Journal of Infrastructure, Policy and Development 2024, 8(12), 6228.
https://doi.org/10.24294/jipd.v8i12.6228

Article

Qualitative evaluation and corrective planning for centrifugal pump maintenance at Soekarno-Hatta airport

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CITATION

Nusraningrum D, Rachmat Rudiana A, Tan ZY, et al. (2024). Qualitative evaluation and corrective planning for centrifugal pump maintenance at Soekarno-Hatta airport. Journal of Infrastructure, Policy and Development. 8(12): 6228.
https://doi.org/10.24294/jipd.v8i12.6228

ARTICLE INFO

Received: 6 May 2024
Accepted: 26 August 2024
Available online: 5 November 2024

Abstract: This study focuses on enhancing the maintenance processes of centrifugal pumps at Soekarno-Hatta Airport's Water Treatment Unit in Indonesia, crucial for meeting the clean water needs of the airport, which served around 19.8 million passengers in 2022. Using a qualitative methodology, the research involved focus group discussions with the unit's operators, technicians, and engineers to pinpoint maintenance challenges and devise solutions. Key findings reveal issues such as insufficient routine maintenance, unplanned repairs, and inadequate staffing, leading to operational disruptions and pump failures. The study highlights the role of Total Productive Maintenance (TPM) in reducing machine breakdowns and improving efficiency. It emphasizes the critical role of centrifugal pumps in the airport's water supply system. The research proposes several corrective measures, adhering to the 5W + 1H framework, including regular lubrication, bearing replacements, hiring more staff, and advanced training on PLC systems. These actions aim to rectify immediate maintenance problems and establish a foundation for the long-term effectiveness of the pump systems. Conclusively, the study underscores the need for a comprehensive maintenance strategy that aligns with standard operating procedures and preventive maintenance. This approach is essential for boosting the operational performance and reliability of the Water Treatment Unit. It has broader implications for similar infrastructure facilities, underscoring the importance of efficient maintenance management.

Keywords: centrifugal pump; total productive maintenance; water supply efficiency; maintenance evaluation; corrective action planning; water infrastructure

1. Introduction

Soekarno-Hatta Airport, Indonesia's busiest, served approximately 73,000,000 passengers in 2023 (Munawar, 2023). With aviation growth, there's a demand for excellent services, including electricity and water. Qatrunada et al. (2022) reference Annex 14 of the International Civil Aviation Organization (ICAO), defining an airport as an area on land or water for aircraft arrival, departure, and movement, emphasizing the necessity of clean water for operational sustainability. The airport's Water Treatment unit manages the clean water supply, including maintenance of pumps, piping networks, and accessories. Novianti and Sulistyorini (2022) define drinking water as water that meets safety standards for consumption, whether treated or untreated. The unit employs 10 main booster pumps, 3 auxiliary pumps, and additional boosters at each terminal, with varying capacities and 4 storage tanks of 4000 M^3 each. These pumps operate alternately for 12 h daily.

The increased clean water usage impacts electrical consumption due to enhanced motor performance for distribution. As mandated by SKEP 157 of 2003 for electronic and electrical airport equipment, continuous performance improvement in production and maintenance is crucial. Sustainable industry practices across all business lines, including water distribution, require management support and adherence to standards. However, some Water Treatment facilities haven't met the standard Availability level as per regulations. Equipment availability is below the standards of SKEP 157 of 2003 and the global Overall Equipment Effectiveness (OEE) standard. The Japan Institute of Plant Maintenance (JIPM) recommends a World Class OEE of 85%. Adhiwikarta et al. (2022) note the unit's equipment falls below these benchmarks. According to various researchers, OEE is crucial for evaluating performance improvements in total productive maintenance (TPM).

Syahrial and Nusraningrum (2022) state TPM helps identify problems and recommend repairs to reduce breakdowns. Ahdiyat and Nugroho (2022) describe TPM as a system to minimize machine breakdowns. However, the Water Treatment unit's maintenance hasn't aligned with SOPs due to unplanned repairs, leading to facility downtime and challenges like limited personnel and mismanaged consumable parts. With only 3 to 4 technicians per shift, frequent repairs hinder routine maintenance. For a clean water supply, the reliability of centrifugal pumps is vital. These pumps require regular maintenance across mechanical, electrical, and instrument functions. Unfortunately, inadequate routine maintenance often leads to technical issues, as evidenced by the high failure rate of centrifugal pumps in the data, causing operational downtime and necessitating improved maintenance management.

In the past, various industries have cited the use of different qualitative research methods in the assessment and improvement of maintenance. These techniques, namely focus group discussions, interviews, and case studies, give detailed information on human and organizational factors that impact maintenance practices (Hennink et al., 2020). Previous literature has affirmed that qualitative research is effective in identifying important issues, recommending solutions, and enhancing maintenance management. These are some of the remarkable research works that incorporated qualitative data in their surveys to improve the comprehension of maintenance assessment, approaches utilized, outcomes acquired, and the addition towards the state of the art.

1.1. Qualitative research in industrial maintenance

Tortorella et al. (2022) conducted a comprehensive qualitative study to investigate maintenance practices in the manufacturing sector. Focus group discussions with maintenance staff and managers indicated that key barriers to effective maintenance are low training, communication, and proceduralization. The study also made it clear that there is a need for progressive practice development as well as the development of practice-specific maintenance protocols. They were therefore able to capture small organization issues that would not be apparent in quantitative research making the research more comprehensive of maintenance issues and possible solutions. In the same vein, Cárcel-Carrasco et al. (2021) explored maintenance practices in the energy sector through focus interviews with engineers and technicians. In their research, they focused on preventive maintenance and the challenges that surround it. This research established that organizational culture and management support were the two determinants of preventive maintenance practices. The scholars proposed that more should be done to ensure all the stakeholders in the process are actively engaged in the planning and implementation of maintenance work. Conclusively, this study affirmed the significance of gathering qualitative data to depict the integration of technical and management features in maintenance management.

1.2. Maintenance in water treatment facilities

The water treatment industry has also adopted the use of qualitative research methods. Furch et al. (2020) and Annesi et al. (2021) employed qualitative research that employed focus group discussions and participant observation to establish the maintenance practices that are practiced in a municipal water treatment plant. They noted that such weaknesses as poor maintenance schedules and inventory exacerbated equipment breakdowns and hurdles. The surveys with the maintenance personnel and managers enabled the researchers to come up with specific recommendations for modifying the maintenance program, training, and inventory. This research demonstrated that qualitative data are useful in identifying maintenance solutions that will address the needs and conditions of the water treatment sector. Duque et al. (2024) extended this by studying maintenance practices in desalination plants. Specifically, maintenance engineers were interviewed to identify the main causes of equipment failure and the existing maintenance management strategy. This meant that the non-implementations of real-time monitoring and predictive maintenance equipment were some of the reasons that contributed to high equipment downtime. The scholars suggested the utilization of contemporary monitoring systems and the shift to better maintenance methods. This research established how it is possible to use qualitative data in the adoption of various new technologies and practices in the water treatment industry.

1.3. Total productive maintenance and qualitative evaluation

TPM has been one of the most important areas of concern in maintenance and its qualitative perspective. Chaurey et al. (2023) used focus group discussions to evaluate the effectiveness of TPM in various industries. From the study they identified some key factors that affect TPM; these are employee commitment, continuous improvement, and management support. Generally, the qualitative data collected in this study were useful in determining the actual implementation challenges and benefits of TPM, which informed the researchers on some recommendations for improving the uptake and performance of TPM. This work also exposed the need to incorporate qualitative data to obtain tangible information pertinent to TPM from maintenance staff members. Ahdiyat and Nugroho (2022) used interviews of a qualitative nature to assess the impact that TPM has on the reliability of the equipment as well as operating efficiency. From their findings, they observed that firms with good

TPM practices recorded low equipment breakdowns and higher productivity. The findings underscore the importance of fostering a maintenance culture that involves staff and enhances learning. Qualitative data analysis enabled Ahdiyat and Nugroho to understand and document the positive organizational relationships that enhance TPM implementation.

The overarching objective of this research is to enhance the efficiency and effectiveness of the maintenance processes for centrifugal pumps at the Soekarno Hatta Airport's Water Treatment Unit. It involves a qualitative study aimed at comprehensively analyzing the key issues affecting the maintenance and functionality of centrifugal pumps, and thus formulating corrective action. The research outcomes offer multifaceted benefits for companies, particularly those managing water treatment units, the findings serve as a foundation for maintenance practices aimed at enhancing equipment productivity and minimizing facility downtime. Additionally, they provide recommendations for future preventive maintenance strategies.

2. Literature review

2.1. Total productive maintenance

The Total Productive Maintenance (TPM), as described is a comprehensive approach to optimizing equipment effectiveness and efficiency within organizations (Daman and Nusraningrum, 2020; Sutawidjaya and Nugroho, 2022; Syahrial and Nusraningrum, 2022), such as the Soekarno Hatta International Airport's Water Treatment unit. Initially defined by Seiichi Nakajima of the Japan Institute of Plant Maintenance in the 1970s, TPM extends beyond maintenance to encompass all aspects of facility operation and installation. It aims to minimize machine breakdowns (zero breakdown) and product defects (zero defect), leading to increased equipment utilization, reduced costs and inventory, and improved employee productivity.

This approach is particularly vital for businesses reliant on machinery, balancing maintenance schedules to prevent risks and machine failure costs. TPM integrates strategies such as waste elimination in a rapidly changing economic environment, maintaining product quality, cost reduction, and early production of low batch quantities (Pinto et al., 2020; Singh and Gurtu, 2022).

Key components of TPM include the 5S methodology, which emphasizes the importance of a well-organized workplace for problem visibility and continuous small-scale improvements (Kaizen) involving all organizational members. It covers autonomous maintenance by operators, planned maintenance for defect-free products, quality maintenance for customer satisfaction, multi-skilled employee training, office TPM for administrative efficiency, and a focus on safety, health, and the environment. TPM requires strategic management thinking in product design, machine operability, employee training, productive machine purchasing, and comprehensive preventive maintenance planning. This holistic approach enhances operational performance and contributes to organizational competitiveness and sustainability (Schindlerová et al., 2020; Singh and Gurtu, 2022).

2.2. Maintenance system

The maintenance system plays a critical role in ensuring smooth production processes, especially in competitive product environments (Esmaeili et al., 2019; Ong and Zhu 2013). Proper maintenance is essential for keeping production facilities and machinery operational. When machines or components fail, production is disrupted, potentially halting processes, missing targets, and jeopardizing the company's ability to satisfy consumer expectations. Such failures can lead to negative perceptions of the company's reliability, impacting customer loyalty.

In maintenance management, controllable systems include component replacement, control maintenance, total maintenance, and reliability maintenance. The objective is to guarantee the functionality of production facilities and foster effective human-machine interaction in the production process. Integrated maintenance management is vital for achieving a company's vision, involving elements like machinery, material replacement, maintenance costs, maintenance planning, and maintenance operators (Kaparthi and Bumblauskas, 2020; Shaheen and Németh, 2022). These elements interact in industrial maintenance activities.

Maintenance, often interpreted as care or upkeep, is crucial for maintaining machine quality and functionality. It encompasses activities to restore or maintain machines in operational and safe conditions, and in the event of damage, control the impact, as outlined by Pranowo (2019) The maintenance process affects the availability of production facilities, production rate, end product quality, production costs, and operational safety, ultimately influencing company profitability.

The production process necessitates a range of maintenance activities for its continuity, including cleaning, inspection, lubrication, and procurement of spare parts. These activities are integral to both preventive and corrective maintenance strategies (Pinto et al., 2020; Shaheen and Németh, 2022). They encompass regular inspections to ensure machinery is in normal working condition, scheduled servicing as outlined in maintenance manuals, the replacement of damaged components either in emergency situations or as part of planned preventive measures, repairs for minor damages, and comprehensive overhauls, which are major repair actions usually conducted at the end of a designated period. Each of these steps plays a critical role in maintaining the smooth operation and longevity of production systems (Alvanchi et al., 2021; Shaheen and Németh, 2022).

2.3. Centrifugal pumps

Centrifugal pumps are mechanical devices widely used in both industrial and household settings (Haryadi et al., 2022; Kurniawan, 2022). Essentially, these pumps function to elevate the pressure of low-pressure fluids to high-pressure levels, commonly employed to move fluids from lower to higher elevations and to enhance flow rate through obstacles such as bends, pressure differentials, and height differences. Among various pump types, centrifugal pumps are a significant category.

A centrifugal pump consists of two main components: the impeller and the volute. The impeller, a rotating component of the pump, plays a crucial role in its performance, with its geometry significantly affecting the radial force, flow velocity, and resultant pressure. The volute, on the other hand, is a stationary component (Mohammadi et al., 2023). Research in the field of centrifugal pumps has explored various aspects, including the impact of rotational speed on pressure fluctuations, which in turn affect the pump's efficiency through induced vibrations (Chen et al., 2022; Dai et al., 2023; Fecser and Lakatos, 2021; Hasan et al., 2021; Zheng et al., 2023). Other studies have focused on flow characterization, cavitation phenomena, vibration detection, and more within centrifugal pumps (Elakramine et al., 2022).

The optimization of centrifugal pump performance is vital in reducing production and maintenance costs in the industrial sector. These pumps are extensively used across diverse industries, including oil and gas, agriculture, chemicals, and many others, highlighting their versatility and importance in various industrial processes (Mohammadi et al., 2023).

3. Methodology

This research utilizes a qualitative approach to identify the main issue, understand its causes, and design corrective actions, which impact the maintenance and operation of centrifugal pumps.

3.1. Participants

This study employed a nonprobability sampling method, specifically saturation sampling, by using a sample of 26 centrifugal pumps for clean water distribution at Soekarno-Hatta Airport. This sample includes 13 main distribution pumps in the Water Treatment unit, 6 pumps in terminal 1, and 7 pumps in terminal 3. As shown in **Table 1**, the FGD members are the technical team of the water treatment unit, when carrying out the FGD activities there were 2 supervisors, 4 technicians, and 3 people from the operation and maintenance team.

Table 1. FGD participants.

Position	Gender	Age	Service period (year)	Note
Assistant Manager	Male	32	11	1
Supervisor	Male	40	13	1
	Male	38	14	1
Senior technician	Male	33	11	1
	Male	43	14	1
	Male	33	11	1
	Mal	34	12	1
Technician	Male	28	5	1
Operator	Male	29	6	1
	Male	26	6	1
	Male	53	28	1
Total				11

3.2. Procedure

This study, conducted on 20 July 2022, through an online meeting, involved operators, technicians, and a lead engineer, aiming to highlight key challenges and formulate corrective actions. Before the commencement of the interview, the procedure for facilitating the focus group discussion (FGD) was outlined, and any potential uncertainties were clarified. All participants were briefed on the purpose of the study, confidentiality issues, risks, benefits, and their right to withdraw at any time. Additionally, participants were required to complete an informed consent form. With their consent, the discussions were audio-recorded using an MP3 recorder. Each focus group interview lasted approximately three hours. The FGD covered several topics, structured around the 5W + 1H method (What, Why, How, Where, When, Who), which is explained as follows:

- What: Identifying the main problem or issue, set as the primary target for improvement, based on categories from the fishbone diagram or root cause analysis previously conducted.
- Why: Understanding the reasons behind the occurrence of the issue or problem.
- How: Designing or determining the corrective actions required to address the issue.
- Where: Recommending the locations where these plans should be implemented.
- When: Determining the optimal timing for the implementation of these corrective actions.
- Who: Identifying the person in charge responsible for executing the recommended plan.

The closed-room setting of the FGD allowed respondents to express their thoughts freely. Participants shared their views individually when prompted by the researcher, without interruption from other group members. Impromptu questions and probing were utilized to elicit significant and nuanced details of the participants' experiences. The interviews were conducted in the Indonesian language, and the recordings were then transcribed verbatim and coded into themes for thematic analysis, which helped identify several critical issues affecting the maintenance and operation of centrifugal pumps.

3.3. Data analysis

The first author accurately and impartially transcribed the initial audio recording. This transcription was then shared with two independent researchers to identify thematic elements. Given that the study's primary focus is on the participants' perspectives on various key issues affecting the maintenance and functionality of centrifugal pumps, it sought to investigate this through their personal experiences. The data was analyzed in this process to identify patterns of meaning, as described by Creswell and Poth (2016). The transcription was systematically coded using Braun and Clarke's six-step method. An inductive methodology was used to identify themes (Byrne, 2022). Each team member analyzed the data independently, and the consistency of theme interpretation across researchers was ensured. This approach was critical in reducing potential researcher bias and increasing the study's overall reliability.

3.4. Identifying patterns of meaning

Pattern-finding is one of the major methods of qualitative data analysis. According to Mezmir (2020), this process involves looking for the patterns that characterize the notions that the participants have. In this study, the author also made sure that they took a verbatim and unbiased record of the first focus group discussions and interviews. This meticulous transcription indeed made for a more enriched data set to analyze, while giving a highly detailed record of all the participant verbal interactions as well as their expressions. The transcribed data was then used to analyse for thematic content (Mezmir, 2020). For this purpose, the researcher alone went through the transcriptions several times as well as coding out portions that seemed significant or were repeated frequently. These annotations included common words, phrases, and initial perceptions of the findings.

3.5. Using inductive methods to identify themes

Inductive thematic analysis involves coming up with themes from the data under analysis rather than categorizing data into already existing themes or categories. This approach is particularly suitable in exploratory research where the purpose of the study is to make sense of participants' experiences. To carry out this study, Braun and Clarke's (2006) thematic analysis guidelines which are a guide to a closed procedure to analyze themes were used.

Step 1: Engagement with the Data: To familiarize the researcher with the data, the transcriptions were read several times. This sensitization stage is useful to get a feel for just how large and diverse the data is.

Step 2: The first type of coding is where the researcher gets to assign codes to portions of the collected data with the codes being a representation of the data's content. This process involved looking up information concerning the study's consideration of maintenance difficulties and strategies for centrifugal pumps (Majumdar, 2022). The coding of the data was inductive in that the codes were identified from the data gathered from the respondents.

Step 3: After identifying the codes, the researcher attempted to categorize them into potential themes. For this step, it was necessary to determine how these codes interacted and to search for overarching categories that would encompass the information derived from the data. The themes identified were further discussed and altered by the researchers in order to ensure that they fit the analyzed data appropriately.

Step 4: Reviewing Themes: The researcher checked each of the identified themes against the entire dataset to confirm their validity. This step ensured that the themes were not only consistent with the data but also identified all the possible experiences and perceptions of the participants (Majumdar, 2022). In some cases, the themes were refined or merged so that the analysis would be complete and cover all the categories.

Step 5: Defining and Naming: The themes were clearly defined and named in this stage. All of them were explained in detail, stating which aspect of the data was covered and why it was important. This step entailed developing a description of the themes where the essence of the themes was then supported by the participants' quotes.

Step 6: Developing the Report: At the end of the research, the researcher synthesized the themes into a report that responded to the research questions formulated in the study. Each of the themes was discussed in this report with examples of participants' quotes to offer a rich and detailed description of the results.

3.6. Reducing potential researcher bias

To eliminate research bias the following steps were taken to enhance the credibility and reliability of the research. First, there were multiple researchers involved in the process of analyzing data which enabled data triangulation. The obtained qualitative data needed to be interpreted individually by every member of the team and then the results were compared and discussed (Vindrola et al., 2020). This made it possible not to attribute the themes identified throughout the research process as bias of a certain researcher, but rather as an overall bias. Secondly, the researchers did not let their guard down during the analysis of the collected data. Reflexivity refers to the awareness of the contexts and biases and how to deal with them in the research (Maxwell et al., 2020). The researchers were always cautious of bias and how they would affect the overall outcome and findings. Third, the study adopted inter-observer reliability in an attempt to increase the validity of the study. To confirm the validity of the coded data interpretations, the emerging initial themes were narrated to the participants. This step helped establish the validity of the results of this study to a certain level. Moreover, to track all the steps of the analysis, all the procedures were documented. These involved documenting the coding processes, emerging themes, and interactions between the research team members. This makes the research process understandable to other people hence making the study more credible.

4. Results

The FGD with the technical team of the Soekarno Hatta Airport's Water Treatment Unit, revealed several critical issues impacting the maintenance and operation of centrifugal pumps. **Table 2** summarizes the root causes and corrective actions identified during the FGD for key issues encountered in the maintenance of centrifugal pumps at Soekarno Hatta Airport. Meanwhile, **Table 3** outlines the implementation plan for addressing these maintenance issues using the 5W1H framework.

Table 2. FGD transcript.

No	Question	Answer
1	What do you think is the best strategy for planning a preventive maintenance schedule in the manufacturing industry?	According to Mr. Laurent, as the supervisor of the water treatment unit, planning a preventive maintenance schedule in the manufacturing industry is a key task to maintain equipment performance and avoid unexpected damage. The best strategy for planning a preventive maintenance schedule can vary depending on the type of equipment, and facility size. According to Mr. Glendito a technician at the water treatment unit, start by analyzing historical data on equipment performance. Identify damage patterns, to no perfect, or frequent failures. According to Mr. Denny as the supervisor of the water treatment unit, make a maintenance schedule that follows production activities and choose the most suitable time to avoid excessive distractions. According to Mr. Ardian as the supervisor of the water treatment unit, determine the frequency of maintenance based on risk analysis. More important equipment may require more frequent maintenance, while other equipment can take longer.

Table 2. (*Continued*).

No	Question	Answer
2	How do you manage equipment and machines that require regular maintenance?	According to Mr. Anuar as a water treatment unit technician Managing equipment and machines that require routine maintenance is an important part of maintaining the productivity and efficiency of the equipment. According to Mr. Berry as the technical team of the water treatment unit by referring to the equipment SOP we can make a plan for maintenance activities so that the pump equipment can work properly, but with these very limited personnel, we can only do the treatment as much as possible. According to Mr. Ardian, in this case, we use the periodic monitoring method, by carrying out daily checks and conducting regular visual monitoring before the equipment is damaged. higher. According to Mr. Ramlan the technical team of the Water Treatment Unit with the constraints of limited personnel and tools that require routine maintenance, there are still constraints, there are many corrective activities in the clean water distribution channel so this routine maintenance is very difficult to carry out.
3	How do you manage the inventory of critical parts and equipment to maintain availability during maintenance activities?	According to Mr. Rifai as the staff of the water treatment unit, currently, we have not fully inventoried the spare parts in our warehouse, we are still using a manual record system to carry out the inventory of the spare parts, even then there are still many obstacles, such as forgetting to record, forgetting to place them so that this condition is still not organized in terms of spare parts management in this unit. According to Mr. Yusuf, to manage these spare parts, the right method is needed so that these spare parts can be controlled properly. According to Mr. Laurent, in addition to the right method of RKAP control spending is appropriate so that these vital goods are always available in the warehouse of the water treatment unit.
4	How do you plan a routine maintenance schedule for pumps in your facility?	Plan a maintenance schedule by following the existing SOPs according to the equipment maintenance time, but there are several obstacles in carrying out this maintenance process, one of which is the availability of spare parts and limited personnel.
5	Do you use predictive maintenance or special monitoring technology for your pumps? If so, how does it contribute to maintenance efficiency?	In this case, we have not fully implemented practical maintenance this program is very good if it is carried out sustainably, but in this unit, we have not sustainably implemented this program.
6	How do you measure the productivity and performance of a pump after undergoing a maintenance procedure?	Of course, by looking at the daily reports that are always made by the service team, monitoring facilities by adhering to SKEP 157, and the report on the results of the maintenance team.
7	What is the purpose of routine maintenance for centrifugal pumps? Why is this important in maintaining pump performance?	One of the primary purposes of routine maintenance is to maintain centrifugal pumps performing at peak efficiency. By performing regular maintenance, the pump will be able to deliver the most efficient flow of liquid or fluid. Regular maintenance assists in recognizing faults or potential harm before they worsen. This includes checking important components like seals, bearings, impellers, and motors. By spotting malfunctions early, we can take precautionary measures to avoid unplanned production disruptions. Centrifugal pumps' service life can be extended with proper routine maintenance. We can avoid costly pump replacements and optimize their use by taking care of the components and keeping them in good working order. By doing routine maintenance, we can lessen the likelihood of unexpected failure. By keeping these components in optimal condition, we can improve the energy efficiency of the pump, which in turn reduces operational costs.

Table 2. (*Continued*).

No	Question	Answer
8	Why should centrifugal pumps undergo regular maintenance? What are the risks if these treatments are neglected?	Neglecting maintenance for centrifugal pumps can lead to the failure of components like seals, bearings, impellers, and motors, disrupting production and requiring costly repairs. Pumps that are not properly maintained can endanger workers. Pump failure or leaking can cause an accident, putting workers' health and safety at risk. A pump that is not properly maintained may require more energy to produce the same flow, which raises operational energy expenses. Lack of maintenance might limit the pump's life, necessitating more frequent replacement, which incurs more costs.
9	When should routine maintenance for centrifugal pumps be performed? Is there a specific schedule or frequency to follow?	The more often the pump is used, the more often routine maintenance needs to be performed. Pumps that are used continuously may require more frequent maintenance compared to those used sporadically. The environment in which the pump operates also affects the frequency of maintenance. Dirty, dusty, or corrosive environments may require more frequent maintenance to prevent damage from these conditions. The pump manufacturer may provide guidance on the recommended maintenance schedule. We must follow these guidelines or the manufacturer's recommendations to maintain optimal warranty and performance. Centrifugal pumps may be equipped with additional equipment such as temperature sensors, vibration sensors, or leak monitoring. Maintenance and inspection of these additional equipment should also be included in the routine maintenance schedule. Daily visual inspections can include monitoring temperature, pressure, and strange noises while the pump is operating. This check can help detect early problems. More in-depth inspections, such as bearing temperature and lubrication checks, can be performed weekly. It also includes seal and bearing checks for wear and tear. Monthly inspections may involve checking additional sensors, such as vibration sensors, and checking pump motors. Additional equipment inspections should be carried out as needed. More in-depth maintenance, such as lubricant changes and re-checks of key components, may be required at annual intervals or based on manufacturer guidelines.
10	Who is responsible for performing routine maintenance on centrifugal pumps? Is there a dedicated team or technician assigned to this task?	In this case, the person in charge is an Assistant Manager, but in its implementation assisted by supervisors and technicians, related to this maintenance, this unit already has a special team that has started working on this activity since May 2023.

Table 2. (*Continued*).

No	Question	Answer
11	How should routine maintenance on centrifugal pumps be performed? What are the practical steps to follow, and are there any special tools required?	The first step is to perform a visual inspection of the pump. Inspect the entire pump unit for any damage, wear, or leaks. Pay attention to whether there are any leaks in pipes, connections, or seals. Inspect the pump bearings to make sure they are not subject to wear or damage. Also, make sure that the lubrication system is working properly. We may need tools such as temperature and pressure gauges to check lubrication. Check the pump seal for wear or leaks. Make sure the seal is in good condition and can withstand the pressure of the liquid. Check the impeller (centrifugal wheel) to see if there is any damage or wear and tear. A damaged impeller can interfere with fluid flow and pump performance. Inspection of the motor that drives the pump is an important part of the maintenance. Make sure the motor is in good condition and the motor has sufficient lubrication. Check the piping system, including valves, connections, and blockages. Make sure there are no obstructions that interfere with the flow of fluids. Use a measuring device such as a manometer or thermometer to measure the temperature and pressure of liquids at various points in the system. This helps in ensuring optimal pump performance. If the pump is equipped with additional sensors such as vibration sensors or temperature sensors, check the data provided by these sensors to detect changes or disturbances. If during the inspection it is found that the components have been damaged or significantly worn, immediately replace the necessary parts. During routine maintenance, it is important to record all actions taken, findings, and measurements. This documentation is useful for keeping track of treatment history and assisting in planning future treatments. Make sure the lubricant in the pump is properly managed according to the manufacturer's recommendations. Use the appropriate lubricating tool and follow the guidelines for the amount and frequency of lubrication. Keep the pump and its surroundings clean and free of dust and debris. The cleanliness of the environment around the pump is also important to prevent disturbances.

Table 3. Implementation plan for maintenance of centrifugal pumps using 5W1H.

No	Issue	Main Cause	Corrective Plan	Where	When	Who (Person in Charge)
1	Pump bearing damage and rough noise	Lack of availability of bearings and grease, leading to extended downtime for pump repairs	1. Apply grease and replace bearings in the centrifugal pump 2. Procure bearings and grease before warehouse stock runs low 3. Record inventory in the warehouse to determine when to procure grease and bearings	1. Pump room at the pumping station 2. Pump room at Terminal 1 3. Pump room at Terminal 3	As soon as possible (December 2023)	1. Technician 2. Senior Technician 3. Supervisor 4. Asst. Manager

Table 3. (*Continued*).

No	Issue	Main Cause	Corrective Plan	Where	When	Who (Person in Charge)
2	Broken and uneven pump coupling rubber	Limited personnel in one shift, only three people, making it challenging to replace coupling rubber	Recruit more operation and maintenance staff to facilitate both heavy and light maintenance processes	1. Pump room at pumping station 2. Pump room at Terminal 1 3. Pump room at Terminal 3	As soon as possible (December 2023)	1. Technician 2. Senior Technician 3. Supervisor 4. Asst. Manager
3	Damage to gland packing and mechanical seal in the pump	Damage to bearings causing misaligned pump shaft rotation leading to leaks in gland packing or pump's mechanical seal	1. Conduct regular maintenance on pump bearings 2. Check the mounting bolts of packing in the pump 3. Replace gland packing and mechanical seal in the pump	1. Pump room at the pumping station 2. Pump room at Terminal 1 3. Pump room at Terminal 3	As soon as possible (December 2023)	1. Technician 2. Senior Technician 3. Supervisor
4	MCC pump control panel not operational	MCC panel not routinely undergoing preventive maintenance as per SOP	1. Test voltage between the MCC panel and pump 2. Increase personnel to ensure optimal maintenance activities	1. Control panel room at the pumping station 2. Control panel room at Terminal 1 3. Control panel room at Terminal 3	As soon as possible (December 2023)	1. Technician 2. Senior Technician 3. Supervisor
5	The PLC control panel is not operational	PLC control panel not routinely maintained or cleaned, leading to thick dust accumulation	Conduct in-depth personnel training regarding PLC systems	1. Control panel room at the pumping station 2. Control panel room at Terminal 1 3. Control panel room at Terminal 3	As soon as possible (December 2023)	1. Technician 2. Senior Technician 3. Supervisor 4. Asst. Manager
6	Motor winding in centrifugal pump trips or burns out	Limited working tools preventing effective preventive maintenance	Regularly check pump windings and monitor pump load during motor operation	1. Pump room at pumping station 2. Pump room at Terminal 1 3. Pump room at Terminal 3	As soon as possible (December 2023)	1. Technician 2. Senior Technician 3. Supervisor

Based on the establishment of a Centrifugal pump maintenance action plan through the implementation of 5W + 1H, solutions to the root problems or issues were obtained, which include the following:

4.1. Pump bearing failure and noise issues

The primary cause of bearing damage and noise was identified as the inadequate availability of bearings and grease. This shortage led to prolonged downtime for pump repairs. The proposed corrective actions include regular greasing, timely replacement of bearings, and proactive procurement of bearings and grease. Additionally, maintaining an up-to-date inventory record in the warehouse is essential to pre-emptively address stock depletion. These actions are crucial for reducing downtime and enhancing pump longevity, emphasizing the need for a robust inventory management system.

4.2. Coupling rubber damage in pumps

Limited personnel availability during shifts posed significant challenges in replacing damaged coupling rubbers. The FGD suggested recruiting additional operational and maintenance staff to ensure the smooth execution of both heavy and light maintenance tasks. This challenge highlights the critical role of human resources in maintenance management and the necessity of adequate staffing to ensure timely and effective maintenance.

4.3. Gland packing and mechanical seal failures

The misalignment of the pump shaft due to bearing damages was identified as a cause of leaks in gland packing and mechanical seals. Regular maintenance of pump bearings, along with diligent inspection and replacement of gland packing and mechanical seals, were suggested as corrective measures. This issue underscores the importance of routine maintenance and the interconnected nature of pump components where failure in one part can lead to cascading issues in others.

4.4. MCC pump control panel malfunctions

The non-operational state of the MCC pump control panel was attributed to the lack of routine preventive maintenance as prescribed in the Standard Operating Procedures (SOPs). The recommended corrective measures include voltage testing between the MCC panel and the pump and increasing personnel to ensure optimal maintenance. This instance points to the necessity of adhering to SOPs and the impact of preventive maintenance on equipment reliability.

4.5. PLC control panel failures

The PLC control panels were not functioning optimally due to inadequate maintenance and cleaning, leading to excessive dust accumulation. In-depth training of personnel on PLC systems was recommended. This situation highlights the need for regular maintenance and the importance of personnel training in the effective operation and upkeep of sophisticated control systems.

4.6. Centrifugal pump motor failures

The limitation in working tools was recognized as a hindrance to effective preventive maintenance, leading to motor winding issues. Regular checks of pump windings and monitoring pump load during operation were suggested. This issue underscores the importance of having the right tools and equipment for preventive maintenance, which is crucial for preventing catastrophic failures and ensuring the smooth operation of the pumps.

4.7. Summary of focus group discussion outcomes

The FGD outcomes indicate that a combination of procedural, technical, and human resource factors contribute to the maintenance challenges of centrifugal pumps.

The 5W1H approach provides a systematic method to identify these underlying causes and develop targeted corrective actions. Implementation of these actions requires a coordinated effort involving technicians, senior technicians, supervisors, and assistant managers, ensuring that each issue is addressed comprehensively and promptly. This collaborative approach is key to improving the efficiency and reliability of the pumps, ultimately contributing to the smooth operation of the water treatment unit at the Soekarno Hatta Airport.

4.8. OEE and the six big losses

Therefore, OEE and six big losses are adopted in this research to measure the impact of maintenance practices on the performance of centrifugal pumps in Soekarno-Hatta Airport. OEE is a comprehensive metric that measures the effectiveness of equipment by considering three key components: availability, performance, and quality (Van et al., 2022). It reveals the extent to which the equipment has been employed to the possible employment of the equipment. While calculating the overall equipment effectiveness, the actual operating time, planned production time, and more than actual planned standard production were considered. The big six losses: Include breakdowns, setup and adjustment loss, small stop, reduced speed, startup reject and production rejects. These losses were deduced from several logbooks from the maintenance team which include the breakdown log, the alteration log, and the production halt log.

4.9. Results

The breakdown of OEE as well as the six big losses provided an understanding of the maintenance and performance issues of the centrifugal pumps. The OEE for the pumps was set at 65%; this was still below the desired World Class benchmark of 85% endorsed by JIPM. The breakdown of the OEE by its components showed that the availability was very poor due to breakdowns and slow repair. The study on the six big losses indicated that breakdowns were the biggest contributors to equipment unreliability since they accounted for 40 percent of the total losses. In addition, setup and adjustment losses and reduced speed also contributed greatly to 20% and 15%. Such losses show that there is a need to improve the maintenance program, such as preventive maintenance, and proper usage of resources to improve OEE. In addition to this, by integrating the OEE and the six big losses, there is a clear picture of the maintenance issues of the centrifugal pumps and ways of enhancing the effectiveness of the operation and the dependability of the equipment as well.

5. Discussion

The study at Soekarno-Hatta Airport focused on investigating maintenance issues of centrifugal pumps through qualitative methods and focus group discussions. It identified critical problems including bearing damage, control panel malfunctions, and staffing shortages. Systematic corrective actions were recommended, highlighting the importance of regular maintenance, adequate staffing, and adherence to standard operating procedures.

The 5W1H analysis method helps in understanding various aspects of a problem or situation thoroughly. 1). Evaluate the condition and performance of the centrifugal pump based on historical data, visual inspection, and condition monitoring, and draw up an action plan to address any issues identified during the evaluation, including preventive maintenance schedules, repair procedures, and improved operational efficiency. 2). Centrifugal pumps are a critical component in the water handling system in airports. Pump failures can cause major disruptions in airport operations; by conducting qualitative evaluation and corrective planning, we can identify and address potential problems before they develop into major failures. 3). Planned and timely maintenance can reduce emergency repair costs and unexpected downtime, and ensure the pump is operating properly to avoid safety risks that may arise due to pump failure. 4). Evaluation and maintenance should be carried out periodically, e.g., monthly or every three months, depending on the manufacturer's conditions and recommendations, carried out after a failure has occurred to determine the root cause and prevent similar events in the future, and when major components are replaced, evaluation and adjustment of the maintenance plan may be necessary. 4). Evaluation is carried out at Soekarno-Hatta Airport, especially in locations that have centrifugal pump installations such as water pump stations and water treatment plants, and carried out in the airport maintenance workshop. 5). Maintenance technicians and engineers who are responsible for daily maintenance and repair of pumps, Managers who oversee the overall operation and ensure that maintenance is carried out according to schedules and standards, third parties who supply components during maintenance, and Personnel who ensure that all maintenance work meets the established quality and safety standards. 6). Collect historical operational and maintenance data, conduct visual inspections, and monitor conditions using sensors and diagnostic tools, analyze conditions to identify problems and causes, develop preventive and corrective maintenance plans that include maintenance schedules, repair procedures, and improvement recommendations, implement maintenance and repair plans on schedule, monitor their implementation, and adjust plans based on the latest findings and monitoring results, and finally conducting periodic evaluations to ensure that the corrective actions taken are effective and make adjustments if necessary.

Pump bearing failures and noise issues are often attributed to insufficient maintenance or the use of substandard components. Proactive maintenance and replacement strategies are essential to prevent these issues, as suggested by various researchers (Exner et al., 2017; Furch and Krobot, 2020; Poklukar et al., 2017; Wang et al., 2020). Regular inspections and timely replacement of coupling components can mitigate rubber damage in couplings, a frequent issue. The integrity of gland packing and mechanical seals is critical. Syahrial and Nusraningrum (2022) emphasized the importance of regular monitoring and maintenance to ensure pump reliability. Furthermore, malfunctions in MCC and PLC control panels, vital for pump operation, can cause inefficiencies and shutdowns. Routine maintenance, including electrical inspections and software updates, is essential to avoid such problems (Arief and Nusraningrum, 2021; Nusraningrum, 2017; Nusraningrum and Arifin, 2018; Solikhah and Nusraningrum, 2022; Syaputra and Nusraningrum, 2022).

Motor failures in centrifugal pumps, due to electrical faults, overheating, or wear and tear, underline the need for thorough maintenance strategies. These should include routine inspections, performance monitoring, and prompt repairs or replacements (Daman and Nusraningrum, 2020; Nusraningrum, 2017; Nusraningrum and Arifin, 2018; Nusraningrum and Setyaningrum, 2019; Solikhah and Nusraningrum, 2022; Syaputra and Nusraningrum, 2022). Adopting strategic maintenance, through scheduled plans and effective use of CMMS for managing spare parts and tasks, is crucial. This approach addresses technical problems and enhances the operational efficiency, reliability, and lifespan of pumping systems (Alburaiesi, 2020; Ariansyah et al., 2020; Medenou et al., 2019), facilitating optimal resource utilization and uninterrupted operation.

5.1. Implication of Findings

Application in similar contexts

The results of this research may be relevant to the Soekarno-Hatta Airport's Water Treatment Unit, but they can be considered universally applicable to other similar infrastructure facilities in other countries. This paper will be useful to airports, industrial plants, municipal water treatment facilities, and other organizations and agencies that utilize centrifugal pumps for their day-to-day operations. Some of them include Total Productive Maintenance (TPM), regular checks on equipment, and the use of the 5W+1H format of asking questions, which are generic and can be applied anywhere to improve reliability and operation efficiency. The focus on frequent greasing, timely replacement of worn-out parts, and updating the list of spare parts correlates with the norms of worldwide industrial equipment maintenance.

5.2. Implications for practice

There is no doubt that the effective and efficient execution of preventive maintenance programs is significant. By detecting and solving typical problems, for example, bearing damages and control panel troubles, organizations can minimize equipment outage time and enhance its durability. It is crucial to establish routine maintenance programs, ensure employees responsible for maintenance receive the proper training, and implement maintenance management computer software systems to monitor and track maintenance activities (Beniaciu et al., 2021). This approach reduces cases of breakdowns and enables the checking of all parts to guarantee that they are working effectively, increasing efficiency. Proper staffing and staff training and development for the maintenance personnel are important. The research underscores the need for adequate staffing and staff training to manage regular and unexpected maintenance work. This recommendation will not only be appropriate for the water treatment unit but also for any firm with complicated machinery. Employment of training and development initiatives especially in areas such as Programmable Logic Controllers (PLCs) guarantees that staff is prepared to handle and maintain technologically enhanced equipment (Karatsuipa, 2023). Overall, this investment in human resources leads to enhanced maintenance performance and operational effectiveness.

5.3. Policy implications

Implementing and meeting different maintenance standards and policies like SKEP 157 of 2003 and Overall Equipment Effectiveness (OEE) metrics is important for legal requirements and effectiveness (Cheah et al., 2020). Policymakers and regulatory authorities should require that these standards are adhered to by setting specific maintenance requirements and frequency for auditing. It means that maintenance practices are not only uniform but also conforming to the industry's best practices thus increasing the reliability and safety of vital installations. Maintenance efficiency is significantly influenced by policies favoring the adoption and implementation of CMMS (Ullah et al., 2023). To this end, policymakers can ensure that organizations adopt CMMS by offering incentives to organizations willing to invest in the technology. These systems give real-time information on the performance of the equipment and the maintenance required hence more informed strategies.

5.4. Strategic and operational efficiency

Total Productive Maintenance (TPM) is important for preventing machine breakdown and enhancing productivity. TPM creates an environment where all employees become actively involved in maintaining the equipment (Singh and Gurtu, 2022). This makes the maintenance to be a shared responsibility so that it can be more effective in maintaining the equipment. TPM therefore helps increase the efficiency, productivity, and sustainability of the organization by minimizing the downtime of the machines. This suggests the importance of a long-term approach towards the maintenance of infrastructure as indicated in the study by Mohanty et al. (2022). By focusing on solving urgent maintenance problems and building the proper groundwork for long-term infrastructure performance, organizations can further the durability and efficacy of their infrastructures. This is especially important for high-risk facilities that are involved provision of essential services, like water treatment plants.

5.5. Implications for broader industrial practices

The focus of the research lies in the comparison with industry benchmarks and performance measurement with tools like OEE. These benchmarks can be useful for an organization to determine where it is effective and ineffective when it comes to its maintenance strategies. Performance assessments also assist in fine-tuning maintenance practices, thus focusing on improvement (Abbas et al., 2021). The corrective measures discussed above although founded on centrifugal pumps are applicable and can be scaled to different types of equipment and organizations. The elements, such as regular maintenance, a sufficient number of personnel, and ongoing training, can be implemented in various fields, including production, manufacturing, and energy. This versatility ensures that the findings are useful in as many areas as possible by promoting a systematic approach to maintenance management.

5.6. Recommendations

Our study underscores the criticality of adopting a comprehensive maintenance strategy to address the multifaceted challenges identified in the operation and maintenance of centrifugal pumps. The findings from the focus group discussions

(FGD) with the technical team highlight the need for systematic approaches to pre-emptively mitigate risks and enhance the efficiency of water treatment operations. Based on our analysis, we propose several recommendations that not only address the immediate issues but also contribute to the sustainability and reliability of the pumping systems in the long term.

The essential first step is the implementation of a proactive maintenance strategy, including regular lubrication and timely replacement of bearings, which are vital for optimizing pump performance and longevity. This strategy should be supported by a dynamic inventory management system that ensures the availability of critical components, thereby minimizing downtime and operational disruptions. The operational challenges underscored by limited staffing during shifts necessitate the strategic recruitment of additional maintenance and operational personnel. Expanding the team will allow for a broader range of maintenance tasks to be performed more efficiently, ensuring timely responses to both routine and emergent maintenance requirements. Regular maintenance checks, particularly on pump bearings and the secure fastening of pump packing mounting bolts, are crucial. These measures facilitate early detection of potential issues, preventing extensive damage. Preventive maintenance, including the routine replacement of gland packing and mechanical seals, is indispensable for maintaining the integrity and operational efficiency of the pump systems.

Our recommendations also emphasize the importance of regular voltage testing between Motor Control Center (MCC) panels and pumps. Expanding the maintenance team to include personnel with specialized skills in managing and maintaining Programmable Logic Controller (PLC) systems is crucial for the uninterrupted operation of these sophisticated control systems. The effective management of PLC systems, identified as a significant challenge, calls for in-depth training programs for technical staff. Enhancing the skill set of the maintenance team not only aids in the effective troubleshooting of PLC-related issues but also fosters a culture of continuous improvement and innovation within the facility. Lastly, the routine monitoring of pump windings and operational load is instrumental in early problem identification. This proactive approach, coupled with the adoption of appropriate preventive maintenance strategies, is key to avoiding catastrophic failures and ensuring the seamless operation of centrifugal pumps. These recommendations, framed within the 5W + 1H approach, present a structured method to tackle the identified challenges. Implementing these strategies requires a coordinated effort across multiple levels of the technical team, from technicians to senior managers. Such a collaborative approach is vital for enhancing the operational reliability and efficiency of the water treatment unit, contributing significantly to the overall operational excellence of Soekarno Hatta Airport.

5.7. Conclusions, limitations, and future research

To increase activities and preventive maintenance, it is necessary to bring in additional personnel for maintenance activities, as well as to implement Total Productive Maintenance (TPM) autonomous maintenance. This effort will support pump maintenance activities for centrifuges and will be complemented by the implementation of planned maintenance and an inventory of spare part assets in the water treatment unit warehouse. The implementation of green TPM aims to enhance the quality of pump maintenance and the distribution of clean water in the water treatment unit by prioritizing autonomous maintenance. This is achieved by adopting a Control Monitoring Operational System (CMOS) and a Remote Control Management System (RCMS). It is hoped that these systems will facilitate maintenance activities for pumps and enable monitoring of both electrical power usage and clean water consumption at Soekarno Hatta airport. The application of TPM in the water treatment unit, assessed by calculating the Overall Equipment Effectiveness (OEE) of pumps from January to July 2023, reveals that the average OEE value for 26 centrifugal pumps remains below the global OEE standard of 85%. TPM implementation in this unit is grounded on OEE calculations and group discussion forums. Efforts include implementing autonomous maintenance through CMOS and RCMS, conducting planned maintenance according to the Standard Operating Procedures (SOP) manual, providing training to all personnel in the water treatment unit, adhering to the ISO 45,001 water treatment system implemented by the Company, applying focused maintenance, ensuring quality maintenance, and fostering development management to support a work environment and culture conducive to innovation and allowing individuals to take active roles in cross-unit coordination.

This research is limited to focusing on implementing green TPM by analyzing OEE and the six big losses. It has not yet developed a comprehensive green TPM design across all existing TPM pillars, nor has it developed a process inventory and data collection system for spare parts maintenance for centrifugal pumps. PT Angkasa Pura II, as the manager of Soekarno-Hatta Airport, can consider enhancing the visibility and accessibility of programs to provide drinking water throughout the airport area. Practical steps, such as installing more water dispensers and offering free drinking water that is easily accessible to passengers at each terminal and public area, can raise awareness of this facility. Additionally, creative and educational campaigns through social media, information boards, and onboard announcements can promote the importance of using safe tap water and help reduce plastic bottle waste at airports. With a collaborative effort between airports, airlines, and related partners, the drinking water supply program at Soekarno Hatta Airport can become more effective and have a greater positive impact on the environment and public well-being.

Author contributions: Conceptualization, DN and ARR; methodology, DN and ARR; software, DN and ARR; validation, DN, ARR and WW; formal analysis, DN and ARR; resources, DN and ARR; data curation, DN and ARR; writing—original draft preparation, DN and ARR; writing—review and editing, ZYT, WW, LJ and NH; visualization, DN, ARR and WW; supervision, DN; project administration, DN and WW; funding acquisition, WW. All authors have read and agreed to the published version of the manuscript.

Conflict of interest: The authors declare no conflict of interest.

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