Development of a technical service work order system for a South African private hospital

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ABSTRACT

Private hospitals in South Africa's bilateral public/private healthcare system are known to provide clinical care on par with global standards. To maintain and improve this level of care, effective technical maintenance is required to manage risks and ensure patient safety. A large private hospital in South Africa consists of 16 operating theatres and 469 beds. The facility operates from several buildings of varying ages and interconnected levels. The technical team responsible for maintenance at this hospital faces challenges with unresolved work orders and labour utilisation. This research demonstrates how a work order system is developed to consolidate maintenance data and alert technicians to open work orders.

The requirements for the technical services work order system are derived from a thorough analysis of the shortcomings in the existing system, complemented by insights from industry best practices as identified in the literature. Statistical process control charts are used as a foundational mechanism for the decision support system architecture, resulting in efficient flagging mechanisms and reporting features that collectively promote timely work order closures and proactive maintenance practices. Qualitative results and scenario testing of the system confirm reduced maintenance requests backlog and enhanced operational efficiency.

Keywords: hospital maintenance, technical services, statistical process control, system architecture

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1 INTRODUCTION

The highest standard of healthcare in Africa is found in South Africa [1]. The healthcare system in South Africa is bilateral – it comprises a public and private sector. Approximately 20% of the country's population seeks private healthcare, which operates on a for-profit business model, whereas the other 80% of the population seeks public, government-funded healthcare [2]. Although the private healthcare sector in South Africa is much smaller than the public sector, it accounts for about half of the sector's expenditure [3].

One of the biggest private hospital facilities in South Africa is located in Berea, Durban. It is a 469-bedded hospital, consisting of 16 operating theatres and two cardiac catheterisation laboratories (cath labs). There are 140 highly skilled and experienced specialists practising at the facility. The buildings situated on the facility's premises range in age and level. Renovations are underway at the facility, including the upgrade of theatres to make them more modern and efficient. Maintenance management of this large hospital is consequently a considerable undertaking.

Additionally, maintenance management is closely linked to patient safety and forms an integral part of risk management. Since patient safety is also essential for the emotional well-being of nursing staff [4], the critical importance of effective maintenance management extends to stakeholders throughout the hospital. Attending to patient safety through effective risk management and a technical maintenance approach not only promotes greater resource efficiency and cost savings but also elevates patient satisfaction by ensuring the delivery of higher-quality and more reliable services [5].

The technical services department of this hospital is the custodian of all engineering-related activities at the facility. The disciplines covered by the technical team include electrical engineering, mechanical engineering, civil engineering, and clinical engineering.

The technical services department is responsible for ensuring the timely maintenance of all critical and non-critical equipment, encompassing preventative and reactive maintenance. This includes routine tasks as part of preventive maintenance and responding to equipment breakdowns through reactive maintenance. The technical team's primary objective is to identify and mitigate risks, ensuring a safe environment for patients, staff and visitors throughout the facility.

The technical team at this specific hospital faces challenges with unresolved work orders and fluctuating labour utilisation. Notably, these challenges pertain only to technical work orders, which include engineering-related maintenance tasks such as preventative and corrective activities. This does not include clinical or operating theatre equipment, nor outsourced work, thereby ensuring that the focus remains solely on the department's core technical operations.

Figure 1 provides a high-level overview of the existing work order process, illustrating how maintenance requests are received, assigned, executed, and recorded. The process flow highlights inefficiencies within the current system, including reliance on manual notifications, use of paper-based job cards, and delays in updating the records. Collectively, these factors contribute to prolonged turnaround times and unresolved work orders, emphasising areas where targeted interventions could enhance operational efficiency and reduce delays.

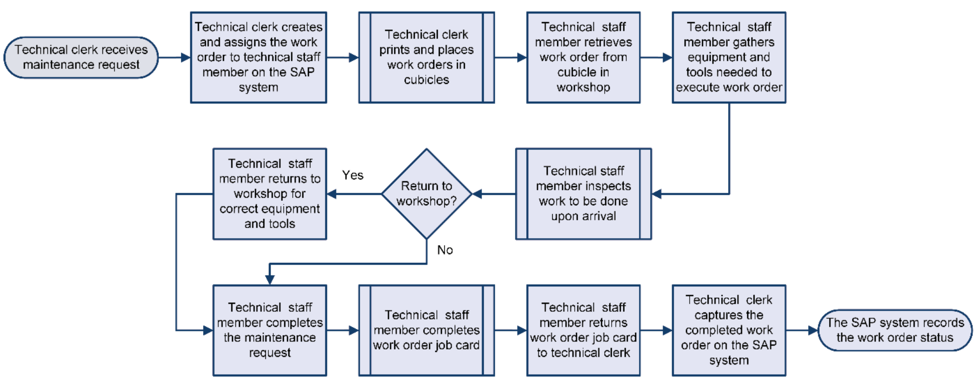


Figure 1: Work order process flow diagram

Compliance levels reveal a concerning trend of an exponential drop in closed work orders and a concurrent increase in both technically closed and open work orders, particularly in the final quarter of the year, with an average of 654 unresolved work orders per month, as shown in Figure 2.

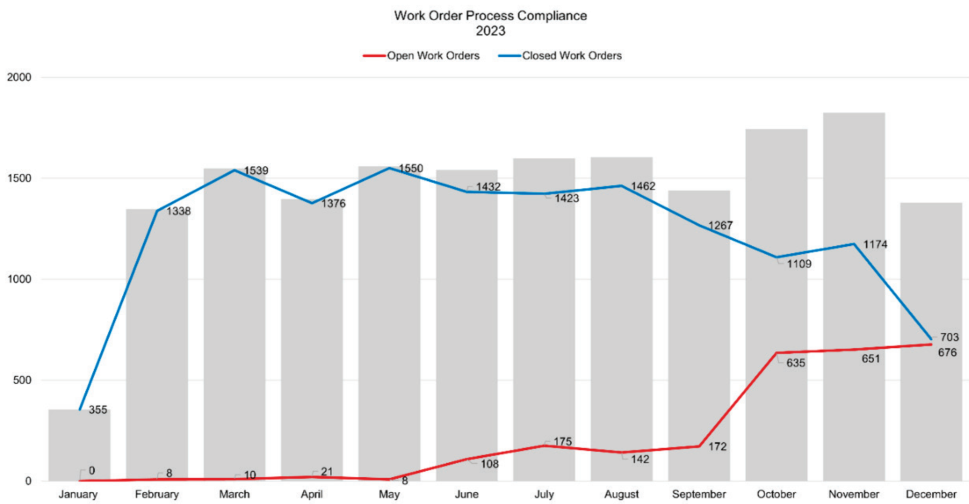


Figure 2: Work order process compliance for 2023

The objective of this research is to address this challenge by developing a system to allow the work orders in the technical services department to be closed sooner, ensuring that labour utilisation is more uniform. This study addresses a specific solution to the case study by applying established theoretical concepts to the maintenance management challenges faced by the technical services department of a private hospital. Our paper aims to explain the theory behind the solution for the specific case study and demonstrate the development of a practical solution. Section 2 of this paper provides an overview of the literature on developing a technical work order system. Section 3 expands on the methodology, architecture and design of the system. This paper concludes in Section 4, where the technical management work order system is demonstrated, and scenario testing results are discussed.

2 LITERATURE OVERVIEW

This literature review aims to provide a comprehensive understanding of maintenance management theories and practices within the context of a private hospital setting in South Africa, informing the design of our solution. The study explores the application of maintenance theories, such as asset management, to optimise the efficiency and effectiveness of maintenance operations, with a specific focus on work order management. It investigates potential strategies for improving work order generation, tracking, and analysis by examining the role of database design and the Internet of Things (IoT). Additionally, the study assesses the utility of Statistical Process Control (SPC) and advanced tools such as Computerised Maintenance Management Systems (CMMS), Power BI, and Microsoft Access in enhancing work order management processes. Through a thorough analysis of existing literature and relevant case studies, this review seeks to identify best practices and potential areas for improvement in work order management within the South African private hospital context.

2.1 Asset and Maintenance Management

Maintenance is the process of preserving equipment, facilities, and systems to ensure continuous and effective operations [6]. It also involves coordinating activities to ensure optimal asset performance and longevity [7].

Maintenance management is a critical function in various industries, ensuring that assets are adequately maintained to prevent unexpected breakdowns and to extend their operational lifespan. In the healthcare sector, efficient maintenance management is essential for ensuring everyone's safety when utilising the premises and the reliability of various types of equipment [8]. Delays in processing maintenance work orders can lead to equipment failures, which in turn impact the quality of the service provided.

Maintenance involves preserving equipment, systems, and facilities to ensure continuous and reliable operation. It includes preventative actions to avoid breakdowns, corrective actions to fix issues, and predictive actions to anticipate potential failures [9]. Asset management is a systematic approach to managing assets throughout their lifecycle, from acquisition to disposal, to maximise value, reliability, and cost-effectiveness [7].

Maintenance management coordinates these activities to optimise asset performance, extend operational life, and support patient safety [10]. It encompasses maintenance planning, scheduling, and performance evaluation, using key performance indicators such as uptime, mean time between failures (MTBF), and maintenance costs to ensure efficient and effective operations [11]. These concepts form the foundation for effective work order management in hospital maintenance systems.

2.2 Quality Management and Statistical Process Control

Quality management in maintenance ensures that activities meet predefined standards and support organisational goals and patient safety [12]. Tools such as Statistical Process Control (SPC), Shewart control charts, and Failure Mode and Effects Analysis (FMEA) are used to monitor processes, detect deviations, and identify areas for improvement [12], [13]. Although resource-intensive, these tools enable timely interventions and prevent equipment failures that could compromise patient care.

Quality improvement methodologies, including Six-Sigma and Lean, enhance efficiency by reducing defects and eliminating non-value-added activities, providing a structured approach for continuous improvement in hospital maintenance operations [12]. Applying quality management and SPC tools supports consistent maintenance standards and high-quality operational outcomes.

2.3 Data Analytics and Business Intelligence for Maintenance

Data analytics and business intelligence support the optimisation of maintenance activities and informed decision-making [10]. Predictive analytics utilises historical and real-time data to forecast equipment failures and schedule timely interventions, thereby reducing unplanned downtime and enhancing asset reliability [5]. Prescriptive analytics extends this by recommending specific actions to mitigate potential issues, enhancing asset performance and resource allocation [5].

Business intelligence tools, such as Power BI and Microsoft Access dashboards, transform raw data into actionable insights. These tools enable the monitoring of key performance indicators (KPIs), such as equipment uptime, mean time between failures (MTBF), and maintenance costs, helping to identify inefficiencies and support data-driven decisions.

Big data analytics further enhances maintenance management by processing large volumes of data from IoT sensors, maintenance logs, and operational systems [10]. This enables comprehensive asset performance analysis and facilitates a shift from reactive to proactive maintenance strategies, improving overall operational efficiency and decision-making.

2.4 Ergonomics

Ergonomics, the study of interactions between humans and other system elements, is critical in hospital maintenance management [14]. Applying ergonomic principles helps reduce physical strain, fatigue, and cognitive overload among maintenance personnel, enhancing efficiency, safety, and job satisfaction [15]. Properly designed tools, organised workspaces, and intuitive interfaces enable maintenance staff to perform tasks more effectively and respond rapidly to equipment needs [14]. Integrating ergonomics supports worker well-being and improves maintenance quality, reduces errors, and optimises operational performance, ultimately contributing to reliable healthcare service delivery. Literature positions ergonomics as a factor influencing the efficiency of work order processing. For instance, proper workstation design can minimise fatigue and improve the efficiency of maintenance staff, leading to better care for assets.

2.5 Database Design for Maintenance

Effective database design is essential for efficient maintenance management, enabling timely access to asset histories, work orders, maintenance schedules, and resource allocation [10], [16]. Basic database systems can handle transactional data, while relational databases and data warehouses, supporting comprehensive analysis, performance evaluation, and improved planning, are more suitable for hospitals. Advanced database structures facilitate the identification of maintenance patterns, optimise scheduling, and enhance resource allocation, thus ultimately contributing to operational efficiency and patient care.

3 METHODOLOGY

The project was executed in alignment with the V-Model methodology, a structured framework that integrates system development with corresponding verification and validation activities [17]. This approach allowed each system design phase – requirements gathering, system analysis, system architecture, model design, and final design – to be systematically tested through unit, integration, system, and acceptance evaluations. Applying the V-Model ensured that each phase was meticulously validated and verified, contributing to the successful development of the technical service work order system, which met stakeholder requirements, functioned correctly within the architecture, and supported efficient work order management.

3.1 Requirements gathering and system analysis

Requirements for the technical work order system were gathered from an analysis of the problems in the current system. The system analysis combined qualitative and quantitative methods, focusing on identifying the root causes contributing towards delayed maintenance work order processing in the private hospital of this case study.

An affinity diagram was used to visually organise and categorise related qualitative data, allowing patterns and relationships among contributing factors to emerge [18]. Analysis of the affinity diagram revealed several key factors contributing to delays in the work order process. Subsequent evaluation using the interrelationship diagram indicated that technical staff members, job cards, and technical clerks exhibited the highest levels of influence and dependency among the identified factors, highlighting them as the primary root causes within the system. These findings suggest that inefficiencies in work order management are primarily linked to the performance and interactions of these critical roles and processes, with delays arising from preparation, execution, or task handovers [19].

A Pareto chart was developed to analyse the frequency of different maintenance activities within the technical services department, following the 80/20 principle, which suggests that approximately 80% of effects stem from 20% of causes [20]. Work order data from October to December 2023 was examined to identify the most common maintenance activities, including repairs (REP), services (SER), inspections (INS), corrective work (CMO), replacements (RPL), and modifications (MOD). The chart allowed for prioritisation of the most significant activities, providing insight into critical areas requiring attention to improve efficiency and resource allocation within the department. Figure 3 illustrates that repair and service activities dominate the workload of the technical services department, accounting for approximately 77% of all maintenance tasks, with repairs contributing 54% and services 23%.

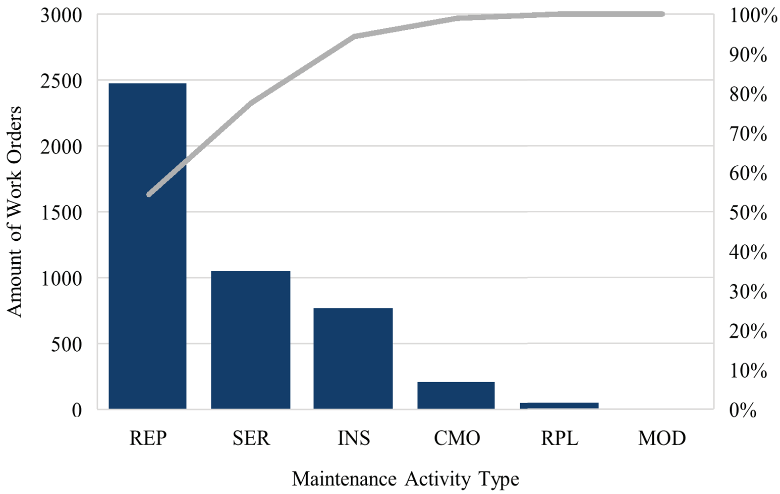


Figure 3: Pareto chart of maintenance activity types for work orders

To further analyse these high-frequency activities, SPC was applied using control charts to monitor process performance and variability over time [12]. Work order turnaround times for repair and service activities from October to December 2023 were extracted from the data, grouped by week, and sampled for analysis. xbar (average) and R (range) charts were generated in R using the Quality Control Charts (QCC) package to track the average completion time and variability, respectively. This approach enabled the identification of trends, anomalies, and potential delays, providing insight into process stability and areas for operational improvement within the department [13].

The quantitative analysis was extended by generating $\bar{x}$ and R control charts for repair and service work orders to assess process stability. The $\bar{x}$ chart (Figure 4) indicated that only one sample marginally violated the standard control limit of seven days for repair work orders, suggesting a potential non-random trend [12]. However, the corresponding R chart (Figure 5) revealed 12 points outside the upper and lower control limits, indicating excessive variability and necessitating corrective action. For service work orders, the $\bar{x}$ chart (Figure 6) identified two points beyond the 28-day control limit, while the R chart (Figure 7) showed 14 violating runs and several points outside the control limits, highlighting significant instability in the service process. It should be noted that the standard timeframes of seven days for repair work orders and 28 days for service work orders, as prescribed by the hospital and organisational performance standards, were incorporated in the control charts as reference benchmarks rather than statistically derived limits. Collectively, these control charts demonstrated that neither the repair nor the service processes were under statistical control, highlighting the underlying factors contributing to delays and variability in maintenance operations. This underscores the need for targeted interventions to reduce variability, improve turnaround times, and enhance overall operational efficiency within the technical services department. Such interventions could involve enhancements such as visual aids for monitoring key metrics, facilitating proactive management, enabling timely task completion, and providing actionable insights that directly address the identified inefficiencies.

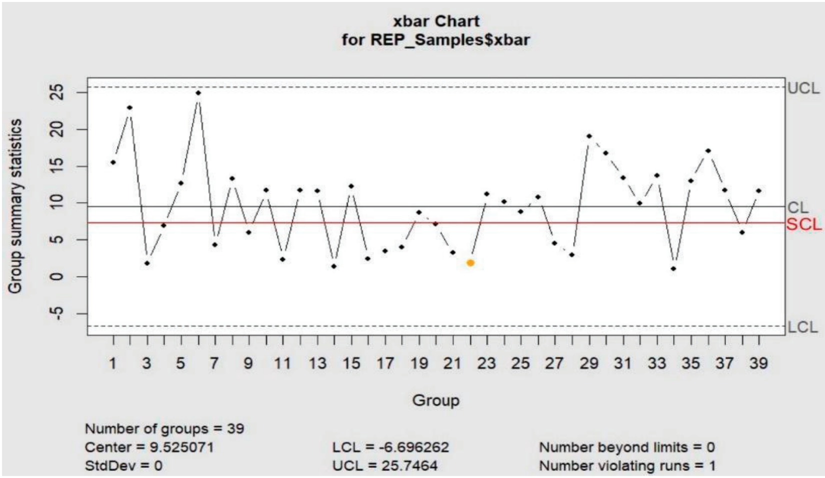


Figure 4: Repair work orders xbar Chart

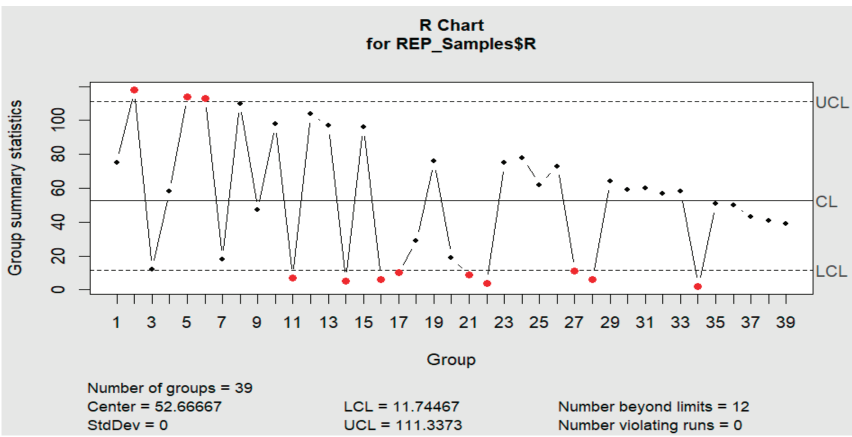


Figure 5: Repair work orders R chart

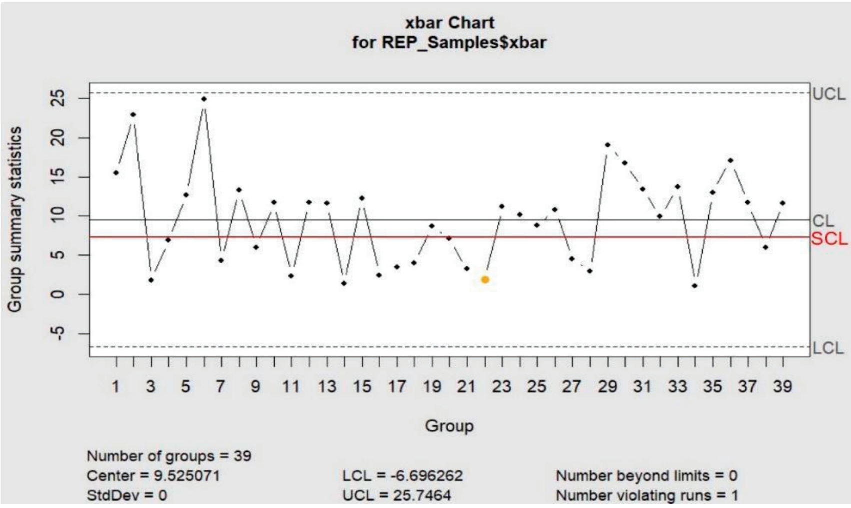


Figure 6: Service work orders xbar Chart

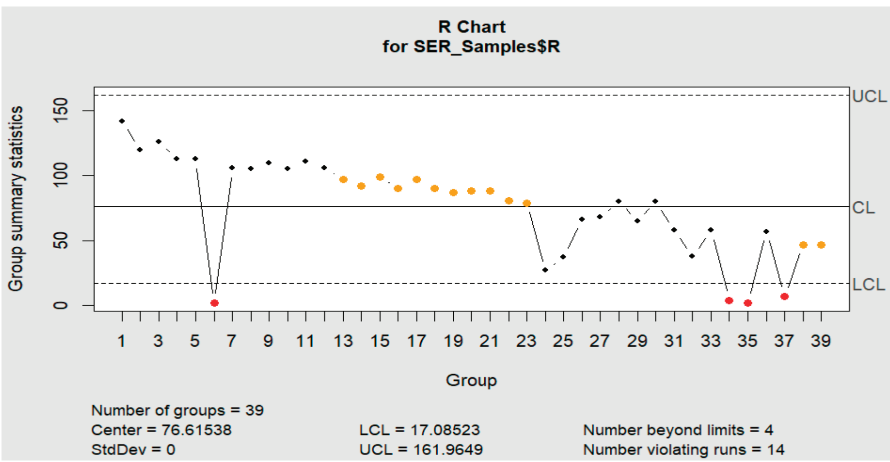


Figure 7: Service work orders R chart

In summary, the current system analysis identified the primary factors contributing to inefficiencies in the technical services department. Qualitative analysis using an affinity diagram highlighted technical staff members, technical clerks, and job cards as key contributors to delays. Quantitative analysis with Pareto charts showed that repair and service activities accounted for 77% of all maintenance tasks. At the same time, statistical process control revealed that turnaround times frequently exceeded the standard limits of seven days for repairs and 28 days for services, indicating process variability and inefficiencies.

The key findings of the root cause analysis are summarised in Table 1.

Table 1: Root cause analysis key findings

Category	Finding
Repair maintenance	The high frequency of repair work orders indicates underlying issues with preventative maintenance.
Service inefficiencies	Variation in service turnaround times suggests inefficiencies in routine maintenance processes.
Process variability	Statistical process control reveals process instability, particularly in turnaround times for repair and service maintenance activities.
Work order processing	Human error by technical clerks and staff in tracking work orders and the respective job cards significantly affects the turnover time for all work orders.

The insights gained from root cause analysis, combined with the structured phases of the V-Model, ensure that the system requirements are comprehensive, targeted, and aligned with operational needs.

3.2 System Architecture

The initial phase, requirements gathering, involved a comprehensive analysis of operational data and stakeholder consultations, as well as the integration of insights from root cause analysis and a literature review. The requirements identified for the technical service work order system intervention include:

- A flagging mechanism to indicate when preventative maintenance is necessary to avoid unexpected breakdowns and extend the operational life of equipment.
- An accurate reflection of current work order turnaround times based on actual operational data.

- A user-friendly interface that enables technical staff and clerks to easily enter, track, and manage work orders.
- Mechanisms to minimise human error in work order entry and job card management.
- Reporting features that allow users to generate reports on maintenance activities and work order turnaround times.
- Utilisation of SPC tools to monitor and control maintenance processes and work order turnaround times, ensuring they remain within acceptable limits.

Building on these requirements, the system architecture was developed with modularity, supporting seamless communication and data exchange between the web browser (client-side), web server (backend), and database server. Figure 8 illustrates the system components and interactions, providing a visual overview of the architecture and data flow. This modular structure enhances scalability and adaptability, facilitating future system enhancements or changes in operational requirements.

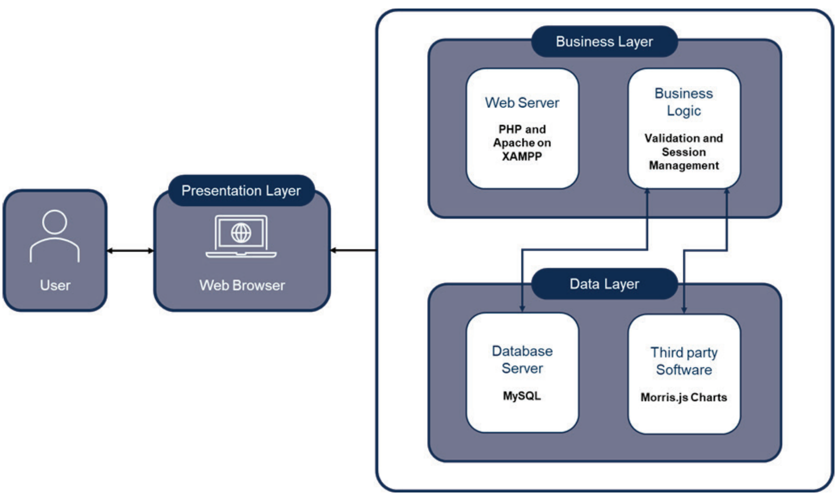


Figure 8: System architecture

The web browser is the presentation layer, validating inputs and displaying information in a user-friendly interface using HTML (Hypertext Markup

Language) and CSS (Cascading Style Sheets). The web server, implemented in PHP (Hypertext Preprocessor), processes user requests, applies business rules, and manages sessions. Through XAMPP (Cross-Platform), Apache provides a robust testing and deployment environment. The database server, powered by MySQL (My Structured Query Language), manages work orders and user data, supporting efficient data retrieval and the execution of business logic. Integration of Morris.js enables dynamic visualisation of key metrics, including SPC control charts, directly within the system.

The system architecture incorporates SPC as a core feature, allowing real-time monitoring of repair and service processes. The system can identify process instability and support proactive maintenance interventions by tracking deviations from control limits, ultimately reducing variability and improving operational efficiency.

3.3 Model design

The design of the technical service work order system is based on the foundations established during the system analysis and architecture design phases. These phases addressed the inefficiencies identified during the root cause analysis. They highlighted key features, including user-friendly interfaces, robust data management, and proactive maintenance strategies enabled by flagging mechanisms and SPC tools. These features, designed to enhance work order management and operational efficiency within the technical services department, were translated into distinct modules with clearly defined designs and functions to ensure compatibility and seamless interaction within the overall system architecture. This phase is crucial, as it outlines the integration of various components, as explained in the Entity-Relationship Diagram (ERD) for the database.

An ERD is a graphical representation used to model a system's data structure. It illustrates the entities (tables), attributes (columns), and relationships between those entities [23]. Establishing the ERD is critical before creating the database or system, as it provides a clear blueprint for data organisation and interaction. This ensures that subsequent development aligns with the intended structure and functionality. In the technical service work order system, the ERD plays a crucial role in organising and managing data, including work orders, administrators, and work order statuses.

The database captures all information regarding repair and service work orders and user actions, ensuring that each work order is tracked from creation to completion. The ERD facilitates the visualisation of this data flow, making it easier to understand how different parts of the system interact with the database. The ERD for the technical service work order system, as shown in Figure 9, demonstrates how each system component connects and interacts, reflecting the underlying structure that supports all system operations.

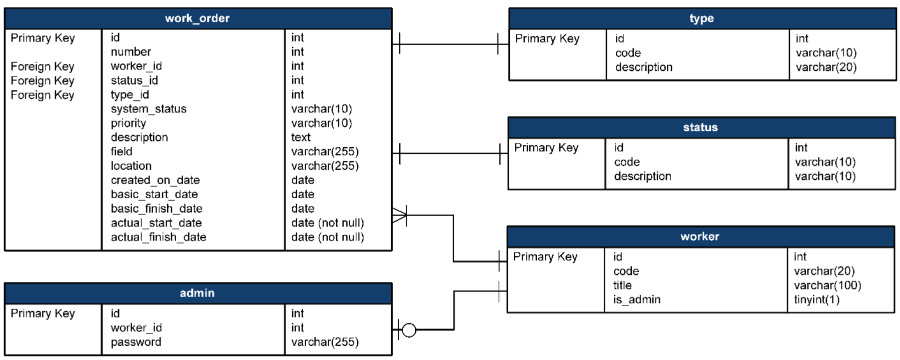


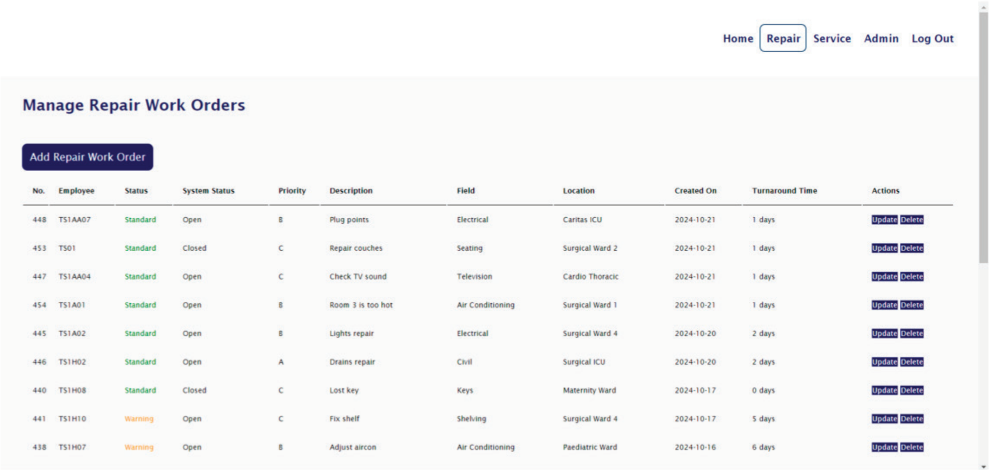
Figure 9: Entity relationship diagram

Each table in the database contains a primary key, which serves as a unique identifier for each record in that table. Primary keys enforce uniqueness, meaning no two records can share the same value for this key. Foreign keys are used to establish relationships between tables, with a foreign key in one table referencing a primary key in another table, thereby linking the two tables [23]. The "work_order" table captures all relevant information about work orders, including the responsible employee, the work order's status (part of the flagging mechanism with categories such as standard, warning, or overdue), the type of work order (repair or service), and the system status (indicating whether the work order is open or closed). The "worker" table stores information about all employees, including details on whether they are administrators with access to the system. The "admin" table stores the passwords of all administrators, ensuring secure access to the system. The "type" table differentiates between repair and service work orders, while the "status" table distinguishes among the various statuses of work orders (standard, warning, or overdue).

3.4 Final design

This subsection presents a walkthrough of the system's functionality, demonstrating how the modules integrate and how users interact with the system and its dashboard visualisation. The final design of the technical service work order system reflects the culmination of the methodology, building on the requirements gathering, system analysis, system architecture, and model design phases. It showcases the system's practical operation, emphasising key functionalities that improve work order management, process monitoring, and operational efficiency. The system delivers a straightforward, user-friendly interface for managing repair and service work orders.

The "Repair" tab, as illustrated in Figures 10 and 11, allows users to view and manage repair work orders. Users are presented with a detailed list of repair work orders, sorted in descending order by the "Created On" date. The status indicates how the work order is progressing relative to the turnaround times. For repair work orders, the control limit is set at seven days; therefore, the status is "Standard" (green) if the turnaround time is less than five days, "Warning" (yellow) if the turnaround time is between five and seven days, and "Overdue" (red) if the turnaround time exceeds seven days. The status updates automatically while the work order remains open and ceases once the work order is closed, functioning as the system's built-in flagging mechanism.


Home Repair Service Admin Log Out

Manage Repair Work Orders

Add Repair Work Order

No.	Employee	Status	System Status	Priority	Description	Field	Location	Created On	Turnaround Time	Actions
448	TS1AA07	Standard	Open	B	Plug points	Electrical	Caritas ICU	2024-10-21	1 days	Update Delete
453	TS01	Standard	Closed	C	Repair couches	Seating	Surgical Ward 2	2024-10-21	1 days	Update Delete
447	TS1AA04	Standard	Open	C	Check TV sound	Television	Cardio Thoracic	2024-10-21	1 days	Update Delete
454	TS1A01	Standard	Open	B	Room 3 is too hot	Air Conditioning	Surgical Ward 1	2024-10-21	1 days	Update Delete
445	TS1A02	Standard	Open	B	Lights repair	Electrical	Surgical Ward 4	2024-10-20	2 days	Update Delete
446	TS1H02	Standard	Open	A	Drains repair	Civil	Surgical ICU	2024-10-20	2 days	Update Delete
440	TS1H08	Standard	Closed	C	Lost key	Keys	Maternity Ward	2024-10-17	0 days	Update Delete
441	TS1H10	Warning	Open	C	Fix shelf	Shelving	Surgical Ward 4	2024-10-17	5 days	Update Delete
438	TS1H07	Warning	Open	B	Adjust aircon	Air Conditioning	Paediatric Ward	2024-10-16	6 days	Update Delete

Figure 10: Manage repair work orders part 1

440	TS1H08	Standard	Closed	C	Lost key	Keys	Maternity Ward	2024-10-17	0 days	Update Delete
441	TS1H10	Warning	Open	C	Fix shelf	Shelving	Surgical Ward 4	2024-10-17	5 days	Update Delete
438	TS1H07	Warning	Open	B	Adjust aircon	Air Conditioning	Paediatric Ward	2024-10-16	6 days	Update Delete
435	TS1A02	Standard	Closed	B	Bed not working	Electrical	Medical Ward 1	2024-10-15	3 days	Update Delete
437	TS1SA01	Standard	Closed	A	Ceiling is leaking	Ceiling	Surgical Ward 4	2024-10-15	1 days	Update Delete
432	TS1AA04	Standard	Closed	B	Repair bed	Electrical	Surgical Ward 1	2024-10-14	4 days	Update Delete
434	TS1AA07	Overdue	Open	B	Wall paint	Walls	Surgical Ward 4	2024-10-14	8 days	Update Delete
431	TS1A02	Overdue	Open	B	Lights repair	Lights	Coffee Shop	2024-10-13	9 days	Update Delete
430	TS1AA06	Warning	Closed	B	Install door	Doors	Surgical Ward 5	2024-10-12	5 days	Update Delete
429	TS1AA07	Overdue	Open	A	Fill generator diesel	Generator 6	Administration	2024-10-11	11 days	Update Delete
428	TS1SA01	Standard	Closed	B	Adjust aircon	Air Conditioning	Medical Ward 1	2024-10-10	1 days	Update Delete
426	TS1H06	Overdue	Closed	C	Toilet door	Doors	Emergency Room	2024-10-07	8 days	Update Delete
423	TS1SA01	Warning	Closed	A	Sink tap leaking	Civil	Medical ICU	2024-10-04	7 days	Update Delete
421	TS1AA07	Overdue	Closed	B	New light bulbs	Lights	Paediatric Ward	2024-10-03	12 days	Update Delete

Figure 11: Manage repair work orders part 2

The "Add Repair Work Order" button directs the user to the "Add Repair Work Order" page, illustrated in Figure 12. This page allows the user to input a new repair work order. The required information includes the work order number, the employee responsible for the work order, and the system status, which, in this case, is set to "Open". Additional information includes priority, description, field, location of the work order, the date the work order is created (which is the current date), and the basic start and finish dates specified in the work order's requirements. These measures standardise key fields, reduce the likelihood of input errors, and enable users to provide all necessary details for each work order.

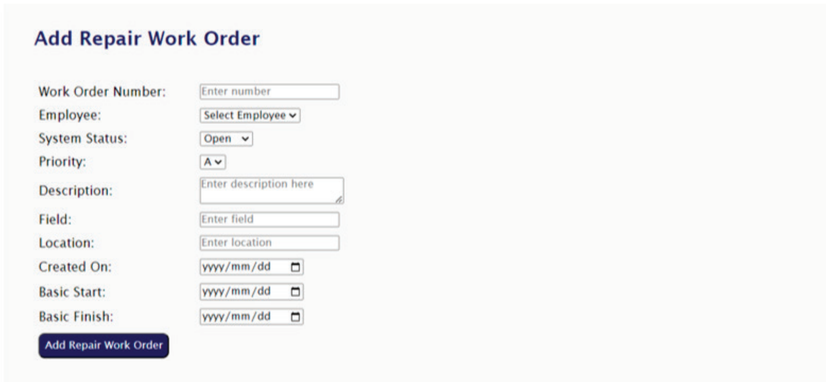


Figure 12: Add repair work order

The "Update" button directs the user to the "Update Repair Work Order" page, illustrated in Figure 13. This page lets the user close the repair work order by updating its status from "Open" to "Closed". Additionally, the user can select the actual start and finish dates for the repair work order.

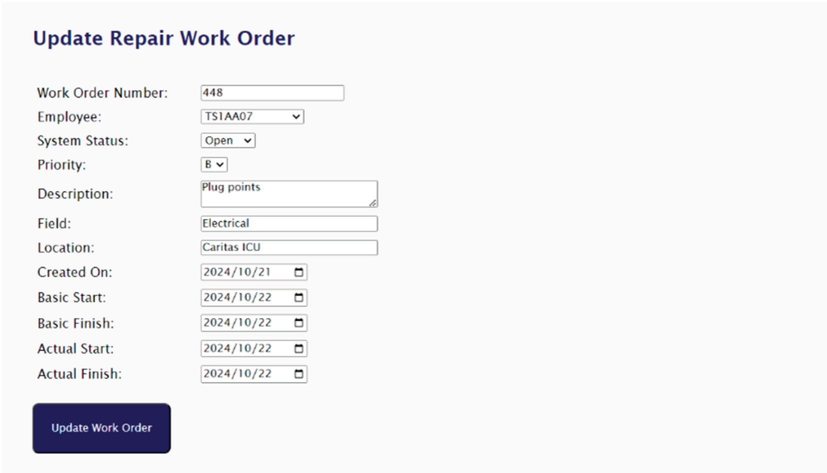


Figure 13: Update repair work order

The "Delete" button removes the repair work order from the database. The message stating "Repair work order successfully deleted" is displayed upon pressing the button. Similar confirmation messages are shown for adding and updating repair work orders.

Similar to the "Repair" tab, the "Service" tab enables users to view and manage service work orders. However, for service work orders, the control limit is set at 28 days; therefore, the status is "Standard" (green) if the turnaround time is less than 26 days, "Warning" (yellow) if the turnaround time is between 26 and 28 days, and "Overdue" (red) if the turnaround time exceeds 28 days.

The dashboard is the homepage and central hub for monitoring work order performance, providing an overview of repair and service tasks. It displays key metrics, including the total number of all work orders, the total number of open and closed work orders, the total number of overdue work orders, and the total number of open and closed overdue work orders, as illustrated in Figure 14. The dashboard also provides an overview of the repair and service tasks, displaying key metrics that mirror those in the overview of total work orders.

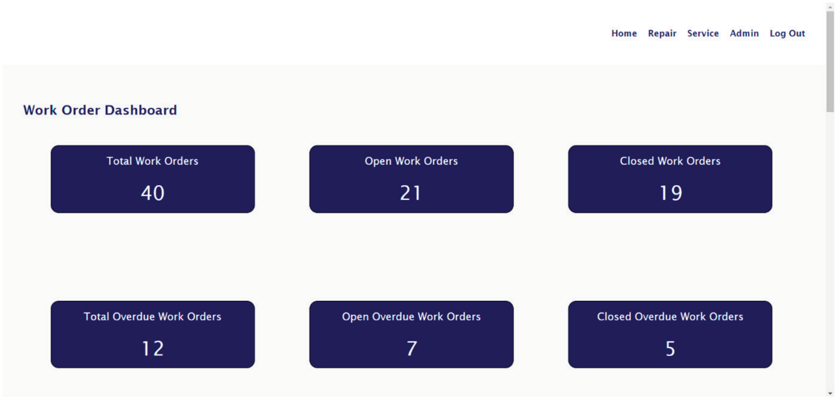


Figure 14: Dashboard of all work orders

All the information displayed on the dashboard comprises buttons that redirect the user to detailed reports. These reports contain a "Search" function, which allows users to search all work orders for specific terms. Users can search for terms such as work order numbers, employee codes, descriptions, fields, or locations, as well as work orders. This functionality enhances management's ability to view and interpret the reports on the technical service work order system dashboard.

The dashboard also features a section dedicated to control charts, incorporating SPC tools within the technical service work order system. The buttons provide access to the control charts for repair and service work orders. Six control charts cover total, open, and closed repair and service work orders.

Figure 15 illustrates the control chart for repair work orders, allowing users to visually monitor and track the status of these work orders. A red line indicates the control limit of seven days, while the warning limit set at five days is shown in yellow. Each work order is represented as a dot on the blue line. Any work order above the red line is deemed unacceptable, while those below it are considered acceptable. As the work orders approach or exceed the warning or control limit lines, the technical clerks and supervisors can easily identify situations requiring prompt attention, facilitating the timely closure of work orders. Thus, these control charts empower technical clerks and supervisors to effectively manage work orders and anticipate overdue cases. The control charts presented demonstrate the system's functionality and capability, illustrating how users can visualise and interpret work order performance data, rather than presenting actual operational outcomes.

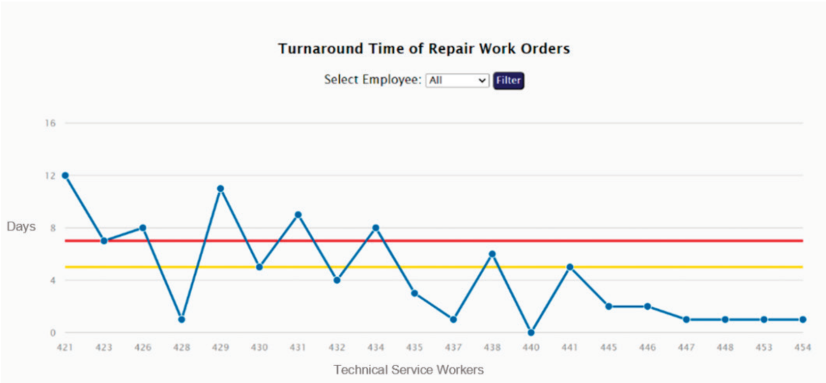


Figure 15: Control chart of repair work orders

Figure 16 illustrates the control chart for service work orders, which functions similarly to the control chart for repair work orders. The key difference lies in the control limits. For service work orders, the control limit is set at 28 days and displayed in red, while the warning limit is set at 26 days and shown in yellow. Each work order is represented as a dot on the blue line.

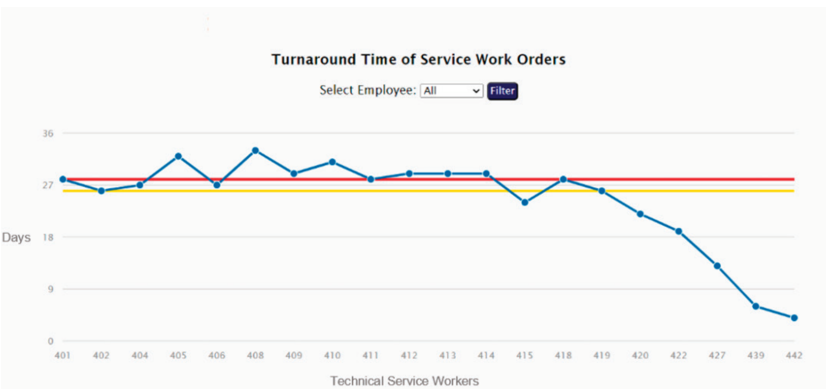


Figure 16: Control chart of service work orders

Each control chart can be filtered by employee (by selecting the desired employee from the dropdown list), allowing users to customise the display to show only a specific employee's work orders. This feature further enhances the performance management aspect of the control charts.

The final design showcases a user-friendly and efficient system for managing repair and service work orders, featuring integrated dashboards, flagging mechanisms, and SPC control charts. This design supports proactive monitoring, accurate record-keeping, and improved operational efficiency, providing a solid foundation for ongoing process improvements.

4 CONCLUSION AND VERIFICATION

This project successfully developed a technical service work order system, completing the full V-Model methodology from requirements gathering and system analysis through system architecture, model design, and final design, to verification and validation. The system integrates key functionalities, including flagging mechanisms, dashboards, and SPC control charts, supporting proactive monitoring, timely work order closure, and improved efficiency. These features provided supervisors and technical clerks with actionable insights, enabling task prioritisation, backlog reduction, and timely maintenance completion—confirming the study's aim through requirements testing, scenario testing, and industry feedback.

Verification and validation were conducted to ensure the system met its defined objectives and user requirements. Table 2 summarises the results of requirements testing, confirming that the system effectively implements critical features, including a flagging mechanism, accurate turnaround times, user-friendly interfaces, reduction of human error, comprehensive reporting capabilities, and the integration of SPC tools.

Table 2: Requirements testing

Requirement Description	Adhering to the Requirement
Flagging mechanism	A robust flagging mechanism was implemented to indicate when intervention on maintenance is necessary, aiming to avoid unexpected breakdowns and extend the operational life of equipment.
Turnaround time accuracy	The system was tested to ensure it accurately reflected current turnaround times for work orders based on actual operational data, thereby enabling more informed decision-making.
User-friendly interface	The interface was assessed for usability, ensuring that technical clerks, supervisors and management could easily enter, track, and manage work orders without extensive training.
Reduction of human error	Mechanisms were integrated in such a manner as to minimise human error in work order entry and job card management, thus enhancing data integrity.
Reporting features	The reporting capabilities were verified to ensure users could generate comprehensive reports on maintenance activities and work order turnaround times, especially on overdue work orders.
Utilisation of SPC tools	The system was tested for its ability to incorporate statistical process control (SPC) tools, using control charts, enabling effective monitoring and control of maintenance processes.

Scenario testing simulated real-world operational conditions, including urgent routine maintenance requests, and demonstrated that the system can handle multiple work orders simultaneously, with real-time updates. Industry feedback confirmed improved tracking, efficiency, and decision-making capabilities. These combined verification and validation processes demonstrate that the system aligns with its initial requirements and meets the end-user's needs.

The project faced several limitations. The system's effectiveness depends on the accuracy and completeness of input data; missing or incorrect data can reduce performance. Successful implementation also relies on staff adaptation and training, as resistance to change could affect utilisation. Additionally, the scope of the analysis was limited to the technical services department.

Several improvements are recommended to enhance system functionality and address limitations. Robust data validation mechanisms should be incorporated to improve reliability. Comprehensive training programmes are essential to support staff adoption of the system and optimise usage. Expanding the scope to include additional departments or integrating comprehensive asset management would enable a more holistic approach to maintenance operations. Implementing mobile-enabled interfaces for real-time work order tracking and digital job card submission would further streamline operations and improve accountability. Longitudinal studies could evaluate the system's impact over time, including part lifespans, task prioritisation, and asset management, supporting continuous refinement and ensuring sustained operational improvements. The study successfully delivered a validated work order system that improves efficiency, promotes proactive maintenance, and provides a foundation for future enhancements.

5 REFERENCES

[1] G. Buswell, "Healthcare basics: The healthcare system in South Africa," *Expatica*, Aug. 19, 2024. [Online]. Available: https://www.expatica.com/za/healthcare/healthcare-basics/healthcare-in-south-africa-105896/. [Accessed: Feb. 15, 2024].

[2] T. Gordon, F. Booysen and J. Mbonigaba, "Socio-economic inequalities in the multiple dimensions of access to healthcare: The case of South Africa," *BMC Public Health,* vol. 20, no. 289, pp. 1-13, Mar. 2020. doi: 10.1186/s12889-020-8368-7.

[3] R. Burger and C. Christian, "Access to health care in post-apartheid South Africa: Availability, affordability, acceptability," *Health Economics, Policy and Law,* vol. 15, no. 1, pp. 43-55, Jul. 2018. doi: 10.1017/S1744133118000300.

[4] M. M. van Zyl-Cillié, J. H. Bührmann, A. J. Blignaut, D. Demirtas and S. K. Coetzee, "A machine learning model to predict the risk factors

causing feelings of burnout and emotional exhaustion amongst nursing staff in South Africa," *BMC Health Services Research,* vol. 24, no. 1665, Dec. 2024. doi: 10.1186/s12913-024-12184-5.

[5] M. H. Galán and E. A. M. Gómez, "A review of maintenance management models: application for the clinic and hospital environment," *The International Journal of Engineering and Science,* vol. 7, no. 9, pp. 1-17, 2018. doi: 10.9790/1813-0709040117.

[6] P. Okoh, P. Schjølberg and A. Wilson, "AMMP: A new maintenance management model based on ISO 55000," *Infrastructure Asset Management,* vol. 3, no. 1, pp. 21-28, Mar. 2016. doi: 10.1680/jinam.14.00042.

[7] J. Schneider *et al.*, "Asset management techniques," *International Journal of Electrical Power & Energy Systems,* vol. 28, no. 9, pp. 643-654, Nov. 2006. doi: 10.1016/j.ijepes.2006.03.007.

[8] M.R. Altaie, "Factors affecting building maintenance practices," *Journal of Engineering,* vol. 29, no. 12, pp. 153-172, Dec. 2023. doi: 10.31026/j.eng.2023.12.10.

[9] I. A. H. Putri, G. G. R. Gita, N. V. Dondokambey, Z. Suryaputri and R. Nurcahyo, "Analysis of Maintenance Management Implementation and Strategy Conceptualization: A case study of hospitals' maintenance management in Indonesia," in *Proceedings of the International Conference on Industrial Engineering and Operations Management.*, Istanbul, Turkey, 2022, pp. 7-10. [Online]. Available: https://ieomsociety.org/proceedings/2022istanbul/48.pdf [Accessed: Jul. 26, 2024].

[10] M. Gallab, I. Ahidar, N. Zrira and N. Ngote, "Towards a Digital Predictive Maintenance (DPM): Healthcare Case Study," in *5th International Conference on Industry 4.0 and Smart Manufacturing (ISM 2023), Procedia Computer Science,* vol. 232, pp. 3183-3194, Jan. 2024. doi: 10.1016/j.procs.2024.02.134.

[11] E. Gavrikova, I. Volkova and Y. Burda, "Strategic aspects of asset management: An overview of current research," *Sustainability,* vol. 12, no. 15, pp. 1-29, Jul. 2020. doi: 10.3390/su12155955.

[12] D. C. Montgomery, *Introduction to Statistical Quality Control*, 7th ed., Hoboken, NJ: John Wiley & Sons, Inc., 2013.

[13] P. Qiu, *Introduction to Statistical Process Control*, Boca Raton, FL: CRC Press Inc., 2014.
[14] N. S. Mujmule, S. D. Katekar, A. P. Gaikwad, S. C. Mali and S. R. Koli, "A systematic ergonomics approach of maintenance workstation," in *IOP Conference Series: Materials Science and Engineering*, vol. 814, pp. 1-8,2020. doi: 10.1088/1757-899X/814/1/012032.
[15] M. Jasiulewicz-Kaczmarek, "The role of ergonomics in implementation of the social aspect of sustainability, illustrated with the example of maintenance," in *Occupational Safety and Hygiene,* 2013, pp. 47-52. doi: 10.1201/b14391-11.
[16] A. C. Marquez, J. F. G. Fernandez, P. M.-G. Fernández and A. G. Lopez, "Maintenance management through Intelligent Asset Management Platforms (IAMP). Emerging factors, key impact areas and data models," *Energies,* vol. 13, no. 15, pp. 1-19, 2020. doi: 10.3390/en13153762.
[17] S. Balaji and M. S. Murugaiyan, "Waterfall vs. V-Model vs. Agile: A comparative study on SDLC," *International Journal of Information Technology and Business Management,* vol. 2, no. 1, pp. 26-30, Jun. 2012. [Online]. Available: https://www.jetir.org/papers/JETIR2008025.pdf. [Accessed: May 26, 2024].
[18] A. Lucero, "Using affinity diagrams to evaluate interactive prototypes," in *Human-Computer Interaction – INTERACT 2015,* Bamberg, Germany, 2015, pp. 231-248, doi: 10.1007/978-3-319-22668-2_19.
[19] B. Kwiecińska, "Cause-and-effect analysis of ship fires using relations diagrams," *Scientific Journals of the Maritime University of Szczecin,* vol. 44, no. 116, pp. 187-191, Dec. 2015. doi: 10.17402/075.
[20] R. Dunford, Q. Su and E. Tamang, "The Pareto Principle," *The Plymouth Student Scientist,* vol. 7, no. 1, pp. 140-148, 2014. doi: 10.24382/swfr-wr17.
[21] C. Coronel, S. Morris and P. Rob, *Database Systems: Design Implementation, and Management*, 12th ed., Boston, MA: Cengage Learning, 2016.