter product life cycles, coping with growing product complexity, and adapting to the dynamic nature of new markets (Chiarini & Cherrafi, 2023).

The ISO 9001:2015 standard incorporates the "Plan, Do, Check, and Act" (PDCA) cycle and risk-based thinking to develop, implement and improve effective processes and systems within an organization (Benzaquen & Narro, 2023). While the PDCA cycle is frequently employed for addressing quality issues, its utility extends beyond problem-solving to serve as a catalyst for continuous improvement initiatives, adaptable to various domains including production processes and maintenance operations (Ferreira et al., 2020). The framework encapsulates the seven fundamental QMP's, namely customer focus, leadership, employee engagement, process orientation, continuous improvement, evidence-based decision-making, and relationship management, synergistically aligned with Total Quality Management (TQM). These QMP's are a set of fundamental beliefs, norms, rules and values that are accepted as true and can be used as a basis for quality management to guide an organization's performance improvement (ISO 9001:2015).

The benefits attributed to ISO 9001:2015 implementation include increased access to international markets, operational improvements, enhanced profitability, and strategies to reduce internal costs, boost productivity, and improve efficiency (Fonseca et al., 2021). However, simply obtaining a QMS or ISO certification does not guarantee a company's success. Achieving success requires a steady commitment to managing the entire system using quality tools and techniques. Without this dedication, there is a risk of creating a false sense of continuous improvement and customer satisfaction (Zlatic, 2019).

2.2.2 Quality Tools

Within the ISO 9001:2015 framework, Ishikawa's seven quality tools are crucial for evaluating process conditions and identifying potential root causes and their effects (Antony et al., 2021). These tools (comprising flow charts, Pareto diagrams, check sheets, control charts, histograms, scatter diagrams, and cause-and-effect diagrams) provide structured methodologies for analyzing processes, systematically collecting data, monitoring changes, graphically presenting data, assessing variable relationships, and identifying root causes of issues (Erkoyuncu et al., 2017; Gadre et al., 2015). Their effective utilization, coupled with proper training and integration into organizational processes, significantly enhances quality management practices and organizational performance (Chiarini & Cherrafi, 2023).

While these quality tools offer invaluable guidance, a common concern arises from the improper application of a suitable tool for a specific purpose, often stemming from a lack of understanding regarding its appropriate utilization and integration with other tools (Fonseca et al., 2021). Moreover, interpretations and applications of these tools vary significantly across individuals, organizations, industries, and situations (Chiarini & Cherrafi, 2023). The most frequently used quality tools and techniques include check sheets, graphics, flowcharts, brainstorming, and benchmarking, primarily due to their perceived ease of use and simplicity (Abdel-Hamid & Abdelhaleem, 2019).

Erkoyuncu et al. (2017) recommend leveraging these essential quality tools in process identification, data acquisition, and analysis to transition from static to dynamic improvements. Furthermore, Antony et al. (2021) suggest integrating these quality tools and techniques within processes to enable management and employees to grasp the true cost of wastage that result from rejected work. The consistent utilization of quality tools does not only positively impact individuals involved but also enhances their cognitive abilities, fosters creativity, and refines their planning skills (Gadre et al., 2015). This aligns with El Manzani et al. (2019), who argue that organizations utilizing quality tools, techniques, and knowledge to enhance performance are better positioned to optimize processes holistically within the organizational context.

2.2.3 Total Productive Maintenance

Total Productive Maintenance (TPM) is an innovative maintenance approach that complements production, quality, and other organizational strategies (Benzaquen & Narro, 2023; Zlatic, 2019). It serves as the fundamental pillar within quality standards such as ISO 9001:2015 that integrates QM principles into maintenance processes to ensure the efficacy and reliability of maintenance operations (Chaurey et al., 2023; Modgil & Sharma, 2016; Kurniati et al., 2015). Furthermore, ISO 9001:2015 plays a critical role in linking an organization's maintenance strategies, operational plans, and QM principles into the TPM strategy to foster a culture of continuous learning and improvement (Kurniati et al., 2015).

TPM goes beyond traditional reactive or preventive maintenance strategies as it aims to maximize the overall effectiveness of equipment and machinery by involving all stakeholders in the organization, from frontline operators to senior management (Bashar et al., 2022; Modgil & Sharma, 2016). It focuses on empowering employees to take ownership of equipment maintenance and care, shifting from a mindset of "fix it when it breaks" to one of proactive maintenance and continuous improvement (Chaurey et al., 2023). Therefore, TPM serves as a bridge between strategic objectives and operational execution as it translates strategic goals, such as improving productivity, reducing costs, and enhancing customer satisfaction, into actionable maintenance practices. Top management support is thus a key determinant for TPM as there needs to be buy in and cooperation at every level of the organization (Agustiady & Cudney, 2018; Zlatic, 2019). Hadidi et al. (2023) further suggest that addressing intangible leadership factors, such as people management and partnerships, is essential to cultivate a new organizational quality culture that supports continuous improvement initiatives through TPM.

The three main categories of TPM are: Planned maintenance, to ensure equipment reliability through scheduled inspections and adjustments; Quality maintenance, to guarantee consistent standards through preventive measures and customer feedback; and Education and training, to foster continuous improvement by equipping employees with necessary skills and knowledge (Chaurey et al., 2023; Zlatic, 2019; Agustiady & Cudney, 2018). This holistic approach does not only improve equipment reliability but also promotes a sense of ownership and responsibility among employees, leading to a more engaged workforce and better overall performance (Molęda et al., 2023).

2.2.4 Supplier Management

Effective supplier management is integral to preserving the integrity of products and information across the entire value chain. From sourcing raw materials to delivering finished products to customers, every stage hinges on robust supplier relationships (Lambert & Enz, 2017). Both internal and external processes influence the quality of goods and services within an organization, underscoring the pivotal role suppliers play in organizational success (Kartha, 2022). Consequently, integrating supply chain operations allows organizations to optimize their resources and capabilities, internally and externally, thus enhancing long-term performance (El Manzani et al., 2019).

As supply chains grow increasingly complex, effective management and information processing become imperative (Lambert & Enz, 2017). Managing supplier-client relationships is therefore paramount in outsourced processes, with factors like quality, trust, collaboration, cost, and communication taking center stage. Kartha (2022) emphasize that a QMS such as ISO 9001:2015 is critical in creating structures and processes to select suppliers. The quality certification of suppliers, as highlighted by Vanichchinchai (2022), does not only aid in current supplier selection but also lays the groundwork for fostering future partnerships. Furthermore, research by Benzaquen and Narro (2023) suggests that companies certified under ISO 9001:2015 extend their value networks and are perceived to have superior relationships with their suppliers compared to non-certified companies.

High-performing suppliers are widely acknowledged for their essential role in enhancing the performance of any organization (El Manzani et al., 2019). They demonstrate the proactive procurement of parts and materials in advance, ensuring a well-planned and timely supply chain, and efficiently completing maintenance tasks (Mostafa et al., 2015). This proactive approach not only enhances operational efficiency but also fosters a culture of reliability and dependability within the supply chain, crucial for maintenance interventions requiring integration and cooperation among internal and external systems and stakeholders (Vanichchinchai, 2022).

3. Research Design and Methodology

This study adopted a cross-sectional survey type research design to explore the factors that can improve maintenance performance at a selected PGP in South Africa. The decision to utilize a cross-sectional approach stems from its ability to efficiently collect data from a diverse sample at a specific point in time, providing a comprehensive understanding of current practices and challenges within the PGP (Sekaran & Bougie, 2016). This approach enables the examination of multiple variables simultaneously and explores relationships between them (Maier et al., 2023). Consequently, the quantitative technique was used to systematically measure and analyze variables related to maintenance backlog, quality tool utilization, and adherence to quality principles.

3.1 Survey Instrument Design

The research instrument was informed by the ISO 9001:2015 standard and established frameworks from previous literature, ensuring content validity and alignment with the research objectives (Benzaquen & Narro, 2023; Solomon et al., 2017; Modgil & Sharma, 2016; Sinha, 2015). The questionnaire comprised two distinct sections to comprehensively capture respondent data. Section A focused on gathering biographical information through a brief set of 5 questions. Section B probed deeper into research-related inquiries, featuring a total of 18 questions thoughtfully organized into four categories of questions. These categories were strategically delineated to explore specific facets of the research topic, namely: the extent of quality tool integration in maintenance practices (Question 1), adherence to ISO 9001:2015 QMP's (Question 2), identification of factors influencing corrective maintenance backlog (Question 3), and the extent to which external service providers contribute to corrective maintenance backlog (Question 4). These sections of the questionnaire used questions based on a 5-point Likert scale. The Likert scale, as described by Jebb et al. (2021), enables respondents to express their opinions, attitudes, or sentiments in a structured manner, facilitating subtle insights into the research subject. Pilot testing was conducted to refine the questionnaire and ensure clarity and comprehensibility for participants.

3.2 Sampling Strategy

The PGP's permanent employees (320) served as the target population for this study. The sampling size strategy was guided by the population-to-sample ratio as espoused by Sekaran and Bougie (2016). A sample size of 221 participants was deemed adequate representation for this study as it was at based at 95% confidence level. A stratified random sampling technique was employed to select adequate participants from the different job grades which consisted of management level (M-level), senior advisors' level (G-level), professionals' level (P-Level) and supervisors and technicians' level (T-level). This sampling strategy was used to capture a diverse range of perspectives and experiences, enhancing the generalizability of the findings to the broader population of maintenance personnel at the PGP.

3.3 Execution of Survey

The survey was administered electronically to participants, allowing for efficient data collection while minimizing logistical challenges associated with traditional paper-based surveys (Sekaran & Bougie, 2016). The list of participants email addresses was accessed through the organizations email database directory. The participants were given 6 weeks to complete the questionnaire. However, at the end of this period, the response rate was low, with only 43% of the expected feedback received. Subsequently, a follow up email was sent to the participant's, giving them an additional 2 weeks to complete the survey. In addition, a notice was uploaded on the organizations intranet system, highlighting the importance of completing the questionnaire. This was done to increase the response rate within a designated timeframe and to ensure consistency and minimize response bias. At the end of the extended timeframe, a total of 207 responses were received, representing a response rate of 93.67%. Of these, three incomplete surveys were excluded, resulting in 204 valid responses, accounting for 92.31% of the total.

3.4 Data Analysis

SPSS version 27.0 was used to analyze the data collected from the responses. Descriptive statistics were presented as graphs and percentages, while inferential techniques such as correlations and Chi-square tests were employed, with interpretations based on their respective p-values. A statistically significant result is indicated with "$p<0.05$" (Napitupulu et al., 2017). The instrument's internal consistency was evaluated using Cronbach's alpha to assess the reliability of the data. Typically, a Cronbach's alpha score above 0.7 is considered acceptable (Lopes et al., 2018). Furthermore, the face validity, content validity, construct validity, and criterion validity of the instrument were assessed by industry leaders, academics, and senior-level managers at the PGP. Their role was to review the content and structure of the instrument and provide feedback. The feedback received was then used to refine the questionnaire before it could be used for the fieldwork.

Factor analysis was employed to condense multiple questions into a smaller number of hypothetical factors (Goretzko et al., 2024). The Kaiser-Meyer-Olkin (KMO) Measure of Sampling Adequacy was used to assess the proportion of variance in the variables that the underlying factors might cause, while Bartlett's test of sphericity was conducted to assess the hypothesis that the correlation matrix is equivalent to an identity matrix (Napitupulu et al., 2017). For factor analysis to be valid, the KMO should exceed 0.500 and Bartlett's Test of Sphericity should yield a significance level below 0.05 (Napitupulu et al., 2017). Factor analysis typically focuses on Likert scale items, with specific items divided into finer components. Consequently, in Section B of the survey (Questions 2, 3, and 4), the classification of disagreement and agreement was streamlined by merging the two tiers into overarching categories labeled as overall disagreement and overall agreement. This decision was made considering the satisfactory levels of reliability and consistency revealed during the factor analysis, as discussed by Rathilall and Singh (2018).

4. Results and Discussions

4.1 Section A - Biographical Data

The results pertaining to the biographical profile of the respondents are presented in Table 1.

Category	Profile	Percentage
Job grade	M-Level	14.4
	P-Level	13.9
	G-Level	5.9
	T-Level	65.8
Department	Maintenance	46
	Engineering	25.7
	Operations / Production	15.4
	Risk and Assurance	4.5
	Outage and Environment	4.4
	Projects and Procurement	3
	Finance and Human Resource	1
Occupation	Technician	36.9
	Supervisor	14.6

	Manager	15.7
	Engineer	17.7
	Co-ordinator	2.5
	Risk and Assurance	6.1
	Operator	6.6
Gender	Male	30.7
	Female	69.7
Work Experience (Years)	0 - 5	14.4
	10-Jun	24.9
	15-Nov	21.4
	16 - 20	12.4
	21 - 30	10.9
	31+	15.9

Table 1 – Profile of respondents

Source: Table created by the authors

As shown in Table 1, approximately 65.8% of the respondents were from the T-Level ($p<0.001$) job grade, thus affirming the prevalence of lower-level employees over higher-level counterparts within organizational structures. In terms of departments, over 70% of respondents were from Maintenance or Engineering ($p<0.001$), with maintenance exhibiting particularly high participation. Among occupations, Technicians comprised the largest group at 36.9%, while Supervisors, Managers, and Engineers had an average representation of 16.0% ($p<0.001$), mirroring participation trends observed across job grades.

Regarding gender distribution, male participation dominated, with a ratio of approximately 2:1 (69.7% male, 30.3% female) ($p<0.001$), attributed partly to the higher male representation in the organization's demographic profile. The Length of service analysis indicated that employees with 6-10 years of experience constituted the highest frequency at 24.9%, suggesting a level of comfort and expertise in their roles. Notably, approximately 85% of respondents had been employed for more than five years ($p=0.003$), indicating a substantial representation of experienced participants thereby enhancing the credibility of the study's findings.

4.2 Section B – Survey Data

The results pertaining to the KMO and Bartlett's Test of Sphericity are presented in Table 2.

Kaiser-Meyer-Olkin Measure of Sampling Adequacy		0.813
Bartlett's Test of Sphericity	Approx. Chi-square	2776.715
	df	496
	Sig.	0.000

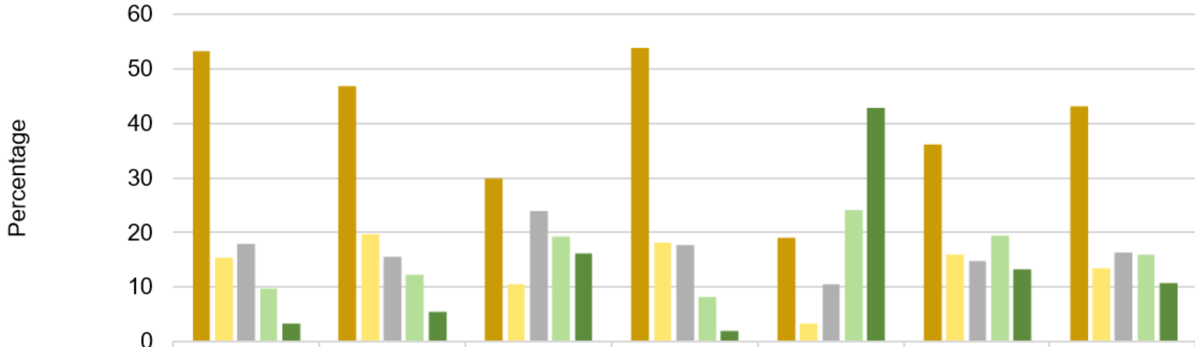
Table 2 – KMO and Bartlett's Test of Sphericity results

Source: Table created by the authors

As can be seen in Table 2, the factor analysis of the data revealed that the KMO value was 0.813, while Bartlett's Test of Sphericity significant value was 0.000. This means that all the conditions for factor analysis have been satisfied for this part of the survey. The statements that constituted Questions 1, 2 and 3 in Section B of the questionnaire loaded perfectly along with a single component. This implies that the reports that included these sections perfectly measured what they set out to measure. It is noted that the variables that constituted Question 4 in Section B of the questionnaire loaded along with two components (sub-themes). This means that respondents identified different trends within the section. For example, in question 4.5, the item "External service providers are often not provided with clear specifications of the required product and services, by the power generation plant" loaded differently from its other related items.

4.2.1 Question 1 - Quality Tools

This part of the questionnaire was to determine the extent to which the seven basic quality tools are embedded in the maintenance practices at the selected PGP. The results pertaining to the extent to which each quality tool is embedded in maintenance practices are presented in Figure 2.



	Scatter Plot	Cause and Effect Diagram	Flow Chart	Pareto Diagram	Check Sheet	Control Chart	Histogram
Very Rarely	53.1	46.6	29.9	53.6	19.1	36.1	43
Rarely	15.5	19.7	10.7	18.2	3.5	16	13.5
Occasionally	18	15.6	23.9	17.8	10.6	14.9	16.5
Often	9.8	12.4	19.3	8.3	24.1	19.6	16.1
Very Often	3.6	5.7	16.2	2.1	42.7	13.4	10.9

Figure 2 – Quality tool usage within the maintenance environment

Source: Figure created by the authors

Figure 2 depicts a clear trend where the check sheet, among the seven basic quality tools analyzed, stands out with notably higher usage frequency compared to the others. This observation highlights a significant variance in the adoption rates of basic quality tools within the maintenance department, contradicting Benzaquen and Narro's (2023) findings that ISO 9001 certified companies usually employ all seven basic quality tools more consistently compared to non-certified counterparts.

The prevalence of the check sheet as the most frequently employed tool, with 64.8% of respondents indicating its use "Often and Very Often", suggests that the maintenance department predominantly relies on data collection and visual representation for problem-solving and decision-making. This observation resonates with previous studies by George et al. (2018) and Gadre et al. (2015), who reported that check sheets are commonly used for daily maintenance checks. Such a trend indicates a strong emphasis on collecting real-time data to identify trends, patterns, and anomalies in maintenance activities. Furthermore, as underlined by Abdel-Hamid and Abdelhaleem (2019), the inherent advantages of check sheets such as its ease of implementation and clarity in interpreting results accentuate their pivotal role in maintenance practices.

The mixed distribution of responses regarding the use of flowcharts and control charts suggests that there is a moderate level of adoption within the maintenance department. This implies that while some employees may be using these tools, others might not be using them to the same extent. The difference could indicate varying levels of familiarity or training among staff when it comes to process mapping and statistical process control.

The infrequent use of histograms (56.5%) and cause and effect diagrams (66.3%) in maintenance tasks suggest a lack of consistent integration into operational practices. This inconsistency may arise from the challenge of designing these tools to be user friendly and practical for maintenance personnel, as highlighted by Abdel-Hamid and Abdelhaleem (2019) and George et al. (2018). Notably, Pareto diagrams (71.8%) and Scatter plots (68.6%) exhibit the lowest frequency of usage. The underutilization of these tools may signify missed opportunities within the maintenance department to prioritize improvement efforts and to identify correlations and interrelationships among variables (Antony et al., 2021).

4.2.2 Question 2 - Quality Management Principles

The results pertaining to the extent to which ISO 9001:2015 QMP are embedded in maintenance practices are presented in Table 3.

Question 2	The extent to which ISO9001:2015 quality management principles are embedded in the maintenance practices	Disagree	Neutral	Agree	p-value for department	p-value for occupation
2.1	Maintenance activities at the power generation plant meets customer needs	17.3	31.2	51.5	0.180	0.002
2.2	Maintenance personnel are engaged in achieving the power generation plant's maintenance objectives	13.8	18.7	67.5	0.190	0.019

2.3	Sharing of knowledge and experience is encouraged among maintenance personnel	15.8	21.2	63.1	0.000	0.001
2.4	Documented information is available for use where and when is it is needed to perform corrective maintenance	15.6	23.6	60.8	0.017	0.002
2.5	Improvement is recognized and acknowledged within the maintenance environment	24.8	29.7	45.5	0.072	0.017
2.6	Decisions made within the power generation plant are based on evidence, balanced with knowledge and experience	15.8	19.2	65.0	0.882	0.766
2.7	Relationship with external service providers is balanced between short-term gain and long-term power generation plant performance	19.3	35.6	45.0	0.022	0.116

Table 3 – ISO 9001:2015 QMP adoption in maintenance practices

Source: Table created by the authors

As can be seen in Table 3, the substantial level of agreement for statement 2.1 (51.5%) demonstrates that maintenance activities within the PGP are directed towards fulfilling customer needs. This is aligned with Fonseca et al. (2021) that the robust commitment to established quality management standards signifies a profound dedication to customer satisfaction, emphasizing the pivotal role of customer-centricity in the organization's maintenance philosophy. Chaurey et al. (2023) refer to quality in maintenance as the driver to delight the customer by ensuring that equipment, facilities, or infrastructure continue to perform their intended functions at the desired level of quality. The statistically significant p-value of 0.002 within different occupational groups indicates that the commitment to meeting customer needs is not uniform across all roles. This underscores the existence of variations in the dedication to customer-centric practices based on the nature of specific job roles within the PGP.

The positive responses for statement 2.2 (67.5%) highlight the strong commitment of maintenance personnel to achieving the PGP's objectives. This is consistent with Abuazza et al. (2020), who emphasized that when leadership defines and communicates business strategies and quality objectives across the organization, it fosters a shared purpose and direction among all employees. The statistically significant outcome within the type of occupation (p=0.019) implies a strong association between the type of occupation and the demonstrated commitment towards the organizational strategies and goals outlined by leadership.

For Statement 2.3, the agreement rate of 63.1% indicates a positive cultural attitude within the maintenance environment. This is aligned with Benzaquen and Narro (2023) that a positive culture promotes active employee engagement and elevates performance and outcomes by cultivating a robust connection between employees and their work centrality. The significant p-values within departments (p=0.000) and occupations (p=0.001) highlight a collaborative atmosphere, promoting a free flow of information and fostering a sense of unity among employees.

The high level of agreement for statement 2.4 (60.8%), signifies the ease of accessibility of documented information for corrective maintenance within the PGP. This finding corroborates the efficacy of the PGP's procedures as outlined in the ISO 9000:2015 standard and is statistically significant across departments (p=0.017) and occupations (p=0.002). Furthermore, it highlights the PGP's dedication to maintaining well documented maintenance processes, thereby ensuring transparency and enabling easy access to records. Although statement 2.5 has an agreement rate of 45.5%, the statistically significant p-value of 0.017 observed within occupations indicates that the identified distribution is not due to random chance. The statistically significant findings imply that the identified factors contributing to improvement recognition are substantive and not incidental (Goretzko et al., 2024). Consequently, this emphasizes the need for organizations to actively engage in ongoing efforts to enhance processes within the maintenance environment. This observation aligns with Ferreira et al. (2020) who assert that businesses should consistently strive for improvement across various processes, as even small enhancements can eventually translate into significant gains in the final output.

The substantial agreement for statement 2.6 (65.0%) infers an equal balance among empirical evidence, knowledge, and experience in decision making processes within the PGP. This combination indicates the presence of a well-informed decision-making culture that integrates both data-driven insights and personnel expertise, highlighting the importance of a holistic approach to decision making within maintenance practices. This perspective, as demonstrated by Chiarini and Cherrafi (2023), contributes to shaping business decisions that achieve optimal outcomes.

The 45.0% agreement rate of the PGP's relationship with external service providers (statement 2.7), emphasize the need to navigate a delicate balance between short-term gains and the long-term performance within these relationships. This perspective is supported by Abuazza et al. (2020), who demonstrated that an organization's success is intricately tied to its effective management of relationships with all relevant parties and stakeholders throughout the entire supply chain. The statistically significant p-value of 0.022 within departments further substantiates the importance of addressing and optimizing these relationships. It does not only reinforce the significance of the PGP's interactions with external service providers but also underscores the need for a comprehensive approach to managing relationships within different organizational departments. This is corroborated by Kartha (2022), who established that suppliers tend to emulate the quality systems implemented by their customers, suggesting an upstream adoption of practices between organizations.

4.2.3 Question 3 - Factors contributing to maintenance backlog

The results pertaining to the factors that contribute to the corrective maintenance backlog are presented in Table 4.

Question 3	The factors that contribute to the corrective maintenance backlog	Disagree	Neutral	Agree	p-value for department	p-value for occupation
3.1	Corrective maintenance backlog is increased by the underutilization of the workforce at the Power Generation Plant	28.4	18.9	52.7	0.070	0.030
3.2	Corrective maintenance backlog is negatively influenced by poor management of inventory of spares/parts at the power generation plant	12.4	10.4	77.1	0.901	0.208
3.3	There is too much unnecessary motion/movement of maintenance personnel within the plant	38.8	41.3	19.9	0.253	0.000
3.4	The lack of an effective maintenance data management system impedes the optimizing of maintenance backlog	13.5	32.0	54.5	0.016	0.119
3.5	The level of rework due to poor maintenance workmanship is at such a level that it has a significant impact on corrective maintenance backlog	14.9	21.4	63.7	0.747	0.117

Table 4 – Factors contributing to corrective maintenance backlog

Source (s): Table created by the authors

From Table 4, statement 3.1 shows that most respondents (52.9%) agree that corrective maintenance backlog is influenced by the underutilization of the workforce. The statistical significance found within occupations (p=0.030) indicates that certain professional groups within the workforce significantly contribute to the observed relationship between underutilization and maintenance backlog. This finding highlights the need to focus on particular roles or departments where interventions could have the most substantial impact. Hadidi et al. (2023) support this by establishing that optimizing equipment effectiveness requires the active involvement of personnel across different organizational departments. Consequently, the strategic focus on workforce optimization emerges as a key avenue for improving the efficiency of corrective maintenance operations.

Concerning statement 3.2, the significant level of agreement (77.1%) highlights a shared perspective among the respondents on the adverse effects of inadequate spares and parts inventory management on the corrective maintenance backlog within the PGP. This finding is consistent with Erkoyuncu et al. (2017), who emphasize the importance of considering both the demand for specific spares, which is closely linked to their failure rates, and the delays incurred when these spares are unavailable. This underscores the complexity inherent in the relationship between inventory management practices and the challenges presented by maintenance backlog.

Statement 3.3 shows that 38.8% of respondents disagree that there is unnecessary movement of maintenance personnel within the PGP. Despite this, the statistical significance observed across different occupations (p=0.000) highlights the critical need to optimize personnel activities within the plant. This is essential for improving operational efficiency and mitigating backlog issues.

Statement 3.4 highlights the significance of maintenance data management systems in addressing corrective maintenance backlogs. However, the substantial agreement rate of 54.5% among respondents emphasizes the impact of ineffective systems on optimization efforts. Additionally, the statistically significant p-value of 0.016 within departments signifies the pivotal role of systematic data analysis facilitated by these systems in improving decision making processes. This aligns with the findings of Mendes et al. (2023), who demonstrated that proficient maintenance data management systems enhance operational efficiency through the systematic collection, processing, and real-time storage of crucial parameters and data.

The high level of agreement (63.7%) for statement 3.5 highlights the respondent's view on the substantial repercussions of rework resulting from substandard workmanship on the corrective maintenance backlog. This is consistent with the findings of Mostafa et al. (2015) that incorrect maintenance repairs often require multiple repetitions to rectify the repair job accurately. Hadidi et al. (2023) further explain that rework can occur directly through human factors such as fatigue or incompetence, and indirectly, through interactions between humans and machines or incorrect procedures. Consequently, the escalation in rework escalates the likelihood of accidents, often associated with maintenance and repair activities. These repetitions also have adverse effects on both maintenance costs and product quality (Sinha, 2015). Therefore, by closely examining specific aspects of workmanship and considering relative factors, organizations can uncover crucial insights that inform the development and implementation of targeted strategies to improve maintenance processes and reduce the impact of rework.

4.2.4 Question 4 - External Service Providers

The results pertaining to the extent to which external service providers contribute to corrective maintenance backlog are presented in Table 5.

Question 4	The extent to which external service providers contribute to the corrective maintenance backlog	Disagree	Neutral	Agree	p-value for department	p-value for occupation
4.1	The power generation plant's external non-certified service providers have a lower value adding impact on maintenance activities outputs than the plant's external ISO 9001 certified service providers	23.3	40.1	36.6	0.000	0.000
4.2	There is a more negative impact on maintenance activities output in cases where the power generation plant has a distant relationship with suppliers than where the relationship is close	12.9	29.7	57.4	0.000	0.004
4.3	Delivery schedules of external service providers have a negative impact on maintenance activities output at the power generation plant	15.4	19.4	65.2	0.036	0.001
4.4	Lead times of external service providers have a negative impact on maintenance activities output at the power generation plant	10.9	21.3	67.8	0.094	0.014
4.5	External service providers are often not provided with clear specifications of the required product and services, by the power generation plant	25.7	25.2	49.0	0.090	0.606

Table 5 – External service providers contribution to corrective maintenance backlog

Source: Table created by the authors

With reference to Table 5, the high number of neutral responses (40.1%) for statement 4.1 is understandable, as many respondents may lack sufficient information about the quality status of their suppliers. The statistically significant values within departments (p=0.000) and occupations (p=0.000) suggest that the PGP's external ISO 9001 certified service providers have a higher value adding impact on maintenance activity outputs compared to their non-certified counterparts. This aligns with Kartha's (2022) findings, which demonstrated that ISO 9001 certified organizations consistently outperform their non-certified counterparts across various performance metrics such as product quality, customer satisfaction and operational efficiency. The correlation established between service provider certification and the quality of maintenance outcomes underlines the potential influence of certification in creating value (Benzaquen & Narro, 2023). This insight is crucial for decision makers when selecting service providers, as it suggests that certified providers are more likely to positively contribute to maintenance outcomes.

For statement 4.2, the observed 57% agreement rate indicates a significant correlation between the proximity of supplier relationships and the effectiveness of maintenance activities. A close association with suppliers demonstrates a favorable impact, while a distant relationship tends to have a more adverse effect. This finding aligns with Vanichchinchai's (2022) study, which established a positive correlation between ISO 9001 certification and improved relations, coordination, and collaboration within the supply chain. Similarly, Benzaquen and Narro (2023) highlighted that ISO 9001 certified companies tend to promote stronger relationships with their suppliers compared to non-certified counterparts, thus reinforcing the idea that ISO 9001 certification enhances value networks. The statistical significance values within departments (p=0.000) and occupations (p=0.004) further substantiate the critical role played by relational dynamics within the external supply chain network.

The observed agreement rate of 65.2% for statement 4.3 highlights the adverse influence of untimely delivery schedules from external service providers on the output of maintenance activities. The statistical significance values within departments (0.036) and occupations (0.001) further indicates that the impact of delivery schedules on maintenance activities is not only substantial but also manifests differentially across various organizational departments and occupational roles. This reaffirms the critical influence of external service providers' delivery timeliness on various aspects of organizational functioning (Dellana et al. 2020).

For statement 4.4, the majority of respondents agree (67.8%) on the negative impact supplier lead times have on maintenance activities. The statistically significant value (p=0.014) within occupations emphasizes the importance of minimizing lead times for optimal maintenance activities output. These findings align with Thevenin et al. (2022), who advocate for the development of robust organizational strategies aimed at addressing challenges arising from disruptions and uncertainties in supplier lead times.

For Statement 4.5, 49% of respondents acknowledged that external service providers often face challenges due to unclear specifications provided by the PGP. This highlights significant communication gaps between the expectations of service providers and the requirements set by the PGP. These findings align with Alghababsheh et al. (2023), who noted that while suppliers generally understand the reasons behind sudden changes in order volumes and specifications, such changes prompted by unforeseen events may still lead to disruptions in their operations. The proportion of respondents who expressed neutrality or disagreement with this statement may be attributed to factors such as varying interpretations of provided specifications, limitations in communication channels, or the absence of standardized guidelines.

5. Summary of main findings

Firstly, it was observed that the underutilization in tool usage across the maintenance department indicates a lack of standardized approaches to problem-solving and decision-making. Failure to leverage these tools effectively may hinder the department's ability to identify and address root causes of maintenance issues, potentially leading to increased downtime, resource inefficiency, and decreased equipment reliability. Secondly, the notable commitment among maintenance personnel at the PGP to achieve organizational objectives reflects a dedication to the QMP’s. However, opportunities for improvement were observed in recognizing and celebrating continuous improvement activities.

Thirdly, the study identified operational challenges related to workforce efficiency, workmanship quality, and ineffective streamlining of maintenance personnel functions. This observation is corroborated by Bashar et al. (2022) and Mostafa et al. (2015), who detail the similar fundamental types of waste present within the maintenance processes. Additionally, the management of maintenance spare parts inventory emerged as an area for improvement. Lastly, the findings revealed the adverse effects caused by untimely delivery schedules and prolonged lead times from external service providers, as well as the divergent perspectives that exist regarding the clarity of specifications communicated to them. These observations indicate communication gaps that need addressing to enhance maintenance outcomes.

6. Recommendations and Conclusion

6.1 QM Tools and Principles

To address the underutilization of quality tools, it is essential to promote an understanding of each tool's advantages and encourage a culture of continuous improvement, which can potentially enhance problem-solving abilities. Benzaquen and Narro (2023) assert that one of the key drivers for the superior performance of organizations holding ISO 9001 certification is attributed to the certification's role in promoting continuous improvement, which is generally achieved through the proper use of quality tools. However, despite the PGP's ISO 9001 certification, which should promote a competitive advantage in continuous improvement within maintenance operations through optimized tool utilization, this advantage is not fully realized. One viable strategy involves the incorporation of quality tools into maintenance procedures through the adoption of standardized methodologies and the provision of comprehensive training on their utilization. Chiarini and Cherrafi (2023) allude that quality tools can only be beneficial if proper training is provided to the workforce to ensure they understand the use of these tools. This approach holds promise for aligning practices and bolstering overall efficacy within maintenance operations. To enhance a working environment that readily acknowledges and celebrates continuous improvements, it is important to strengthen the communication channels within the organization. This would entail encouraging employees to actively participate in decision-making processes, and providing them with appropriate recognition, potentially accompanied by rewards for their contributions to improvement initiatives.

6.2 Factors Contributing to CM Backlog

To enhance workforce capacity, measures should be taken to optimize efficiency, such as conducting workload assessments, and engaging in strategic workforce planning to ensure effective personnel deployment for the respective processes (Zlatic, 2019). In terms of improving workmanship quality, it is imperative to ensure that employees are thoroughly trained for their respective roles and that follow-up assessments are conducted regularly to monitor adherence to work instructions and standard operating procedures. Sinha (2015) emphasizes the importance of thorough testing after repairs, including trial runs, to ensure they are completed as intended. Hadidi et al. (2023) further stress the importance of consistently assessing the likelihood and potential impact of human errors that may be linked to repairs and defects, and developing robust strategies for prevention and mitigation. By understanding the root causes and potential consequences of errors, the PGP can implement effective measures to minimize their occurrence and mitigate their adverse effects, thereby enhancing overall operational reliability and safety.

The concern regarding unnecessary movement of maintenance personnel within the PGP can be mitigated by implementing streamlined operational procedures, which involve strategic planning of maintenance activities, prioritizing critical equipment for repair, and conducting preventive maintenance inspections based on equipment criticality. Additionally, the management of spares and parts inventory can be improved by performing demand forecasting, maintaining an up to date inventory control system, and conducting frequent physical audits of inventory levels to ensure optimal stock levels. Sinha (2015) emphasizes the importance of proper planning of spare parts and manpower to balance costs associated with shortages and overcapacity. Therefore, planning spare parts inventory based on demand patterns, even if only approximate, can yield significant benefits compared to ad hoc approaches.

6.3 External Service Providers

To enhance maintenance activities and mitigate supply chain risks, the PGP plant should first prioritize engaging ISO 9001 certified service providers due to their demonstrated positive impact on maintenance processes (Benzaquen & Narro, 2023). This entails conducting thorough supplier assessments and mandating ISO 9001 certification in procurement contracts. Additionally, the PGP could reduce their dependence on a sole single supplier and decrease the risks associated with relying too heavily on one source by seeking out alternative ISO 9001 certified suppliers and regularly auditing them.

Moreover, the PGP should promote collaborative partnerships with their suppliers by maintaining regular communication channels, including meetings and reviews, to establish clear expectations, define performance metrics, and align on shared goals (Vanichchinchai, 2022; Fonseca et al., 2021). Strategies to address issues like delivery delays should possibly include transparent information exchange channels, such as real-time tracking systems and online portals. By integrating these practices into supplier management, the PGP can enhance maintenance outcomes and effectively mitigate supply chain risks.

6.4 Proposed Maintenance Operational Framework

Given the above considerations, it is recommended that the PGP to implement the proposed operational maintenance framework as depicted in Figure 3 to optimize maintenance performance.

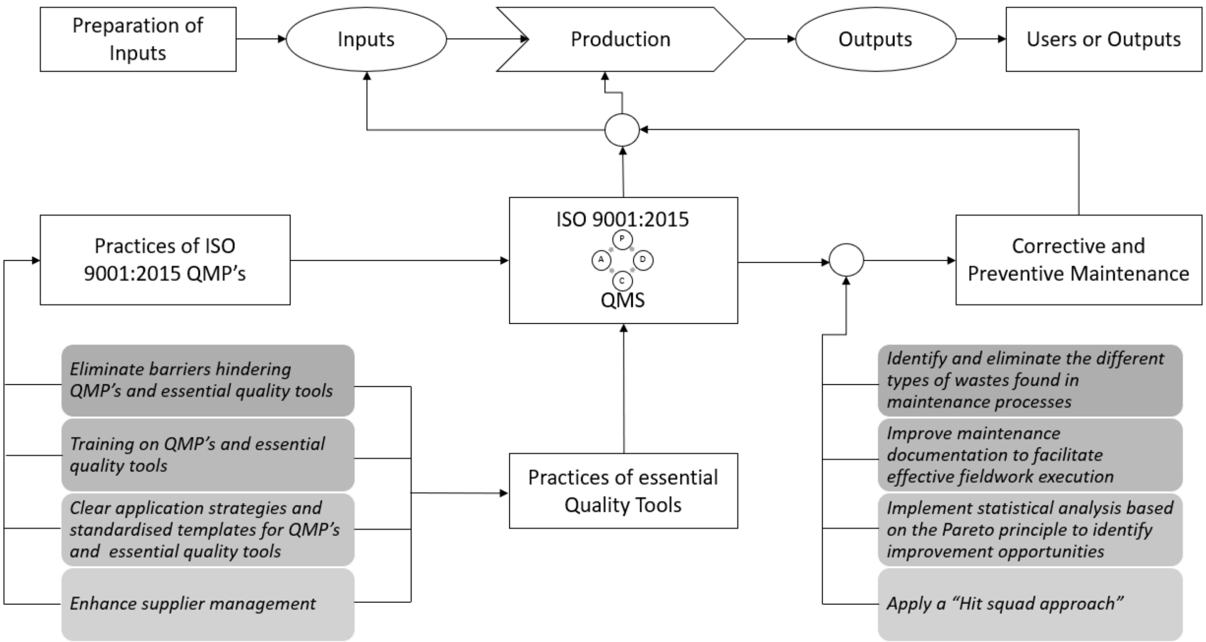


Figure 3 – Maintenance Operational Framework

Source: Figure created by the authors

As represented in Figure 3, the initial phase termed "preparation of inputs" entails the creation of process inputs. These inputs are then transformed during the production phase, resulting in outputs disseminated to end-users (ISO 9001:2015). The end-users encompass both internal and external stakeholders, including pertinent interested parties. Figure 3 underlines the importance of adhering to ISO 9001:2015 QMP's and the essential quality tools, which necessitates the establishment of a conducive operational environment. To promote such an environment, the following strategies are required:

- Eliminate barriers hindering the use of the QMP's and the quality tools.
- Provide comprehensive training to employees regarding QMP's and essential quality tools.
- Provide clear application strategies and standardised templates to implement the QMP's and quality tools
- Enhance supplier management by improving specification clarity through standardised formats, detailed technical documentation, and supplier training sessions, thereby enhancing communication effectiveness.

It is suggested that if the quality tools and quality principles are practiced effectively, the QMS will positively impact corrective and preventive maintenance processes. Furthermore, the following specific maintenance strategies are deemed imperative to influence corrective and preventive maintenance processes:

- Identify and eliminate the different types of wastes found in maintenance processes.
- Improve maintenance documentation to facilitate effective fieldwork execution.
- Implement statistical analysis based on the Pareto principle to identify improvement opportunities.
- Apply a "Hit squad approach" which means moving resources to where the main issues are and normalizing the situation. This approach will ensure that critical issues are addressed first, leading to a more efficient allocation of resources and a reduction in maintenance backlog over time. Moreover, this approach fosters a culture of teamwork and collaboration among maintenance personnel, thereby enhancing overall morale and productivity within the PGP.

In summary, the "Hit Squad" approach provides a proactive and systematic solution to address problem areas and drive continuous improvement in maintenance operations. Once the corrective and preventive maintenance activities are deemed adequate, production performance is expected to improve. Ultimately, the outputs of the PGP will meet the requirements of both internal and external customers. An essential aspect of maintenance interventions is their integration and interface with other internal and external systems, resulting in enhanced cooperation between maintenance and its stakeholders (Hajej et al., 2021; Farahani & Tohidi, 2021; Kurniati et al., 2015). The undertaken is that effective corrective and preventive maintenance processes will positively contribute to the PGP's performance.

6.5 Conclusion

The study highlighted the critical role of cohesive strategies in optimizing maintenance operations, both within the PGP studied and the broader industry context. Proactive measures such as standardized problem-solving approaches, forming strategic partnerships with ISO 9001 certified service providers and comprehensive training on quality tools were found crucial for enhancing maintenance effectiveness. Moreover the "Hit Squad" approach offers promising avenues for fostering collaborative teamwork and systematically resolving maintenance backlogs. Transforming the maintenance department into a data-driven, quality-focused organization requires technical expertise, leadership support, cultural alignment, and effective change management strategies. Industry stakeholders and managers must prioritize implementing cohesive approaches to drive continuous improvement and ensure long-term operational success in maintenance practices. These insights significantly contribute to enhancing maintenance efficacy within industrial settings, affecting both internal operations and supply chain partners, whether they are customers or suppliers.

7. Limitations and future study directions

The study's focus was limited to just one PGP out of a total of fifteen within the organization group, which might not fully represent the maintenance practices and challenges across all plants. Additionally, the study did not include interviews with the top management of the plant, missing out on important insights into strategic decision-making. Another limitation is that the study was conducted within a specific timeframe, and maintenance practices may have evolved or been influenced by external factors before or after the study period, potentially affecting the validity and relevance of the findings over time.

Future research could include multiple case studies across various industries to provide a more comprehensive understanding of maintenance practices and challenges. In addition, conducting comparisons between organizations with and without ISO 9001 certification could help us understand how certification affects maintenance effectiveness, resource use, and operational performance. It could further be interesting to find out how the “Hit Squad” approach can be unfolded to prove a positive impact on the performance of the PGP.

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