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THE INFLUENCE OF DIGITALISED MAINTENANCE DATA ON OPTIMISING PREDICTIVE MAINTENANCE IN THE SOUTH AFRICAN PETROCHEMICAL INDUSTRY

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ABSTRACT

This study investigates the impact of digitalising maintenance data on the optimisation of predictive maintenance practices within the South African petrochemical industry. A conceptual model framework was developed through a systematic literature review. The framework explored the relationship between current maintenance practices, centred around Computerised Maintenance Management Systems (CMMS), and the projected benefits of digitalised predictive maintenance. A questionnaire was administered to maintenance and operations personnel to determine the status of maintenance data usage, perceptions of digitalisation benefits and organisational readiness indicators within the South African petrochemical industry. Findings indicate that while maintenance data are already utilised for operational decisions, much of it is manually collected and input into CMMS platforms. There is a clear opportunity for digital transformation, even though the supporting infrastructure remains partially developed. The results affirm that digitalising maintenance data can significantly improve predictive maintenance capabilities and decision-making effectiveness. Recommendations highlight the need for further research into how maintenance personnel, especially those from older or less technologically exposed cohorts, can be supported in embracing digital tools. The study's managerial implications underscore the necessity for leadership to address human-centric challenges when deploying data-driven maintenance strategies and to foster a culture that enables digital transformation in maintenance environments.

Keywords: predictive maintenance, CMMS, maintenance data digitalisation, maintenance optimisation, petrochemical

INTRODUCTION

Maintenance has been the driving force in organisations because when done well, the organisation can operate stably, reliably and profitably and much downtime will be avoided. The digitalisation of maintenance in oil and gas facilities is becoming a new theatre of operations as effective solutions can be employed to convert data into usable knowledge and information for the improvement of maintenance operations [1]. Maintenance strategies are executed through the CMMS, although in some cases different applications will be integrated to develop the maintenance strategies. Compare et al. [2] outline that predictive maintenance is one of the improvement opportunities brought along by Industry 4.0; this maintenance uses condition monitoring data to detect

anomalies in production processes, manufacturing equipment and products, as well as diagnosis and prognosis.

The petrochemical industry in South Africa that the research will be focusing on is a long-standing petrochemical organisation. The organisation's size is magnificent and has all the different disciplines in the maintenance field. It is a maintenance-intensive organisation with ageing assets that depend on good maintenance to ensure the safety, stability, and reliability of the operations, as it accounts for most of the fuel and chemical supplies in Africa and in the years expanded in other European and American countries. The research will only be focused on this organisation.

The technology era is upon us, and the influence of the 4th Industrial Revolution is apparent in all industries. It is important to leverage all accessible resources to maximise the return on investment. Bokrantz et al. [3] argue that maintenance organisations are key in fulfilling the expectations of extraordinarily complex and automated equipment to deliver high performance. Their emphasis is that with manufacturing industries digitalising their processes and operations, maintenance organisations must also follow suit by looking into engineering tools and methods to support the equipment to achieve high performance with minimum losses due to equipment breakdowns and failures [4].

The implementation of digital maintenance has dramatically enhanced the development, refinement and utilisation of new tools and technologies, making them more efficient by leveraging copious amounts of historical and real-time data with analytical capabilities. This has become the foundation of modern maintenance services [5]. The introduction of digitalisation of maintenance data to an existing CMMS and condition-based maintenance will influence as it will enable machine learning. It has the ability to extract hidden patterns, discover dependencies, and predict future events; furthermore, it can be used to create predictive models that make it possible to predict failures and the necessary maintenance [6]. This can be achieved through the analysis of historic maintenance data.

This research study reconnoitres the influence that maintenance data digitalisation will have on the optimisation of predictive maintenance in a petrochemical organisation in South Africa. This petrochemical organisation is also one of the biggest energy companies in South Africa and it was constructed in the early years of industrialisation in South Africa.

The existing literature on the digitalisation of maintenance data and its influence indicates that there is work being done in the manufacturing organisation to move in the direction of digitalisation. However, there is not enough literature that focuses on how predictive maintenance will be influenced by maintenance data digitalisation. There is an indication that other industries, such as petrochemicals, are still lagging in following the digitalisation trend for the optimisation of operations and maintenance. This gave rise to the objectives of this research study to focus on the influence that the digitalisation of maintenance data will have on the optimisation of predictive maintenance. It is pivotal to evaluate the value that digitalisation of maintenance data can bring, determine the readiness and status of maintenance data, and determine the integrity of the decisions made when applying maintenance data for maintenance and repairs in the petrochemical industry in South Africa. The following research questions were answered through this research study.

- RQ1: How will digitalising maintenance data improve predictive maintenance planning and scheduling?

- RQ2: To what extent is the South African petrochemical industry ready to adopt the digitalisation of maintenance data?

Therefore, this paper focuses on a leading South African petrochemical organisation and examines how the digitalisation of maintenance data can optimise predictive maintenance strategies through improved CMMS performance. While much of the current literature concentrates on digitalisation within manufacturing, there is a marked gap in research specific to the petrochemical sector, especially regarding the integration of CMMS and predictive analytics. The study's novelty lies in its empirical exploration of maintenance data readiness, the influence of digitalisation on predictive capabilities, and the validation of a conceptual model tailored to the petrochemical industry's operational realities. This work contributes new insights into digital maintenance transformation in complex, asset-intensive environments.

LITERATURE REVIEW

Maintenance in the Petrochemical Industry

Hassani et al. [7] defined petrochemicals as chemicals formed from natural gas, natural gas liquids, or refinery products originating from crude oil distillation, or cracking. The petrochemical industry is a huge industry involving upstream, midstream, and downstream sections. They subsequently consider new ways of cutting operating costs, enhancing production efficiency, and increasing throughput with the advancement of technology [8]. Reliability of equipment is regarded as a critical aspect in the oil and gas industry and the petrochemical industry; failures of such equipment can lead to catastrophic outcomes that can affect the organisation on different levels. In addition, in the petrochemical industry, the criticality of maintenance considers the consequences of failure on safety, cost and the environment [9].

Bevilacqua and Braglia [10] found that in many organisations, maintenance is regarded as an inevitable source of cost; they end up performing maintenance operations as a corrective function when incidents of failures have already occurred. Furthermore, this form of intervention is no longer acceptable these days because of certain elements such as production quality, plant safety, and the increase of maintenance department costs, which amount to about 15 to 70% of the total production costs [10].

It is difficult to choose the best mix of maintenance policies when basing this choice on preventative maintenance elements during the design phase, as this was found to be due to the lack of operational historical data on the equipment [10]. This finding highlights the importance of maintenance data of assets in support of the reliability of the assets, as argued by Bevilacqua and Braglia [10], underlining the importance of the total knowledge of the reliability aspect of the plant machines by indicating the impossibility of deciding on what type of maintenance to adopt during this phase. Bevilacqua and Braglia [10] further argue that the assignment of maintenance at this stage must be postponed until the data from the operating production system is available. This elevates the importance of data in maintenance as supported by Qingfeng et al. [11], who established that the objectivity, authenticity, and accuracy of data determine how effective the decision-making indicators are.

Petrochemical and other process industries are in the process of trying to implement risk-based maintenance programmes to improve the reliability, availability, maintainability and safety (RAMS) of the plants. RAMS is one of the risk evaluation models that is

applied in the maintenance and system integrity (MSI) [11]. Qingfeng et al. [11] trust that the success of this application is heavily reliant on the accuracy of the probabilistic models that are used and the reliability of the data. This further highlights the importance of data in maintenance.

Pre-literature review and article selection

A systematic literature review following the PRISMA method was used in identifying the relevant academic literature as shown in Table 1. The keywords included maintenance, digitalisation, data, optimisation, predictive maintenance, and maintenance management.

Table 1. *PRISMA diagram of scoping review articles*

Scopus		
Key words	**Searh string and Exclusions**	**Article tittle search**
Maintenance Digitalization	Maintenance AND Digitali*ation AND data AND Predictive OR Management OR System OR Optimi*ation	4856 (Article tittle search)
		Article tittle, Abstract, Keywords search
Digitalisation	Maintenance AND Digitali*ation AND data AND Predictive OR Management OR System OR Optimi*ation	552
Data Predictive Management Management System		
Years	2000-2023	542
Language	English	512
Subject Area Limited to	Engineering Computer Science Energy Dicision Science	442
Document type limited to	Conference paper Articles Book chapter Conference review Review	439
Access	Open Access	137
Selected	Relevant Abstract and key words	17

The objective of the review was to identify well-documented literature that seeks to address the questions asked about the digitalisation of maintenance and the impact it has on maintenance organisations. The processes that are taken in data digitalisation, maintenance improvement and optimisation, and how to ready equipment for data exchange and communication, were identified and examined through the literature to establish the context for evaluating their role in predictive maintenance enhancement. The main target was to understand the influence that the adoption of digitalised maintenance data will have on the present CMMS and how it will improve predictive maintenance.

The literature that has been selected will serve as the cornerstone for examining the influence of digitalized data on the petrochemical industry. The articles were carefully chosen for their pertinence to the digitalisation of maintenance in the petrochemical sector, as well as predictive maintenance optimization.

The analysis of relevant literature has brought to light a notable void in the digitalisation of maintenance data within the petrochemical industry. While there is existing research on digitalisation in various sectors, such as manufacturing, there is a significant lack of focus on the petrochemical industry. The literature highlights the criticality of optimising

planning and scheduling and closely monitoring the conditions of equipment. Despite the use of CMMS in petrochemical maintenance, it is imperative to investigate the effects of digitalising maintenance data on the overall execution of maintenance processes.

Maintenance Data

Labib [12] referred to maintenance as the management, control, execution, and quality of those actions which will guarantee that optimum levels of availability and overall performance of the plant are attained, to meet business objectives.

"Maintenance concept can be defined as the set of various maintenance interventions (corrective, predictive, condition-based, etc.) and the general structure in which these are foreseen" [13]. In this context, it is the data that relates to the maintenance of assets that is collected through a CMMS and other data collected through sensors from the asset for maintenance.

Many organizations across industries are embracing digital technology, transforming key business operations to exploit the benefits [14]. Digital maintenance is regarded by Saihi et al. [15] as a subset of Industry 4,0 that is based on the emphasis on the efficiency, intelligence, and automation that is introduced to maintenance through automated data collection, visualisation, analysis, and decision-making. This is supported by Kans [16] who denotes that IoT enables the collection of large amounts of data, which is usually referred to as big data, that can help with the possibilities of reducing wastage and losses with the combination of sensors.

Maintenance Management and Data Digitalisation

To remain competitive, organisations must stay current with the latest industry trends and adopt Industry 4.0 and its associated technologies, such as the Internet of Things and Big Data. Predictive maintenance strategies are becoming more popular because they potentially transform maintenance practices. With predictive maintenance, equipment can be scheduled for maintenance before it breaks down, resulting in better planning and scheduling, reducing the risk of unforeseen downtime, and keeping equipment running efficiently [17]. Condition-based maintenance is increasingly popular to improve overall equipment efficiency by reducing unplanned downtime through better planning and scheduling.

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Carnero [18] suggested that a CMMS in an industrial plant is necessary for implementing a predictive maintenance program. While having a CMMS can enhance the organisational aspects of a predictive maintenance program through training and programming, it is not strictly required for developing the program's technical specifications [18]. However, having a CMMS does not guarantee the success of a predictive maintenance program. Although the suggested evaluation methods in the study do not guarantee predictive maintenance success, they increase the probability that there might be success [18].

Studying the value added that is brought about by the usage of data might help answer some of the questions about the relationship between predictive maintenance optimisation and CMMS utilisation improvement when looking into data digitisation. In the existence of CMMS in an organisation, there can be an assumption that there is historical data from machines [18]. In industries such as petrochemicals, data integrity can be questionable. This study examines the quality and influences of historical maintenance data.

Extensive literature was studied by Grooss [19] in the area of interoperability of IT infrastructure, accumulating and exploring data, and prototypes using existing resources. This was to establish the possibilities of companies optimising their resources for the digitalisation of maintenance data. The outcomes of this study indicated the possibility of leveraging the current resources for maintenance digitalisation and the value that this will add to companies. What still needs to be investigated further, according to their findings, is the research on the role of organisational factors in the digitalisation of maintenance processes.

Jasiulewicz-Kaczmarek et al. [20] gave attention to the development and potential opportunities to explore data-driven maintenance technology ideas for sustainable production. The study identifies manufacturing organisations to be faced with two major changes that are affecting their business: digitalisation and sustainability. Industry 4.0 in this literature is defined by Jasiulewicz-Kaczmarek et al. [20] as collectively describing changes in the technological scope and organisation of the value chain whereby two main aspects are highlighted in the digital transformations space, the technological aspect and the business aspect.

Computerised Maintenance Management System (CMMS)

Noor et al. [21] defined CMMS as a software package that stores information databases regarding maintenance operations, evolving in the 1960s as the era of computational and mathematical systems commenced; furthermore, its evolution has continued to evolve with the ready availability of technology and its necessities. Relative to maintenance management, CMMS is utilised as a repository of information or data related to maintenance concepts such as asset base, spare parts, personnel information and planning methods [21]. Maintenance schedules can be transformed from a painstaking manual task into a strategic advantage by the implementation of machine learning algorithms and maintenance data [22].

CMMS is recognised as being vital for the coordination of all activities that relate to the availability, productivity and maintainability of complex systems by Labib [12]. The capabilities of CMMS in handling substantial quantities of data purposefully and rapidly have opened new opportunities for maintenance and provided a more deliberate and considerate approach to managing assets [12]. Furthermore, CMMS has benefits in resource control, cost management, scheduling, integration and reduction of breakdowns, as the most important benefit, as this is the main objective of maintenance [12].

CMMS is a prerequisite to achieving the next generation that is expected to have more user-friendly operations with the latest technology and maintenance solutions that are led by industrial digital transformation; this is based on the fact that CMMS is seen as a system that is based on information gathering and operating relationships [21]. Therefore, it is pivotal to understand the requirements and functions for CMMS preparation in the adoption of new technology and how it is going to be impacted [21]. The chronological order of transformation of CMMS is well indicated by Noor et al. [21].

CONCEPTUAL MODEL

To create the conceptual framework, we formulated a proposition regarding the impact of the digitalisation of maintenance data on the CMMS and predictive maintenance. We focused on the key performance indicators associated with efficient CMMS and predictive maintenance. The measure of the influence of digitalisation of maintenance data on CMMS and optimisation of predictive maintenance can be assessed by indicators that indicate efficient maintenance management and optimised predictive maintenance. The development of the conceptual model was designed based on the research study propositions outlined as the following.

- Adopting digital maintenance is beneficial when it reduces the dependency of CMMS on manual data through the digitalisation of maintenance data.
- Maintenance decision-making based on process parameters and equipment performance for predictive maintenance is fundamental for optimising predictive maintenance.
- Eliminating the human factor in processing and acquiring maintenance data will improve maintenance management efficiency.
- Digitalisation of maintenance data using the latest technologies is beneficial for the petrochemical industry in South Africa.

The conceptual model presents the research problem through variables of interest. Arkansas [23] has defined a variable as any condition that can change or vary in quantity or quality. Additionally, an independent variable is what the experimenter controls, while the dependent variable is the behaviour potentially affected by the treatment and measured.

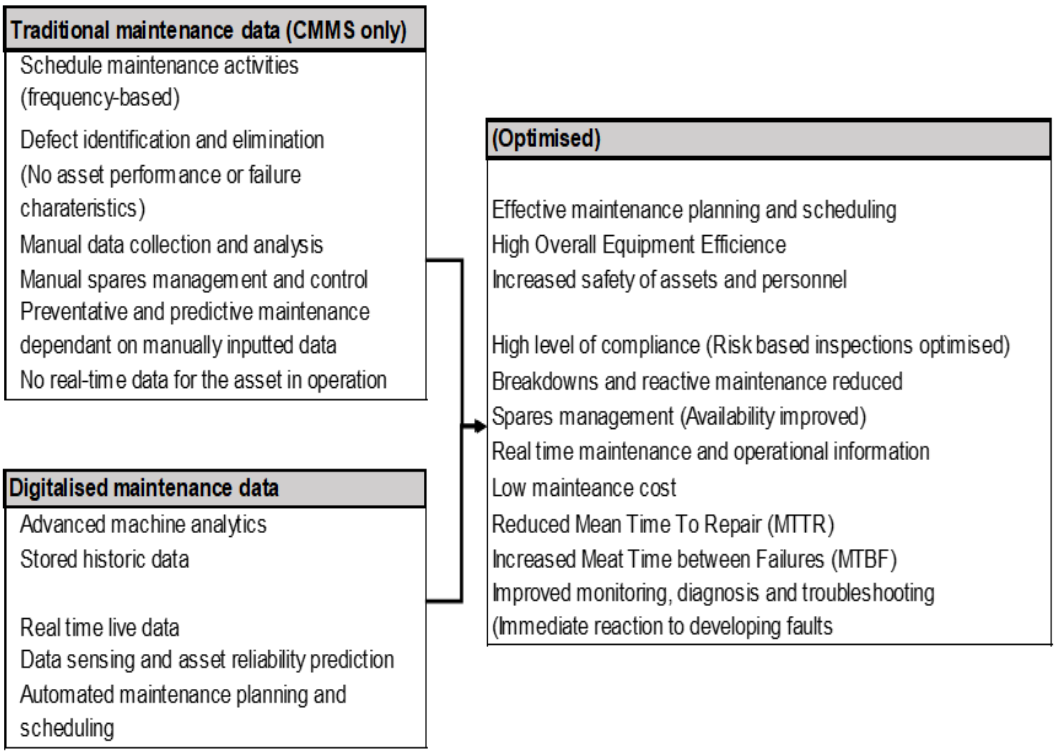

Figure 1. *Conceptual model of the study.*

METHODOLOGY

The previous chapter developed a conceptual model to examine the relationships between variables. The aim was to evaluate the proposed proposition. In this chapter, the research design and methodology that was used to investigate the proposition and framework are presented. Additionally, the process of data collection and analysis is explained in detail.

Research Paradigm

A research paradigm is defined as a philosophical way of thinking that shows the perspective of the researcher and informs the meaning or interpretation of research data [24]. Research paradigms can be outlined into three major paradigms, namely positivism, interpretivism and critical theory, supported by the four components of research, namely ontology, epistemology, methodology and methods [25].

Positivism relies on neutral and measurable observation to reveal knowledge, whereby a proposition is put forward in propositional or question form of a theory that explains the effect of the independent variable on the dependent variable [25]. The required data can be collected through closed-ended questionnaires, and the numerical data can be analysed statistically.

Interpretivism is a research approach that assumes reality to be subjective, socially constructed, and multifaceted. Unlike the deductive approach, interpretivism uses an inductive approach where theory emerges from data collection rather than being the driving force behind research [25]. In applying interpretivism, qualitative data can be collected through questionnaires with open-ended questions and observations.

Critical theory, which seeks to uncover and challenge power dynamics and socio-organisational constraints, is also relevant in the context of this research. Although the study primarily adopts a positivist paradigm to evaluate the relationship between digitalised maintenance data and predictive maintenance optimisation, it acknowledges that the adoption of digital technologies in maintenance environments is shaped by human and cultural factors. Digital transformation can influence the distribution of decision-making power, redefine job roles, and alter how maintenance personnel interact with technology. Recognising these underlying social implications provides a more holistic understanding of digitalisation, not merely as a technical advancement, but as an organisational and cultural shift requiring critical reflection and management intervention.

Research Design and Approach

This research aimed to understand the influence of the digitalisation of maintenance data on CMMS and the optimisation of predictive maintenance in a petrochemical organisation in South Africa. This can be realised with the improvement in the overall effectiveness of maintenance, considering the overall maintenance health in this industry and looking at how predictive maintenance can be leveraged to improve its efficiency in reducing reactive maintenance and improving equipment availability and reliability.

The research questions are answered through the analysis of the collected data and by referring to the conceptual framework. It provides an understanding of the current state of CMMS and its effectiveness in the petrochemical industry in South Africa, focused on a particular organisation and what influence the digitalisation of maintenance data can have, considering the benefits of maintenance data digitalisation and its value-added on predictive maintenance (PdM).

A qualitative approach is given more importance since no data was available to compare a fully implemented digitisation of maintenance data with the quantitative data. The lack of fully implemented digitalised maintenance data to compare to hindered the ability to assess the influence of digitalised maintenance data on the optimisation of current CMMS and predict maintenance accurately, resulting in less dominant quantitative data.

Research Sampling

The population included maintenance engineers, technicians, managers, and any other stakeholders who played a role in the maintenance of the petrochemical industry in South Africa. Only by involving and engaging with these individuals did the research truly capture the nuances and complexities of maintenance data and maintenance execution in the petrochemical industry and provide meaningful insights and recommendations for improvement.

The research was aimed solely at investigating the influence of digitalised maintenance data on optimising PdM in the South African petrochemical industry. In this petrochemical organisation, business units have adopted and followed similar maintenance approaches whereby the same CMMS is used, and maintenance procedures are implemented uniformly throughout the organisation.

Data Collection

Questionnaires were distributed to a specific population sample and were checked continuously until the minimum required number of samples was attained for analysis. To better understand the influence of maintenance data digitalisation on the optimisation of predictive maintenance and to evaluate the overall effectiveness that this will bring, it was essential to consider the perspectives and experiences of those who participate in maintenance. This was achieved by asking questions to identify the gaps in maintenance data digitalisation and how they can be addressed.

The questions had been designed to be comprehensive and cover all relevant sections related to the proposition and the research question. These questions focused on essential terms such as digitalisation of maintenance data, CMMS, PdM, and the petrochemical industry in South Africa. They also included critical maintenance-related terms such as measurement, review, optimisation, and continuous improvement. The questionnaire data collection method is prevalent and has successfully evaluated the concepts in the existing literature.

RESULTS

The interpretation of data was made using descriptive statistics, and results were deduced from the analysis of the collected data. Data was collected from different departments in the maintenance and operations of the selected organisation. Most of the responses came from people with over five years of experience, with a contribution of over 90%. The answers given can be regarded as responses from people with knowledge and experience in the maintenance and operations field in the petrochemical industry, considering the exposure they have had through the years to maintenance improvement.

Plant technical support contributed more than all other departments in the study. In the petrochemical industry in South Africa, plant technical support is required in the development and implementation of maintenance policies, strategies, and approaches. The other departments are the executors of the initiatives from the plant technical support.

Reliability engineering is involved in optimising, measuring, and managing the performance of maintenance execution and improvement.

Assessment of the traditional maintenance data status was indicated by illustrating where maintenance data is used in the maintenance and operations. There is an indication that between 50 and 100% of maintenance is based on frequency or interval rather than on failure history or equipment failure characteristics in the petrochemical industry in South Africa.

Defect identification in the petrochemical industry in South Africa can be identified through maintenance data collected from the equipment. The time to failure can be increased only if it is noted that the failure does not happen randomly but as a consequence of deterioration occurring as the equipment ages; monitoring this deterioration properly can predict the health or condition of the equipment and be used to predict its failure period, thereby scheduling maintenance before a complete failure [26].

A mean of 50.71% from the collected data agreed that spares are kept based on the equipment performance and failure characteristics. This indicates that most of the decisions made for spares management are based on equipment performance. Monitoring equipment performance with maintenance data digitalisation will increase this number as more reliance on data increases. McKinsey [27] alluded to the impact of inventory on capital and presented findings indicating that leveraging Industry 4.0 and using real-time data for supply chain optimisation can reduce costs for inventory by 20 to 50%.

With a mean of 54,08%, it is believed that more time is spent analysing data manually to identify equipment integrity issues. This is a high percentage of time spent on analysing data. This indicates that manual interventions consume most of the time for the people involved in identifying equipment integrity issues due to the lack of digitalised maintenance data and analysis. Labib [12] argues that most existing software for CMMS and enterprise resource planning is usually greedy for data input but seldom provides any output in terms of decision-making support. Hence, there is a high percentage of manual data analysis.

Preventing failures or identifying them before they occur is indicated to be the case in the petrochemical industry under study, as a mean of 44.15% indicates that failure identification before the actual failure and prevention using the work order feedback is low. This indicates the importance of maintenance data applications to prevent failures before they occur using the actual digitalised maintenance data. Kareem and Jewo [26] determining expected failure periods can ensure that maintenance activities are planned proactively, thus facilitating the effective organisation of required resources, tools and equipment.

The data indicates a mean of 50.29% for the critical equipment, indicating their essential online operating parameters. It shows that operating parameters in this petrochemical industry in South Africa are key to operations and it will not be eccentric to apply critical operating parameters in improving maintenance.

All the results indicate that in the petrochemical industry in South Africa, even though digitalised maintenance data is not the primary driver of maintenance and decision-making, there is headway in utilising data for equipment maintenance and operations. High percentages of data usage were reported in this section. An aggregated percentage of approximately 56% of traditional maintenance data usage is reported for various applications.

It can be observed that 99% of the respondents indicated that using advanced machine analytics will improve maintenance efficiency. An overwhelming (100%) response was given to agreeing that digitising maintenance data enhances the quality of maintenance historical data. It is believed that the efficiency of equipment maintenance and operation is high, with 100% of the respondents agreeing. 99% of the respondents responded that using data sensing for digital maintenance data in failure prediction is beneficial. With the automation of maintenance planning and scheduling enabled through digitalisation, 94% of the respondents responded positively to the idea of improving equipment reliability. Only 78% of the respondents believe that the analysis of condition monitoring results in real-time, without any human intervention, will increase the value already added by predictive maintenance.

An aggregate percentage of approximately 95% responded that digitalisation of maintenance will add value to different spheres of maintenance and operations. This indicates an overwhelming belief in the benefits of digitalisation for maintenance data.

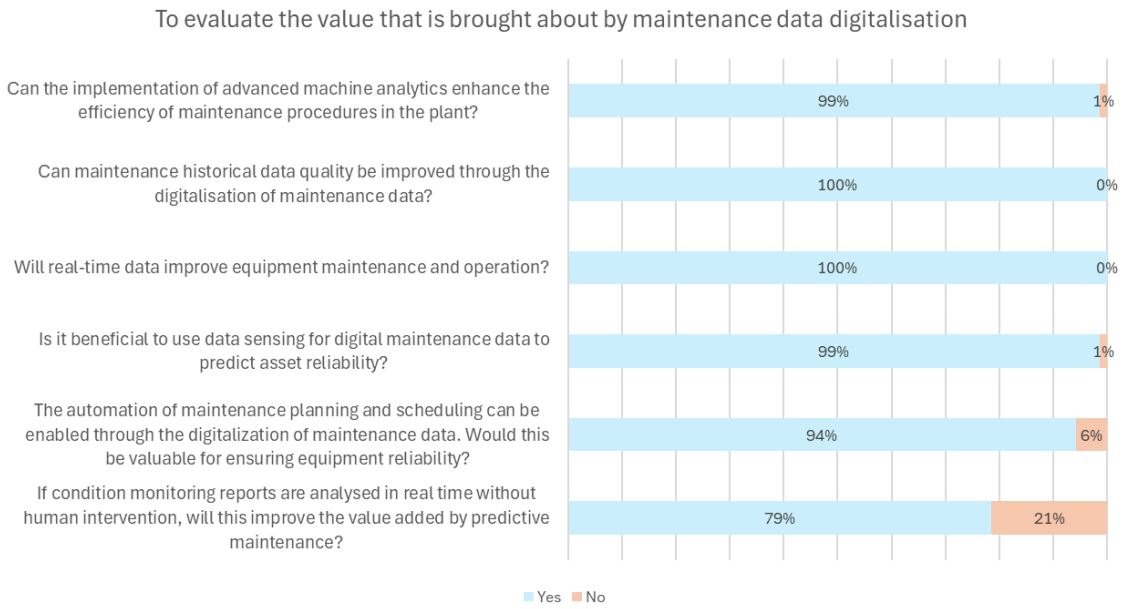

Figure 2. *Maintenance data digitalisation value-adding evaluation*

With the study based on assessing the impact of maintenance data on the current CMMS and the impact on predictive maintenance, it was key to get perspectives from the people who are involved in maintenance in the petrochemical industry in South Africa in the assessment of the readiness. More than half of the respondents (69%) indicated that the organisation has expertise in analysing and applying digitalised maintenance data. This is key in deciding on new projects to start innovative technologies. The literature in this study indicated that one of the levers of success in obtaining new technologies is the organisation's ability to acquire the required expertise. Labib [12] expressed that there is a need to design training and education programmes to address the considerable gaps between the skills that are essential to maximise the potential benefits that advanced technologies bring in the maintenance and asset management areas.

The digitalisation of maintenance data benefits proposition results using a Likert scale and descriptive statistical data analysis about the conceptual model as seen in Table 2.

The respondents indicated with a percentage of 90% that they agreed with what the research study's proposition suggested.

Table 2. *The digitalisation of maintenance data benefits evaluation.*

	Strongly Disagree	Strongly Disagree	Neutral	Agree	Strongly agree
Automated scheduling and planning with digitalised maintenance data can be highly effective.	1%	7%	8%	54%	30%
Improving overall equipment efficiency is possible through the application of digitalised maintenance data for predicting and preventing failures.	1%	0%	6%	61%	32%
Digitalizing maintenance data will enhance equipment failure identification and reporting, thereby improving the safety of personnel and assets.	1%	1%	3%	55%	39%
Effective predictive maintenance can improve compliance with the support of digitalised maintenance data for risk-based inspections.	1%	1%	7%	52%	38%
Effective predictive maintenance is based on actual equipment performance and failure characteristics obtained from digitised maintenance data, which can reduce breakdown and reactive maintenance.	1%	0%	10%	51%	38%
By predicting potential failures, maintenance can be scheduled more efficiently, leading to increased mean time between failures and reduced mean time to repair.	0%	1%	7%	42%	49%
Digitalisation of maintenance data enables better monitoring, diagnosis, and troubleshooting for immediate fault detection and resolution.	0%	3%	4%	45%	48%

A Cronbach's alpha test was conducted to assess internal consistency. The results showed a Cronbach's alpha of 0.872, indicating acceptable reliability. From Figure 3 it can be deduced that the infrastructure that can support digitalised maintenance data is perceived to be low by the respondents (37%) in the organisation. This infrastructure is necessary for data collection with sensors and other required tools. Most of the respondents (70%) indicated that digitalised maintenance data is currently being used for decision-making. There is a split in trust in the current infrastructure's capabilities to support the installation of IoT sensors and other advanced solutions for collecting data from the existing database.

Overall, their responses indicated that work still needs to be done to get the organisation ready for the digitalisation of maintenance data. McKinsey [27] reported that only 48% of manufacturing felt prepared for Industry 4.0, and this can be seen in regional differences. They furthermore cited that the biggest obstacles to implementation are process control and knowledge for employees, data security and safeguarding systems, uniform standards for data transfer and end-to-end connectivity via wireless networks.

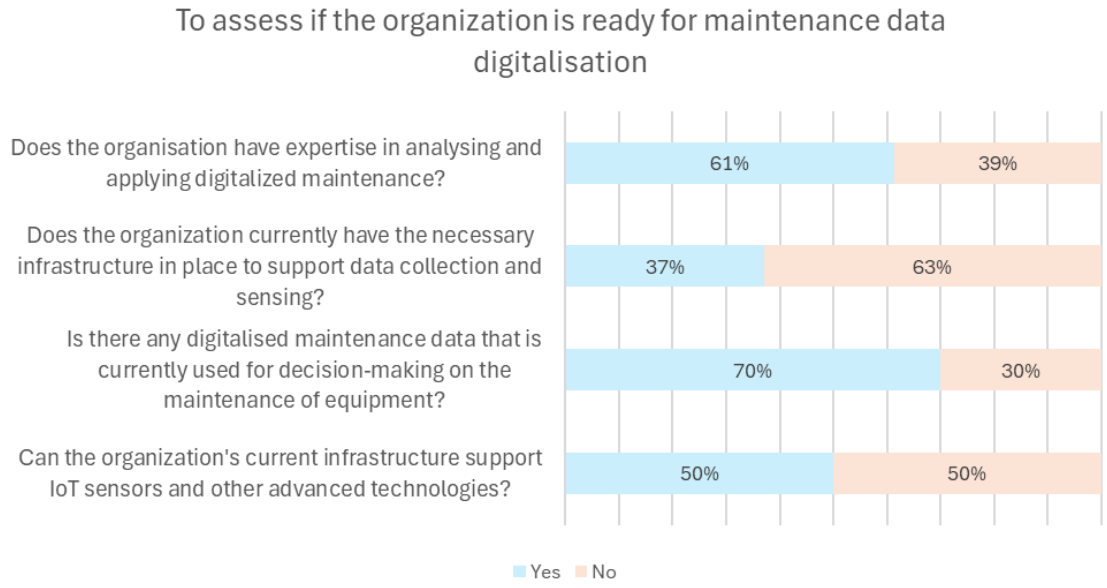

Figure 3. *Organisation readiness assessment.*

FINDINGS AND DISCUSSION

RQ1: How will digitalising maintenance data improve predictive maintenance planning and scheduling

The process of digitalising maintenance data provides a transformative shift in how predictive maintenance is planned, scheduled, and executed. By replacing manual data handling with automated collection and analysis, maintenance personnel gain access to accurate and timely information that supports more informed decision-making. Real-time monitoring through sensors and IoT-enabled systems allows early detection of equipment deterioration, enabling maintenance tasks to be scheduled before failures occur. This enhances resource utilisation, reduces downtime, and aligns maintenance interventions with actual equipment conditions rather than predetermined intervals. The study's findings confirmed that the majority of respondents recognised the efficiency gains derived from automated planning and scheduling made possible through digitalisation. Consequently, predictive maintenance evolves from a reactive or time-based activity into a proactive, data-driven process that strengthens operational reliability, improves safety, and supports sustainable maintenance management within the petrochemical industry.

RQ2: To what extent is the petrochemical industry ready to adopt the digitalisation of maintenance data?

The questions asked during data collection focused on checking the expertise in the analysis and application of digitalised maintenance, and 61% indicated a positive response in this regard. 63% of the petrochemical industry in South Africa believes that the necessary infrastructure for the collection of maintenance data is not in place. However, there is an indication that 70% responded to using digitalised maintenance data for decision-making. Further research is required to ascertain the data used for decision-making. There is a split between agreeing that the current infrastructure can support IoT sensors and other advanced technologies, which was responded to at 50%.

In summary, the petrochemical industry in South Africa is not ready for the digitalisation of maintenance data. Although there is an indication of an understanding of what maintenance data digitalisation is and where it can be used. This is well summarised by Hajizadeh [28] when citing that the petrochemical industry has abundant raw data, expert knowledge, sensor recording data every second, and access to cloud-based systems, albeit having large amounts of data, the petrochemical industry still experiences slow adoption and implementation of new developments.

CONCLUSIONS

The research recommends leveraging digitalisation in maintenance data within South Africa's petrochemical industry, building on the study's conceptual model and framework alignment. This shift can improve maintenance scheduling by focusing on actual equipment performance rather than set intervals. By digitalising maintenance data, data integrity can be enhanced through minimising human intervention, enabling a more data-driven approach to identifying and eliminating equipment defects.

Currently, maintenance scheduling relies on frequency-based data stored in the CMMS, often missing equipment-specific performance insights. Integrating real-time data from sensors would allow a proactive approach to predictive and preventive maintenance. By identifying key parameters for critical equipment and deploying sensors, real-time data can be used to optimise maintenance frequency, reducing reactive measures and improving scheduling.

As the industry holds extensive knowledge among maintenance personnel, upskilling in digital tools and data applications is recommended. This training would align with Industry 4.0 developments and the IoT, fostering a more interconnected and comprehensive approach to digitalisation. Such skills would ensure digitalisation efforts extend beyond isolated tasks, integrating fully into maintenance processes.

While the petrochemical sector shows some readiness, digitalisation adoption has been slower compared to industries like manufacturing. Harnessing digitalised maintenance data for predictive maintenance and CMMS could significantly improve asset reliability and maintenance decision-making, yet a comprehensive approach to big data and analytics remains an untapped opportunity for further optimisation.

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