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Impact of digital assistance and team collaboration on maintenance management efficiency: Basis for performance improvement on petrochemical industry

Vamanan, Tensimon ✉
Graduate School, Lyceum of the Philippines University - Batangas, Philippines (tensimonstudy@gmail.com)

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Abstract

With the emergence of industry 4.0 and the digital revolution, the petrochemical industry has been given opportunities to improve in maintenance management. Petrochemicals are a vital component of today's economy, with a significant role in the manufacturing of various goods such as plastics and chemical products, fertilizers, pharmaceuticals, and fuels. The integration of sophisticated digital assistance and the improvements of team collaboration will undoubtedly help the petrochemical industry to benefit from the current sweeping wave of digital transformation across different industries. This study evaluated the digital assistance, team collaboration, and maintenance management efficiency in the petrochemical industry. Additionally, it provided a comprehensive framework for performance improvement in these areas. The majority of participation consisted of 400 personnel from petrochemical industries. This study used descriptive research methodology and utilized a questionnaire as the primary tool in data collection. By using the analytical program SPSS and conducting empirical research using weighted means, it further established the correlation between digital assistance, team collaboration, and maintenance management efficiency. The results of the study revealed that asset and equipment management, digital documentation and knowledge management and data analytics and reporting are closely related to digital assistance. Using good digital assistance platforms will make it easier for employees in petrochemical industry to have more accurate maintenance performance and operations. In terms of team collaboration, there are significant relationships among collaborative decision making, communication channels and diversity in teams. That is to say, all of these indicators are complementary. The better the communication channels and diversity in teams, the more effective the team collaboration, which can also enhance the collaborative decision making. Based on the maintenance management efficiency, planning and scheduling, materials management and cost control has a profound impact on maintenance management efficiency. It also showed that the better the planning and scheduling, materials management and cost control is, the better the efficiency performance will be. A framework for performance improvement was suggested and grounded on the subsequent statistical findings. Digital

assistance has a positive impact on maintenance management efficiency and on the dimensions of team collaboration. The dimensions of team collaboration have a positive impact on maintenance management efficiency.

Keywords: digital assistance, team collaboration, maintenance management efficiency

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1. Introduction

Petrochemical industry is one of the most significant economic activities in the world, supporting the manufacturing of a variety of crucial products such as rubber, chemicals, fuels, and oils. It is poised for significant global expansion, fueled by the increasing demand for plastics in emerging economies (Johnson, 2018). The petrochemical plant operations are about high efficiency and reliability necessary to prevent not only the industry inefficiencies but economic losses in the whole country due to uncertainties that they may cause. Maintenance management, therefore, is a very critical aspect that contributes to the smooth running of petrochemical facilities because it ensures that machinery is maintained properly, breakdowns are avoided, and if there is failure, the rate of downtime is minimized.

Maintenance management is an expansive practice involving many different facets such as periodic inspections, preemptive maintenance, emergency remediation, and/or infrastructure renovations. As traditionally, maintenance in the petrochemical industry was reactive and its aim was to fix the fault as it happens. Nevertheless, this method is faced with an array of challenges such as sporadic lapses which causes unnecessary downtime time and rising cost. There are a variety of technologies that include PMS software, IoT sensors and AR applications. According to Turner et al. (2019), the emergence of AI, AR, PMS machine learning, and IoT presents novel complexities in data analytics and decision-making for maintenance. Consequently, it necessitates the implementation of audit trail methodologies for data gathering and analysis. The analysis of the research elaborates details concerning digital assistance technologies occurring in the practice of petrochemical plant maintenance. All these new technology trends are set to change the current practices of maintenance by introducing autonomous and predictive maintenance, thus building a culture of data driven decisions. Digital documentation involves capturing, organizing, and making maintenance-related information available strategically, it may enhance the efficiency and effectiveness of maintenance and repair processes (Falk et al., 2020). Knowledge management aims to share ideas and best practices among maintenance teams (Radosavljević, 2022). Digital assistant technologies provide a lot of alternatives, which help to strengthen digital documenting and knowledge management.

Advancing assistive technologies has a transformative quality on micro-level maintenance management. In this regard, the asset and equipment management find a place at the center. In the micro scale of maintenance management, digital assistance technologies hold the features of being transitional instruments, the resulting to data analytics and reporting. Data analytics refers to the process of gathering, verifying, and making sense of huge volumes of data that comes from machines and systems (Vanani and Majidian, 2019). The actionable insights drawn from this data are published in the scope of reporting where conclusions are reached to guide maintenance decision-making. There are many digital assistance technologies that provide solutions in terms of improving the data-analysis and report generation activities in maintenance management. The technologies involved integrated, and enumerated technologies include predictive maintenance algorithms, IoT sensors, real-time data monitoring systems and advanced reporting tools. The use of predictive maintenance algorithms helps in using both the historical data as well as the real-time data concept to predict the equipment failures for the purpose of optimizing the maintenance process (Paolanti et al., 2018). Through effective tools that use advanced reporting tools, information is presented in an easily understandable format making it possible for other people to apply the acquired insights.

At another micro level of maintenance management, attention is on the forces driving group collaboration as an enabler of increased efficiency and performance in installation situations. In team collaboration, there is constant consistency that comprises parties acting in a team where there are maintenance teams, engineers,

technicians, and subject matter experts. The kinds of practices and technologies that fit into team collaboration are diverse and include real-time communication, cloud-based collaborative tools, and remote expert support systems. These tools provide maintenance crews with avenues of knowledge sharing, sharing information and working cohesively as they deal with maintenance issues (Swart et al., 2022). In addition, they overcame the distance gaps, enabling the involvement of people from different parts of the world to the maintenance undertakings, primarily when a skill knowledge was needed in particular cases.

The approach of collaborative decision-making in maintenance management, therefore, represents a major paradigm shift regarding how organizations handle various asset management issues. It is an active process by a variety of cross-functional teams employing shared knowledge, insights, and experience to make informed decisions which improve maintenance practices. Collaborative decision-making includes practices on on-time communication, sharing of knowledge, and combining data-driven intelligence. Collaborative platforms allow facilitating creative work of a team through breaking down the psychological barrier of distance and enjoy the expertise of remote specialists who need just a click of a button to establish a collaboration (Ammari & Hammad, 2019). With this approach, decisions on maintenance are based on the understanding of condition of the asset, operational constraints, and the organization's goals while ensuring efficiency and reliability of the maintenance teams (Marques et al., 2021).

The tools and channels of communication in maintenance management symbolize the main arteries in the pipelines, through which information is delivered to be consumed, decisions are to be reached, and actions are to take place (Ul'yanickaya, 2022). These tools range from a varied set of technologies such as instant messaging-based platforms, video conferences, mobile applications, and collaborative software solutions. This allows the maintenance teams, engineers, technicians, and stakeholders to realize immediate communication and activities regardless of geographical boundaries. Furthermore, the use of these tools contributes towards increased transparency as it gives real-time updates on state of assets, work in progress and planned maintenance routines, it can serve as efficient communication tools for substantially assisting in the maintenance of weight reduction, particularly during a limited time frame ranging from 3 to 24 months.

Put otherwise, they are the glue that holds together the maintenance teams in one unit, thus obliging everyone to be on the same wavelength as regards the goal to be achieved. The variety of diversity in maintenance management reflects a way of work, which can be recognized and appreciated in the background, experience, and approaches of the employees. This divergence stretches across several qualities, such as gender, race, age, skill level, and even life perspectives. The phenomenon of inclusive approaches in maintenance management extends beyond the matter of mere representation. People of different backgrounds, cultures, and more mixed intelligences collaborating will allow for complexities in maintenance challenges to be looked upon in a way that will result in bolder solutions (Tudball, 2020). Inclusive practices guarantee a democratic voice and access to the availability of knowledge and skills among team members, leaving a possibility to constantly better and harness team and knowledge (Hamp et al., 2020).

Objectives of the study - This study evaluated the impact of digital assistance and team collaboration on the efficiency of maintenance management within the petrochemical industry and developed a framework to improve its operational efficiency. Specifically, it aimed to determine the extent to which digital assistance tools, such as asset and equipment management, digital documentation and knowledge management, data analytics and reporting contributes management efficiency; assess the team collaboration practices in terms of collaborative decision making, communication channels, and diversity in teams; evaluate the maintenance management efficiency in terms of planning and scheduling, materials management, and cost control; test the significant relationship between digital assistance, team collaboration maintenance and management efficiency; and develop a framework for operations performance improvement on petrochemical industry.

2. Methods

Research Design - This study employed a descriptive research design to facilitate the interpretation of the acquired data, utilizing a questionnaire as the principal tool for data collection. According to McCombes (2023), descriptive research seeks to provide an accurate and methodical depiction of a population, situation, or phenomena. It can respond to inquiries regarding what, where, when, and how. Descriptive research is a research methodology that aims to provide an astute description of established phenomena, it aims to methodically depict the phenomena that are being investigated. The researcher collected information from respondents by giving and distributing survey questions to them. This descriptive research method was proven useful for effectively gathering data from respondents. Consequently, the correlation between the three variables of digital assistance, team collaboration, maintenance management efficiency was determined.

Participants - A total of 400 employees from petrochemical plant in Batangas city took part in the survey for this research. Given that the research focuses on maintenance efficiency, all respondents were selected from the maintenance department. This ensured that participants have a comprehensive understanding of the company's condition and can provide more precise evaluations, comprehension, and feedback on the research content.

Instrument - The research was carried out via electronic questionnaires. Table 1 reveals that every single Cronbach Alpha value exceed 0.8 except assets and equipment management. The coefficients for the aspects, namely cost control exceed 0.9. Items are regarded as ‘excellent’. All the numbers for digital documentation and knowledge management, analytics and reporting, collaborative decision making, communication channel, diversity in teams, planning and scheduling and materials management exceed 0.8. The items are considered ‘Good’. The maximum value is 0.902, and the minimum coefficient is 0.739. High quality and reliability of the research data make it appropriate for next large-scale questionnaire surveys.

Table 1

Reliability Test Results of Digital Assistance, Team Collaboration and Maintenance Management Efficiency

Indicators	Cronbach Alpha	Remarks
Digital Assistance		
Assets and Equipment Management	0.739	Acceptable
Digital Documentation and Knowledge Management	0.802	Good
Analytics and Reporting	0.831	Good
Team Collaboration		
Collaborative Decision Making	0.855	Good
Communication Channel	0.812	Good
Diversity in Teams	0.837	Good
Management Efficiency		
Planning and Scheduling	0.887	Good
Materials Management	0.882	Good
Cost Control	0.902	Excellent

Legend: George and Mallery (2003) provided the ff rule of thumb: ≥0.90 = Excellent; ≥0.80 = Good; ≥0.70 = Acceptable; ≥0.60 = Questionable; ≥0.50 = Poor; <0.50 = Unacceptable

Data Gathering Procedure - Prior to gathering data, the researcher prepared a formal letter to seek consent from the human resource management department at petrol chemical plant in Batangas city to carry out the study. It was emphasized that the survey is only performed in written form for academic reasons and that all gathered data was treated as confidential. After the approval of human resource management and research advisor, the researcher reached out to the individual responsible for overseeing human resource management. These responsible individuals delivered the questionnaire to staff in the maintenance department. These employees completed the questionnaire freely and were recovered. The plan for the distribution and retrieval of the questionnaire was reviewed and finalized on a mutually agreed date with the human resource management. The questions were conducted electronically using Google forms or email to guarantee the precision and privacy of the outcomes from 400 target respondents.

Following the distribution of the final questionnaire, a total of 21 initial respondents were allocated among 400 maintenance department employees for the purpose of conducting validity or reliability pilot testing. According to Brosnan et al. (2019), there are ten factors that influence the response rate. These factors include incentives, ease of completion, topic interest, software functionality, utility to others, understanding of the topic, impact of the study, trust in the association with the brand or organization, and the weight given to respondents' opinions. It is not true that these drivers are incompatible with one another; rather, they may complement or compensate one another. A total of 400 surveys were gathered between May 14, 2024 and June 21, 2024. A total of 400 surveys were deemed legitimate, resulting in a 100 percent effectiveness rate.

Data Analysis - Weighted mean and rank were used to assess the effectiveness of digital assistance tools such as asset and equipment management, digital documentation and knowledge management, as well as data analytics and reporting, contribute to management efficiency; assess the extent to which team collaboration practices such as collaborative decision making, communication channels, and team diversity contribute to maintenance efficiency; and determine maintenance management efficiency in terms of planning and scheduling, materials management, and cost control. The Shapiro-Wilk Test resulted in p-values of less than 0.05 for all variables, indicating that the data set was not normally distributed. As a result, Spearman rho was utilized as one of the non-parametric tests to identify significant relationships. Furthermore, all data were processed using a statistical program, namely SPSS version 28, to enhance the interpretation and analysis of the study's findings.

Ethical Considerations - The research adhered to ethical principles to ensure that all acquired information is used solely for research purposes, hence upholding the research's quality and integrity. The researcher obtained approval from the human resource management department via written correspondence and communication. This is to ensure that the intended respondents are adequately prepared to respond to the pertinent inquiries in the research. The survey also guaranteed the privacy and anonymity of the participants by refraining from requesting their names as they completed the surveys. The researcher also guaranteed that the respondents willingly and autonomously completed the questionnaires. Lastly, it also ensured the physical and psychological well-being of all study participants, prioritizing their safety and security.

3. Results & discussion

Table 2

Summary Table on Impact of Digital Assistance

Key Result Areas	Composite Mean	VI	Rank
Asset and Equipment Management	3.19	Agree	2
Digital Documentation and Knowledge Management	3.19	Agree	2
Data Analytics and Reporting	3.19	Agree	2
Grand Composite Mean	3.19	Agree	

Legend:3.50-4.00=Strongly Agree;2.50-3.49=Agree;1.50-2.49=Disagree;1.00-1.49=Strongly Disagree

Table 2 presents the summary of impact of digital assistance. It explained the relevant indicators of the digital assistance from three aspects: asset and equipment management, digital documentation and knowledge management, and data analytics and reporting. The mean value of the index is 3.19, showing that these three aspects are appropriate to interpret the relevant indicators of the digital assistance. As far as the petrochemical industry is concerned, all indicators have the same importance and recognition. This entails that asset and equipment management, digital documentation and knowledge management and data analytics and reporting play a primary and huge part in digital assistance which contribute to the improvement of its operational efficiency. The findings also show that the interviewees think that digital assistance is very helpful to the maintenance work. They are willing to use digital tools to assist daily operation activities.

The primary goal of digital asset management software is to optimize the use of assets, ensure the protection of precious goods, and facilitate the scheduling of maintenance. Another goal is to enhance the efficiency of asset control and reduce equipment loss. This digital tool offers several functionalities that enable petrochemical

plants to efficiently save both time and money. Furthermore, it is vital for the organization's commercial expansion and adherence to regulations (Infinity, 2023).

According to Vaio et al. (2021), the use of digital documentation and knowledge management facilitates the development of innovative business models and enhances performance. The incorporation of digital transformation technologies further enhances long-term value generation and sustainability. In terms of digital analytics and reporting, industrial 4.0 and data analytics have the potential to improve everyday operations by using large amounts of data to make intelligent choices, with research is focused on specific industrial sectors, cyber-physical systems, and analytic techniques (Duan and Xu, 2021). As Miros Group (2024) said in their study, utilizing digital tools, providing real-time information to the petrochemical industry. This enables wider operational windows, improved performance, and enhanced safety, even in the most challenging conditions.

Table 3

Summary Table on Impact of Team Collaboration

Key Result Areas	Composite Mean	VI	Rank
Collaborative Decision Making	3.19	Agree	2
Communication Channels	3.19	Agree	2
Diversity in Teams	3.19	Agree	2
Grand Composite Mean	3.19	Agree	

Legend:3.50-4.00=Strongly Agree;2.50-3.49=Agree;1.50-2.49=Disagree;1.00-1.49=Strongly Disagree

The summary of team collaboration is presented in Table 3. The results elucidated the pertinent indicators of team collaboration from three perspectives: diversity in teams, communication channels, and collaborative decision-making. The respondents' level of team collaboration was moderately evident, as evidenced by the composite mean value of the index, which is 3.19. Clearly, the three sub variables in team collaboration have identical scores, with a weighted mean of 3.19. It illustrates that these three factors are appropriate and suitable for the interpretation of team collaboration.

In terms of petrochemical industry, it is a substantial contributor to the global economy and is one of the greatest industries in the globe. According to one estimate, the petrochemical industry has already generated more than $5 trillion in revenue worldwide (Ajala, 2022). The current petrochemical industry has become increasingly complex since the plant has a large number of high-precision professional facilities, even a tiny screw can make the plant tripped then lead to serious loss. It has resulted in the increased importance of teamwork over the years, so they always need brainstorm and team collaboration to make the maintenance smoothly and precisely. This requires cross-departmental cooperation and knowledge sharing. Therefore, team collaboration is crucially important.

Team collaboration, to be effective, must try to apply collaborative decision-making process, communication channels and enhance the diversity in teams. The petrochemical company's potential for significant competitive advantage is enhanced by the collaborative decision-making culture and infrastructure, which foster transparency and speed. In turn, they can directly affect both their top and bottom lines by optimizing the quantity and type of production. The basis of any successful endeavor is excellent communication. Every stage of a project should assess and design suitable communication channels to guarantee that stakeholders are aware of and participate in decision-making. To display material such that it will be easily understood, the target audience for project information must be determined and suitable communication instruments chosen. Making technical material intelligible to various audiences may require the use of many communication strategies. Shapiro (2020) pointed out that diversity in teams includes not only promoted diversity and cultural diversity within teams but diversity in thought and knowledge to help knowledge sharing and enhance the efficiency of maintenance work. All of these three sub variables together contribute to effective team collaboration.

Table 4

Summary Table on Maintenance Management Efficiency

Key Result Areas	Composite Mean	VI	Rank
Planning and Scheduling	3.21	Agree	1
Materials Management	3.19	Agree	2
Cost Control	3.16	Agree	3
Grand Composite Mean	3.19	Agree	

Legend:3.50-4.00=Strongly Agree;2.50-3.49=Agree;1.50-2.49=Disagree;1.00-1.49=Strongly Disagree

Summarized in Table 4 is the level of the respondents' assessment on maintenance management efficiency. The composite mean of 3.19 reveals that the respondents' level of maintenance management efficiency was moderately evident where planning topped the list (3.21). Though assessed positively, materials management (3.19) and cost control (3.16) obtained the lower mean value and rated the least.

The findings show that better planning and scheduling, materials management and cost control have positive impact on maintenance management efficiency to some extent. Customized Workface Planning (WFP) may enhance the efficiency of planning and overseeing maintenance operations, shutdowns, and turnarounds in the petrochemical industry, resulting in decreased instances of exceeding budget and schedule (Alhamouri, 2019). In the dynamic world of petrochemicals, it is crucial to prioritize the optimization of operations and the effective use of resources. Petrochemical enterprises depend on a variety of tools, maintenance, repair, and operations (MRO) supplies, along with indirect materials and equipment, to ensure the proper functioning of their facilities. Success hinges on diligent upkeep and precise managing materials (Inventor, 2023). The petrochemical business is very intricate. Entrepreneurs in this industry comprehend that even the smallest error may lead to substantial financial setbacks. The industry is demanding and demands accuracy, consistency, and efficiency in all of its procedures. To excel in this sector, it is crucial to prioritize process efficiency and cost control. In recent years, petrochemical companies have been particularly interested in the development of cost control strategies that can be implemented to address the significant obstacles that restrict petrochemical industry production efficiency. Effective utilization of materials, labor resources, and other inputs in the production cycle is guaranteed by a well-designed cost control strategy for a petrochemical plant, which also reduces monetary losses.

Table 5

Relationship Between Digital Assistance and Team Collaboration

Variables	rho	p-value	Interpretation
Asset and Equipment Management			
Collaborative Decision Making	0.688**	< .001	Highly Significant
Communication Channels	0.678**	< .001	Highly Significant
Diversity in Teams	0.671**	< .001	Highly Significant
Digital Documentation and Knowledge Management			
Collaborative Decision Making	0.655**	< .001	Highly Significant
Communication Channels	0.625**	< .001	Highly Significant
Diversity in Teams	0.684**	< .001	Highly Significant
Data Analytics and Reporting			
Collaborative Decision Making	0.734**	< .001	Highly Significant
Communication Channels	0.661**	< .001	Highly Significant
Diversity in Teams	0.670**	< .001	Highly Significant

***. Correlation is significant at the 0.01 level*

The relationship between digital assistance and team collaboration is seen in Table 5. Table 5 shows that the p-values obtained were less than 0.01 alpha level, and the calculated rho-values from 0.625 to 0.734 show a high direct connection between the sub variables of digital assistance and team collaboration. Thus, the treated variables showed a noteworthy correlation. The outcome shows that team collaboration improves with improved digital assistance. The empirical results demonstrate that every aspect of digital assistance has a favorable impact on every aspect of team collaboration. This strongly suggests that the use of digital tools is a successful approach to enhance team collaboration in enterprises.

Rising competition, rising risks, market volatility, worldwide dangers like as the pandemic (COVID 19), and economic swings have pushed many corporate executives, including those in the petrochemical industry, to seek answers. Business executives in the petrochemical industry are now asking questions and looking for new methods to increase their competitive edge. The emphasis is on achieving or maintaining their firms' targeted positions in the global petrochemical industry. It is believed that team collaboration needs constant improvement and combination, and it should make more use of digital tools and other related means.

According to Halifa and Bond (2019), effective communication, message coding and decoding, communication technology use, and varied communication frequency all contribute to increased trust, cooperation, and perceptions of project management success in the worldwide petrochemical industry. In addition, digital collaboration tools improve team communication and collaboration in organizational teams (Lane et al., 2023). Schulz (2024) also claimed that given the intricacy of digital transformation, issue understanding, analysis, and resolution need for substantial multidisciplinary collaboration. It is convenient for employees to reduce misunderstanding and improve knowledge sharing for solving operational challenges. In short, digital assistance and team collaboration are inextricably linked and more staff will use and apply digital tools.

Table 6

Relationship Between Digital Assistance and Maintenance Management Efficiency

Variables	rho	p-value	Interpretation
Asset and Equipment Management			
Planning and Scheduling	0.655**	< .001	Highly Significant
Materials Management	0.672**	< .001	Highly Significant
Cost Control	0.642**	< .001	Highly Significant
Digital Documentation and Knowledge Management			
Planning and Scheduling	0.619**	< .001	Highly Significant
Materials Management	0.682**	< .001	Highly Significant
Cost Control	0.647**	< .001	Highly Significant
Data Analytics and Reporting			
Planning and Scheduling	0.644**	< .001	Highly Significant
Materials Management	0.703**	< .001	Highly Significant
Cost Control	0.663**	< .001	Highly Significant

***. Correlation is significant at the 0.01 level*

Table 6 shows the association between digital assistance and maintenance management efficiency. Based on table 6, the calculated rho-values ranging from 0.619 to 0.703 demonstrate a high direct connection between the sub variables of digital assistance and maintenance management efficiency, with p-values less than 0.01 alpha level. This indicates that there was a substantial association between the treatment variables. The results show that the greater the digital assistance, the higher the maintenance management efficiency. The empirical results show that each dimension of digital assistance positively affects each dimension of maintenance management efficiency, demonstrating that digital assistance can have a significant impact on maintenance management efficiency, and that using digital tools is an effective way to improve the maintenance management efficiency of petrochemical companies.

In terms of the current global economic environment, flexible asset and equipment management systems remove barriers to adapting to new production requirements in the petrochemical industry so as to enhance resources deployment and costs control. Likewise, achieving synchronistic planning and scheduling ensures timely and efficient production process, which are prevalent for meeting market demands and reducing production downtimes in this industry. Efficient materials management plays an important role in the efficient flow of resources to avoid wastage as well as avoiding production processes are interrupted. Digital documentation and knowledge management, this enabler contributes to enhancing the efficiency in organizing, storing, retrieving and sharing information in an organization. However, data analytics and reporting help in gathering information that is useful for planning and decision making and overall enhancement of the petrochemical industry.

It was written in the study of Min et al. (2019) that the petrochemical industry gains economic advantages

and improves production control optimization using a digital twin system. In addition, in petrochemical companies, digital platforms, smart gadgets, and artificial intelligence help to optimize resources and raise production efficiency (Nurgaliev and Nurgalieva, 2021). Digital support also lowers costs throughout the supply chain management cycle, enhances production process design, and reduces equipment downtime (Psareva & Shinkevich, 2021). The manner in which maintenance is administered is being altered by digital transformation. All of the petrochemical plants are keeping pace with the times, harnessing the power of digital platforms to optimize operations. These systems are indispensable for optimizing safety, decreasing downtime, and increasing overall efficiency by overseeing intricate equipment maintenance. Digital assistance is the foundation of building successful petrochemical plants, it is vital to focus on how to make digital assistance better improve management efficiency which is also completely consistent with our finding.

Table 7

Relationship Between Team Collaboration and Maintenance Management Efficiency

Variables	rho	p-value	Interpretation
Collaborative Decision Making			
Planning and Scheduling	0.660**	< .001	Highly Significant
Materials Management	0.666**	< .001	Highly Significant
Cost Control	0.669**	< .001	Highly Significant
Communication Channels			
Planning and Scheduling	0.616**	< .001	Highly Significant
Materials Management	0.696**	< .001	Highly Significant
Cost Control	0.658**	< .001	Highly Significant
Diversity in Teams			
Planning and Scheduling	0.653**	< .001	Highly Significant
Materials Management	0.680**	< .001	Highly Significant
Cost Control	0.667**	< .001	Highly Significant

***. Correlation is significant at the 0.01 level*

Table 7 shows the association between team collaboration and maintenance management efficiency. Based on table 7, the calculated rho-values ranging from 0.616 to 0.696 demonstrate a high direct connection between the sub variables of team collaboration and maintenance management efficiency, with p-values less than 0.01 alpha level. This indicates that there was a substantial association between the treatment variables. The results show that increased team collaboration leads to higher maintenance management efficiency. The empirical results show that each dimension of team collaboration positively affects each dimension of maintenance management efficiency, demonstrating that team collaboration can have a significant impact on maintenance management efficiency. Enhancing team collaboration is an effective way to improve maintenance management efficiency in petrochemical enterprises.

The facility can identify bottlenecks, process inefficiencies, or recurring maintenance issues through regular collaboration and feedback. The company can enhance overall production performance, drive process enhancements, and uncover innovative solutions by combining employees' expertise (Care, 2023). For any manager, collaboration with their team is a critical asset, as it facilitates communication and enhances productivity. It can also facilitate the exchange of constructive feedback among team members and the identification of each other's strengths in various duties and projects. Meanwhile, to enhance productivity in industrial enterprises, it is imperative that production and maintenance functions collaborate effectively. It is obviously that the effectiveness of maintenance is significantly influenced by the quality of communication and collaboration among the teams involved in the maintenance work. It is crucial for all the petrochemical plant to take the team collaboration into account and emerge with their daily operation. These two indicators mutually reinforcing each other.

Proposed Framework for Performance Improvement

A performance improvement framework has been developed for the petrochemical plant maintenance sector with the aim of motivating all workers to actively use digital assistance tools, boost collaboration among teams, and improve efficiency in the maintenance management.

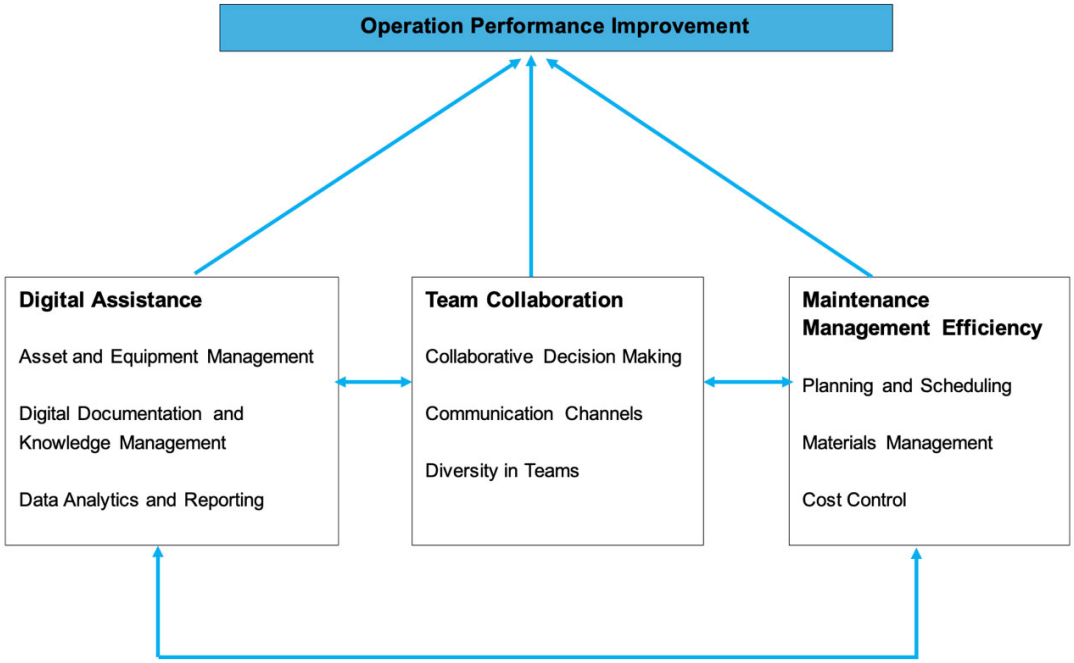

Figure 1. *Operation Performance Improvement*

The figure shows the integrated framework for performance improvement. Based on the theoretical analysis of the relationship between the dimensions of digital assistance, team collaboration and maintenance management efficiency, the results of the empirical study show that the dimensions of digital assistance, team collaboration have a significant positive effect on the improvement of maintenance management efficiency. Therefore, strengthening the application of digital assistance and the cultivation of team collaboration at the strategic level is an effective way to improve maintenance management efficiency. Effective performance improvement requires that digital assistance and team collaboration tend to be efficient. Emerson (2023) believed that operational excellence can be achieved by boosting asset dependability, streamlining site maintenance management, and putting digital technologies to work. Hosseini et al. (2024) pointed out that petrochemical industry can enhance performance, reduce costs, extend the lifespan of equipment, reduce failures, enhance reliability, increase productivity, reduce waste, preserve the environment, and enhance employee safety through maintenance management.

The systematic framework for enhancing petrochemical plant maintenance management consists of three essential elements: digital tools, Team Collaboration, and efficient maintenance management, all aimed at maximizing overall performance. This framework aims at integrating the efficiency improvements resulting from the use of digital technologies with the advantages derived from cross-functional practices in carrying out maintenance activities and attaining the goals envisioned.

In terms of implementation, the framework prioritizes the strategic use of digital assistance tools and the development of a collaborative team environment. Integrating these factors is essential for attaining optimal levels of maintenance efficiency. The framework emphasizes the significance of closely integrating maintenance processes with digital and cooperative endeavors. It is necessary to establish clear objectives for the use of technological tools and to encourage collaboration and the effective management of knowledge.

The real digital assistance primarily entails the implementation and use of predictive maintenance techniques and real-time data monitoring systems across the facility. These technologies should be included in the existing maintenance procedures in order to provide information that enables maintenance to be proactive. It is crucial to include cross-functional maintenance teams that consider maintenance personnel, engineers,

technicians, and remote specialists. This may be achieved by using contemporary communication channels, cloud apps, and/or remote support solutions, ensuring that all group members are connected and kept informed.

The framework includes continuous evaluation and improvement of the maintenance strategy. Therefore, by analyzing data and feedback, it is feasible to identify the necessary actions to improve performance and address current challenges. The effectiveness and suitability of the framework adopted by maintenance teams greatly impact their work. Therefore, it is crucial for the components of the framework to be ready for dynamic adjustments as the organization adopts new technologies and practices.

The framework incorporates the effective use of digital assistance and collaboration among the maintenance team members, resulting in enhanced operational performance in the management of petrochemical plant maintenance. It reduces the amount of time and money lost, while also improving the pace at which parts are stocked and the reliability of goods and services. This is achieved by optimizing maintenance to meet the increasing demands of customers.

4. Conclusion and recommendations

There is moderate agreement on the impact of digital assistance in asset and equipment management, digital documentation and knowledge management, and data analytics and reporting. The employees manifested moderate agreement on the team collaboration practices in terms of collaborative decision making, communication channels and diversity in teams. There is moderate agreement on maintenance management efficiency as to planning and scheduling, materials management and cost control. There is a highly significant relationship between digital assistance, team collaboration and maintenance management efficiency. A framework has been developed to improve the performance of petrochemical industry.

The company management may apply rigorous digital platforms, manuals and guidelines, real-time data analysis and data reporting tools to strengthen the efficiency. Extensive and thorough trainings of the digital plat form users will be key to maximize effectiveness of the digital assistance tools. The company HR management may increase diversity in teams not only gender and age, but also the working experience, backgrounds, ethnicity and skills to have greater number of creative ideas and adept at addressing difficulties. The company may consider enhanced collaboration within teams and with different stakeholders leveraging advanced communication channels to enhance efficiency of maintenance management. The company executives and strategic planners may adopt the framework integrating digital assistance, team collaboration and maintenance management efficiency to achieve performance improvement. Future researchers may explore the long-term impacts of digital transformation and team collaboration on maintenance management efficiency and investigate additional variables like organizational culture and the return on investment.

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