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FACULTY OF ENGINEERING AND TECHNOLOGY

DEPARTMENT OF AGRICULTURAL MECHANISATION AND IRRIGATION ENGINEERING.

OPTIMIZATION OF TRACTOR OPERATIONS AND MAINTENANCE MANAGEMENT SYSTEM

A CASE OF KINYARA SUGAR WORKS

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A project implementation submitted to the department of Agricultural Mechanization and Irrigation Engineering in fulfillment for the award of Bachelor's degree in Agricultural Mechanization and Irrigation Engineering of Busitema University.

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ABSTRACT

This implementation report presents the design, development, and validation of a web-based Computerized Operations and Maintenance Management System (COMMS) for tractor fleet management at Kinyara Sugar Works Limited, which operates over 735 tractors on 11,000 hectares of sugarcane plantations. The company faced critical challenges including unplanned maintenance, poor task scheduling, inadequate spare-parts management, and unreliable paper-based record keeping, resulting in tractor availability as low as 69.4% in the sampled fleet.

To address these challenges, a web-based COMMS was designed and implemented using PHP, MySQL, HTML/CSS, and JavaScript. The system integrates four core modules: operator task logging, mechanic repair tracking, administrator management, and inventory control with automated SMS low-stock alerts. Data were collected from operational logs, maintenance records, structured questionnaires, and field observations across a stratified sample of 50 tractors.

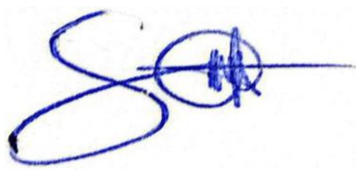
Failure Modes and Effects Analysis (FMEA) was applied to the collected maintenance data to identify and prioritize critical tractor failure modes. Results showed that tyre/brake failures had the highest Risk Priority Number (RPN = 315) due to high occurrence frequency, while engine failures caused the greatest total downtime (over 450 of the 942.75 hours recorded). The implemented COMMS corrected systematic errors in the paper-based records for example, improving reported 4WD tractor availability from 84% to 87% and demonstrated strong technical performance with an average response time of 1.20 seconds and throughput of 2.22 requests per second. The system provides Kinyara Sugar Works Limited with a reliable, data-driven platform to reduce downtime, improve maintenance efficiency, and support cost-effective tractor operations.

Keywords: tractor fleet management, computerized maintenance management system, FMEA, reliability, availability, maintainability, RAM analysis, Uganda, sugarcane estate.

DECLARATION

We, Makmot Ronald Anywar and Kwures Timothy, hereby declare that this implementation report is a result of our own original work and effort. It has not been submitted or presented to any institution of higher learning for the award of any degree or academic qualification.

MAKMOT RONALD ANYWAR BU/UP/2023/3325

Signature 

Date 16/06/2026

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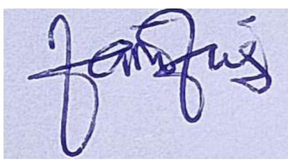
Signature 

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APPROVAL

This final year project proposal report has been prepared and compiled by Makmot Ronald Anywar and Kwures Timothy It is therefore submitted to be approved by,

Supervisors

ERIAU EMMANUEL

Signature: 

Date:12/06/2026

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LIST OF ACRONYMS

GDP	**Gross Domestic Product**
COMMS	Computerized Operations and Maintenance, Management System
MAAIF	Ministry of Agriculture, Animal Industry and Fisheries
MTBF	Mean Time Between Failures
MTTR	Mean Time To Repair
PHP	Hypertext Preprocessor (a web programming language)
LP	Linear Programming
JSON	JavaScript Object Notation
RAM	Reliability Availability and Maintainability
FMEA	Failure Modes and Effects Analysis
RCM	Reliability-Centered Maintenance
SMS	Short Message Service
EOQ	Economic Order Quantity
SQL	Structured Query Language
API	Application Programming Interface
CSS	Cascading Style Sheets
HTML	Hypertext Markup Language
RBAC	Role-Based Access Control

CHAPTER ONE: INTRODUCTION

1.1 Background to the Study

Agricultural mechanization is essential for improving farm productivity, efficiency, and food security across the globe. Tractors are at the heart of this process. They supply more than 60% of the power needed for crop production in developed countries, making tasks like ploughing, planting, and harvesting much faster and easier (Liao et al., 2022). However, maintaining and repairing tractors can be expensive. These costs often account for 30–40% of a farm's total operating expenses. This highlights the importance of having strong systems for maintenance and daily operations (Gitau & Mwangi, 2020).

When tractor operations are managed well, several benefits follow. Downtime drops, which means less time wasted waiting for repairs. Machines last longer because problems are caught early. Farms become more profitable as costs go down and output goes up. For instance, research has found that preventive maintenance fixing things before they break can reduce downtime by up to 25%. It also helps machines run for more years and cuts overall costs, leading to smoother farm operations (Kapoor et al., 2025).

Looking at the bigger picture, mechanization drives growth in agriculture. It creates jobs in rural areas and boosts the economy. Studies show that for every 10% rise in mechanization, agricultural GDP can grow by up to 2% (Caunedo & Kala, 2021). Yet, Africa faces big challenges here. The continent holds over 60% of the world's unused farmland, but mechanization levels are low(Daum, 2023). In Sub-Saharan Africa, farms have only about 1.3 tractors per 1,000 hectares of land. This is far below the 19 tractors per 1,000 hectares seen in South Asia. Worse still, around 40% of tractors in the region stop working within their first five years. The main reasons are poor maintenance, hard-to-find spare parts, and a lack of trained workers (Daum & Birner, 2020).

Uganda shares these issues. Agriculture is a major part of the country's economy. It contributes 21.9% to GDP, provides jobs for 68% of the workforce, and generates 85% of export income (FAO, 2010). With better mechanization, Uganda could see its agricultural GDP jump by up to 15% in the next decade. This would also create thousands of jobs in areas like manufacturing and repair services (. But progress is slow. About 35–40% of tractors given out through government programs end up unused or broken. The problems stem from weak servicing, bad management, and a lack of systems to track operations (MAAIF, 2021).

A clear example is Kinyara Sugar Works Limited. This company farms over 11,000 hectares of sugarcane in Uganda. Tractors are vital for their daily work, including ploughing fields, planting crops, weeding between rows, and transporting harvested cane. Kinyara owns around 735 farm tractors, but many only operate at 50–60% of their full potential. Frequent breakdowns happen because maintenance is not planned well. Task assignment is inefficient, leading to wasted time. Inventory for spare parts is poorly managed, causing delays in repairs. These issues result in operational hold-ups, higher expenses, and lower profits. They also hurt the small farmers who supply sugarcane to the company. In short, there is a strong need for a better system. This system should focus on scheduling work, managing maintenance and inventory, and assigning operators to specific tractors and tasks. Operators will directly input their field entry and exit times via the system, excluding lunch breaks and breakdowns, to track productive hours accurately. A web-based approach would make it easy to access on computers or phones, helping to solve these problems effectively (Of & Animal, 2019).

1.2 Problem Statement

Tractors at Kinyara Sugar Works Limited are not used to their full potential. They operate at less than 60% of their yearly capacity. The key issues include frequent breakdowns, delays in maintenance, poor scheduling of tasks, and uncoordinated assignment of work. In addition, some operators are reluctant to report breakdowns promptly, while certain mechanics handle repairs with bias, often prioritizing jobs based on favoritism or informal payments. Without a proper system to track and manage these, downtime remains high. This means tractors sit idle when they should be working. Utilization rates stay low, and costs increase, especially during important seasons for ploughing, planting, and transporting cane. On top of that, spare parts inventory is not handled well. This leads to long waits for repairs because parts are missing or ordered too late. All these problems raise the total operating costs. They cause delays in farm activities and lower overall productivity. Uganda's national plans, like Vision 2040, and global goals, such as Sustainable Development Goal 2 (Zero Hunger), call for better mechanization in agriculture. This is needed to improve productivity and ensure food security for everyone. To fix this, the study will design and implement a web-based Computerized Operations and Maintenance Management System (COMMS). This system will use a simple website to manage everything. It will handle scheduling, maintenance tracking, inventory for spare parts, and assigning operators to tractors and tasks. Furthermore, the absence of structured failure analysis methods makes it difficult to identify which tractor components pose the greatest risk, prioritize maintenance activities accordingly, and prevent recurring breakdowns before they occur. Operator will log their field entry and exit times directly into the website, excluding lunch breaks and breakdowns, for accurate tracking. The website will be accessible on laptops and phones, allowing real-time monitoring. This will help optimize tractor performance, reduce downtime, and make operations smoother at Kinyara Sugar Works Limited.

1.3 Main Objective

To optimize tractor operations and maintenance management systems.

1.4 Specific Objectives

1. To establish tractor maintenance strategies and operations performed at Kinyara Sugar works Limited
2. To design a web-based Computerized Operations and Maintenance Management System (COMMS).
3. To test and validate the web-based COMMS.

1.5 Research Questions

1. What types of operational and maintenance data are required for effective tractor management, and how can they be collected and analyzed efficiently?

2. How can a web-based COMMS be designed and implemented to manage tractor scheduling, maintenance, and inventory effectively?

3. How effective is the developed COMMS in improving tractor operations, reducing downtime, and lowering operational costs?

1.6 Justification of the study

Improving how tractors are used at Kinyara Sugar Works Limited is crucial. It will lead to higher productivity, better efficiency, and more profits for the company. The proposed web-based COMMS system will provide real-time monitoring through an easy-to-use website. This means managers can check tractor status, schedule preventive maintenance, track spare parts inventory, and assign tasks to operators all from one place.

Technicians and operators can access the website on their laptops or phones to receive alerts about upcoming servicing, low stock levels, or repair needs. Operators will manually input their field entry and exit times, excluding lunch breaks and breakdowns, to ensure accurate tracking of productive work hours. They can also update information right away, like logging a completed task or noting a breakdown. This approach is cost-effective because it does not require expensive hardware. It works on any device with internet, making it ideal for farms with limited resources.

The study aligns with Uganda's goals for modernizing agriculture and achieving sustainable development. By creating this system, we can reduce downtime and costs while increasing output. The findings will serve as a practical example for other farms in Uganda and Africa. This will help with national efforts to transform rural areas and boost the economy through better mechanization.

1.7 Significance of the study

By addressing the limitations of manual and paper-based tractor management systems, this study provides a practical solution for improving efficiency and reliability in agricultural operations. The development of the Computerized Operations and Maintenance Management System (COMMS) introduces a modern way to monitor, schedule, and maintain tractors using real-time data. This helps reduce equipment breakdowns, minimize maintenance costs, and ensure better use of resources. The project also promotes informed decision-making through accurate data collection and analysis, leading to improved productivity and longer equipment lifespan. Overall, the study contributes to the modernization of agricultural practices by demonstrating how digital tools can enhance the management and sustainability of farm machinery.

1.8 Scope of the Study

Conceptual scope

This study will focus on designing a web-based Computerized Operations and Maintenance Management System (COMMS) for farm tractors at Kinyara Sugar Works Limited.

Geographical scope

The study area is the estate of Kinyara Sugar Works Limited, located at 1°38′14″ N, 31°36′30″ E, in Kinyara town, Masindi District, Western Region, Uganda.

Time scope

The project was conducted over a period of eight months, commencing in October 2025 and concluded in May 2026. The project phases were distributed as follows: literature review and needs assessment (October–November 2025); system design and development (November 2025–January 2026); baseline data collection from existing paper-based maintenance records and field observation (December 2025–January 2026); three-month primary data collection and COMMS operational monitoring (January–March 2026); system testing and validation (March–April 2026); data analysis and report writing (April–May 2026).

1.8 Conceptual Framework of the study

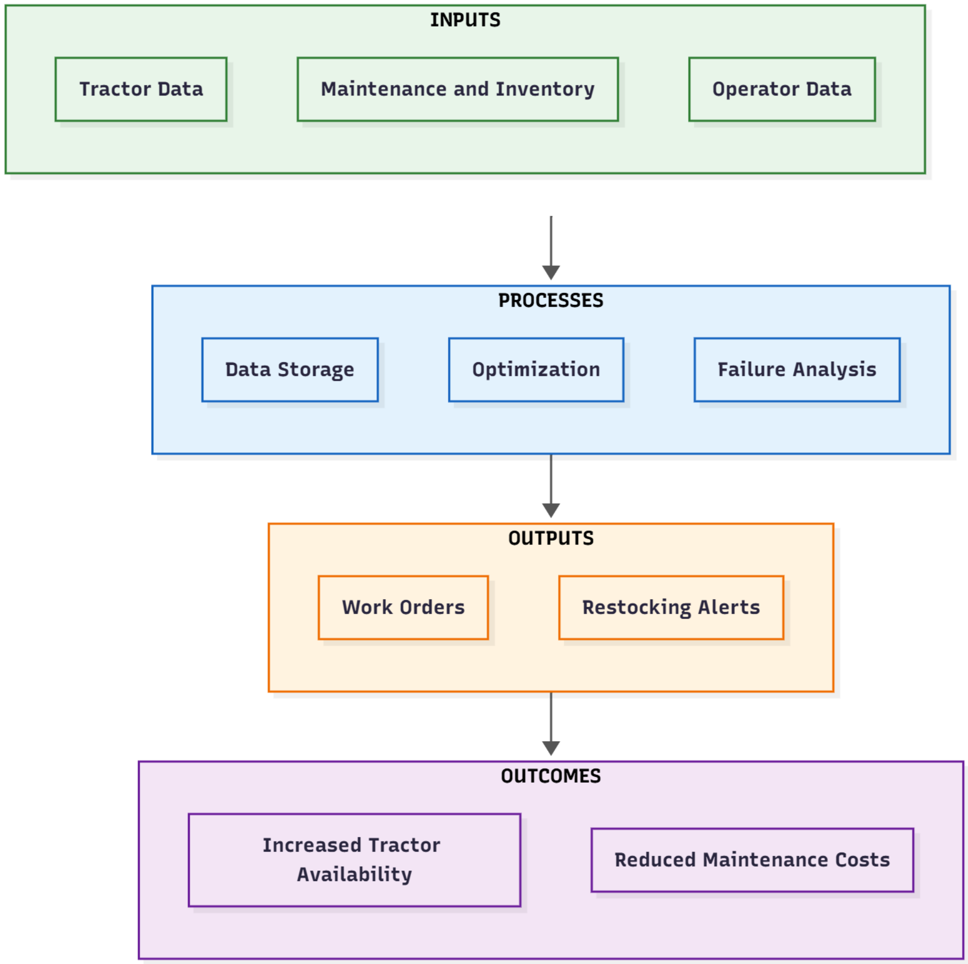


Figure 1 Showing the Conceptual Framework of the study

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

This chapter reviews the existing literature related to tractor operational and maintenance management, emphasizing optimization through digital systems such as Computerized Operations and Maintenance Management Systems (COMMS). The discussion highlights the importance of tractors in large-scale agricultural operations, the challenges caused by poor maintenance, and the evolution of maintenance approaches from traditional corrective strategies to predictive and computerized techniques. The review draws from various academic publications, institutional reports, and recent innovations in agricultural mechanization and operations research. It concludes by establishing the theoretical foundation for designing a web-based COMMS for Kinyara Sugar Works Limited, a system that integrates maintenance scheduling, operator task logging, inventory tracking, and automated SMS notifications for proactive farm management.

2.2 Tractor Maintenance Systems

2.2.1 Overview

Maintenance is the process of ensuring that machines perform their intended functions efficiently and safely throughout their lifespan. According to the Food and Agriculture Organization(“Training of Trainers Manual on the Operation, Maintenance and Repair of Farm Machinery,” 2022), effective maintenance supports agricultural mechanization by sustaining performance, extending machine life, and minimizing downtime. For mechanized estates like Kinyara Sugar Works Limited, tractors are central to operations from land preparation to transportation and any breakdown can cause substantial delays in production. Studies such as(Vezirov et al., 2025) emphasize that maintenance-related downtime can reduce tractor availability to as low as 60–70 % during peak periods. Therefore, an integrated maintenance management system is critical for ensuring operational reliability and cost control.

2.2.2 Preventive, Corrective, and Predictive Maintenance

Maintenance strategies can be grouped into three main categories: preventive, corrective, and predictive (Molęda et al., 2023).

Corrective maintenance (Run-to-failure) involves repairing equipment only after a breakdown occurs. While simple to apply, it is costly and disruptive. (Lips, 2013) found that unplanned repairs can account for over 40 % of total maintenance expenditure in developing-country farms.

Preventive maintenance (Scheduled) is carried out at planned intervals, such as after a fixed number of engine hours or field operations. It reduces failure rates and extends service life but can sometimes result in unnecessary servicing when parts are still healthy.

Predictive maintenance (Condition-based) uses measured data like vibration, oil analysis, or recorded engine hours to predict failures before they occur. (Garcia et al., 2025) demonstrated that predictive systems can reduce downtime by 25 % and maintenance costs by 15 %, especially when integrated with IoT sensors and telematics.

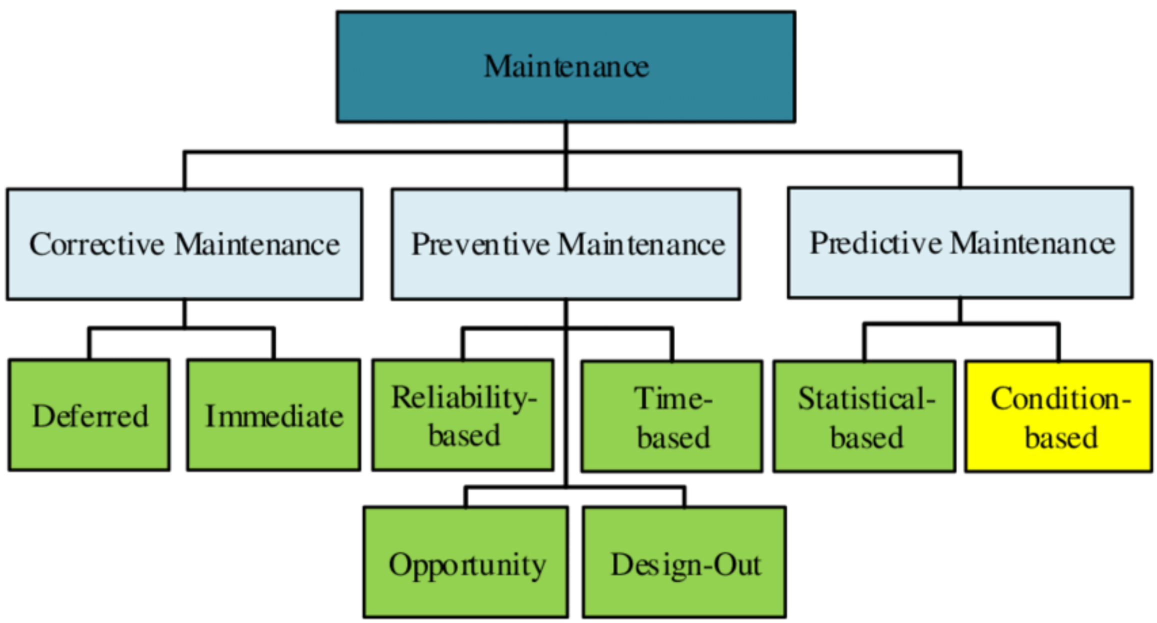


Figure 2 Maintenance Classification Chart

2.3 Reliability, Availability, and Maintainability (RAM)

Reliability, availability, and maintainability (RAM) are fundamental engineering metrics that define the performance of mechanical systems (Rausand, 2005).

- **Reliability (R)** is the probability that a system performs its intended function for a specific time *t* without failure.
- **Availability (A)** is the fraction of total time that equipment is operational.
- **Maintainability (M)** is the probability that a failed system can be restored within a specified time.

These are related through:

$$A = \frac{\text{MTBF}}{\text{MTBF} + \text{MTTR}} \qquad (equation\ 1)$$

where MTBF = Mean Time Between Failures, and MTTR = Mean Time To Repair.

Reliability typically follows the **Weibull distribution**, which models how failure probability changes over time:

$$R(t) = e^{-\left(\frac{t}{\lambda}\right)^{\beta}} \qquad (equation\ 2)$$

where β is the shape parameter (failure rate type) and λ is the scale parameter (characteristic life). The "bathtub curve" illustrates that equipment failures are highest during early use (infant mortality), lowest during useful life, and rise again with wear-out.

Integrating RAM analysis into a COMMS platform allows engineers to analyze patterns from operator-logged data, estimate MTBF dynamically, and plan servicing intervals that minimize total downtime and cost.

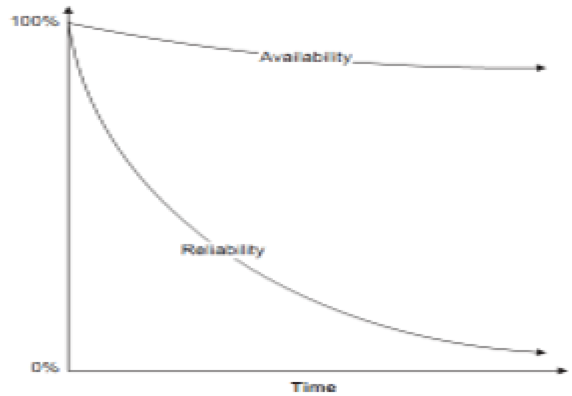


Figure 3 Bathtub Curve Showing Life-Cycle Failure Pattern

2.3.1 Weibull Analysis

The Weibull distribution is a continuous probability distribution named after Waloddi Weibull, who described it in detail in 1951, although it was first identified by Fréchet and first applied by Rosin and Rammler. It is a probability distribution that can be used to model the failure behavior of assets over time. Despite an early unsuccessful attempt to publish the result in a well-known British journal that deemed it to be of no practical importance, Weibull published his landmark paper in 1951 titled "A statistical distribution function of wide applicability." Weibull distribution is preferred because of its flexibility and ability to work even with limited data; it can simulate even other distributions like normal and exponential distributions(Bebbington et al., 2007) . In the context of tractor fleet management at Kinyara Sugar Works Limited, Weibull analysis provides a rigorous statistical framework for understanding how and when tractors are most likely to fail, directly supporting the predictive maintenance capabilities of the web-based COMMS.

Weibull analysis is a powerful tool that can be used to classify failures and to model failure behavior. It involves fitting a time-to-fail distribution to failure data. The several methods for doing this, and the software provides four methods: Maximum likelihood estimation (MLE), Probability plotting, Hazard plotting, and Modified moment estimation(Aboura et al., 2014). Weibull distribution is a parametric life distribution because it can be fully defined by specification of parameters. Such parameters include the shape parameter, scale parameter and at times the location parameter. These parameters are directly computable from tractor maintenance logs and breakdown records captured by the COMMS database, making Weibull analysis a practical and data-driven tool for Kinyara's operating environment.

2.3.2 Weibull Shape Parameter (β)

The Weibull shape parameter, β, determines the shape of the Weibull distribution that best fits the data. It is the slope of the best fit line on the Weibull plot. In maintenance, the Weibull shape parameter is often used to analyze failure data and make decisions regarding maintenance strategies. For example, if an asset has a high shape parameter ($\beta > 1$), it may be more cost-effective to replace the asset before it wears out completely rather than performing frequent repairs. On the other hand, if an asset has a low shape parameter ($\beta < 1$), it may be more cost-effective to perform more frequent maintenance to prevent infant mortality failures. The Weibull shape parameter can also be used to estimate the remaining useful life of an asset. By analyzing the failure data and estimating the shape parameter, maintenance professionals can predict when an asset is likely to fail and plan maintenance activities accordingly. This helps to minimize downtime, reduce maintenance costs, and improve overall asset performance and reliability.

Applied to Kinyara's tractor fleet, the shape parameter estimated from COMMS-recorded breakdown histories will reveal the dominant failure regime for each tractor model or component category. Tractors exhibiting $\beta < 1$ indicate infant-mortality failure patterns commonly linked to poor assembly, inadequate break-in servicing, or operator misuse, all of which the COMMS can address through early-stage maintenance alerts and operator training modules. Tractors with $\beta \approx 1$ suggest random failures independent of age, pointing to the need for condition-based monitoring rather than fixed-interval servicing. Tractors with $\beta > 1$ are experiencing wear-out, and the shape parameter value directly informs the optimal replacement or overhaul interval that should be programmed into the COMMS scheduling engine.

2.3.3 Weibull Scale Parameter (λ)

The Weibull scale parameter, λ, also known as a component's *characteristic life*, is defined as the time at which 63.2% of the population has failed. Within the COMMS, the characteristic life estimated for each tractor subsystem engine, transmission, hydraulics, electrical, and tyres defines the upper boundary of a safe operating interval. The COMMS scheduling module will use λ values derived from historical MTBF data to automatically generate preventive maintenance work orders before the 63.2% failure threshold is approached, ensuring that tractors are serviced while still in their reliable operating window rather than after failure has already occurred. For Kinyara's fleet of 735 tractors spread across 11,000 hectares, this parameter-driven scheduling replaces the current ad hoc approach with a statistically justified, fleet-wide maintenance calendar.

2.3.4 Weibull Location Parameter (μ)

The Weibull location parameter, μ, is found in the three-parameter Weibull distribution. It tells us the period for which the component will work normally before it starts to fail. Different software tools are available at our disposal to estimate the Weibull parameters that best fit our distribution, including MATLAB, Excel Solver Tool, Minitab, Reliasoft, among others. For this study, the Excel Solver Tool (EST) is particularly relevant given its accessibility in low-resource environments such as Kinyara Sugar Works Limited. The location parameter will be especially useful for newer tractors recently introduced to the fleet, where a failure-free operating period can be established before maintenance interventions begin, allowing COMMS to suppress unnecessary early-stage alerts and focus resources on tractors that genuinely require attention.

2.3.5 Excel Solver Tool (EST) for Weibull Parameter Estimation

According to the proceedings of the 4th International Conference on ELECOM (Milod Zakaria Ahmed & Ali, 2022), the most significant benefit of the Excel Solver Tool (EST) is that it does not need the formulation of complicated mathematical equations that require the use of difficult numerical techniques to solve. Additionally, a combination of two or more Weibull distributions provides a better fit than a single distribution. Ramachandran & Amirthalingam (2020) use EST to optimize scheduling maintenance treatment to a road network, incorporating Transition Probability Matrices and condition vectors for pavements.

Manual data analytics is tedious and time-consuming since it involves legwork to collect and organize the data, invoke spreadsheets, and extract the relevant information and insights needed to make solid decisions. It has become exorbitantly challenging due to the large volume of data currently being generated by IoT devices. In order for this information to be useful, it has to be extracted, analyzed, and put into action that is where the true challenge lies. Today, data analytics is more important to maintenance than ever before. With the next wave of prescriptive analytics, instead of manually collecting the data, software collects and analyses the data as Artificial Intelligence (AI) and Machine Learning (ML) decide what actions to take and when. While this is still the future and most operations are still running on manual data readings, many manufacturers are already racing to achieve prescriptive analytics as a reality(Razali et al., 2020).

In the context of this project, EST will be used as an accessible and practical tool to estimate the two-parameter Weibull shape (β) and scale (λ) values from the tractor failure data collected through the COMMS database. The estimated parameters will then feed directly into the Reliability function $R(t) = e^{(-(t/\lambda)^\beta)}$ already embedded in the RAM analysis framework of the COMMS, enabling the system to generate dynamically updated reliability curves for each tractor and component group. This closes the loop between raw maintenance data, statistical modelling, and actionable maintenance scheduling all within a single, integrated platform accessible on both web and mobile devices at Kinyara Sugar Works Limited.

2.4 Failure Modes and Effects Analysis (FMEA) and Reliability-Centered Maintenance (RCM)

2.4.1 Failure Modes and Effects Analysis (FMEA) identifies potential ways in which systems can fail and assesses the severity, occurrence, and detection probability of each failure mode (Rezaei et al., 2018). Each failure mode is assigned a Risk Priority Number (RPN):

$$\text{RPN} = \text{Severity} \times \text{Occurrence} \times \text{Detection}$$

A high RPN highlights area that require immediate preventive attention.

More fully defined, Failure Modes and Effects Analysis (FMEA) is a method of investigation for determining how a product, process, or system might fail and the likely effects of particular modes of failure. Failure modes means the ways, or modes, in which something might fail. Effects analysis refers to studying the consequences of those failures. It originated in the US Military in the 1940s and is an analytical tool widely applied in a number of approaches. The FMEA method appeared in the formal design methodology proposed by NASA in the 1960s for addressing reliability and safety requirements. The system may fail physically due to a faulty part or operationally due to insufficient training of the personnel (Snee, 2016). At Kinyara Sugar Works Limited, where tractors operate across 11,000 hectares and serve multiple functions from ploughing to cane transport, FMEA provides a structured basis for cataloguing failure modes specific to the fleet and embedding them into the COMMS for automated risk tracking.

Prior to undertaking FMEA, it is necessary to complete a process map of the process under study, which could include a specific product under investigation. A process map is a step-by-step pictorial sequence of a process, showing process inputs, process outputs, and processing steps. The FMECA method has some shortcomings, and others have come up with approaches to overcome them, such as introduction of Z-number, rough number, the Decision-making trial and evaluation laboratory (DEMATEL) method, and the VIsekriterijumska optimizacija KOmpromisno Resenje (VIKOR) method to FMECA to overcome its deficiencies in real application(Huang et al., 2020). Based on the results of literature review and bibliometric analysis, there exists room to further refine the FMEA improvement research.

The possible future research avenues advocated in FMEA literature include the following. First, the priority ranking of failure modes in FMEA is often considered as a multiple criteria decision making (MCDM) process. Scholars have applied a variety of MCDM methods such as Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), Analytic Hierarchy Process (AHP), Data Envelopment Analysis (DEA), Grey Relational Method (GRA), and VIKOR to address the setbacks associated tractor fleet without reliance on paper records or disconnected spreadsheets.

In the context of Kinyara's tractor fleet, the FMEA will be conducted by mapping the most frequently occurring failure modes recorded in the COMMS including engine failures, hydraulic faults, transmission breakdowns, electrical faults, and tyre degradation and assigning each a Severity score (1–10), Occurrence score (1–10), and Detection score (1–10). The resulting RPN values will be ranked to identify the highest-priority failure modes requiring immediate preventive action. Components with the highest RPN scores will automatically trigger elevated maintenance alerts within the COMMS notification module, ensuring that workshop teams and supervisors respond to the most critical risks first. This approach transforms the traditionally manual FMEA process into an automated, data-driven decision-support function embedded in the digital management platform.

2.4.2 Reliability-Centered Maintenance (RCM) builds on FMEA to focus on maintaining system functions rather than merely repairing parts. It answers seven key questions including what functions are required, how failures occur, and what the consequences are to determine optimal maintenance actions.

When implemented within COMMS, these tools enable automated prioritization of maintenance activities. For example, components with high RPN values or short MTBF intervals can trigger high-priority alerts, ensuring timely interventions and resource allocation.

2.5 Maintenance Data Classification

Maintenance data typically fall into several categories such as technical (e.g. failure modes, repair times), operational (e.g. usage hours, load factors), servicing (e.g. repair tasks, parts replaced), and cost (e.g. labour, parts, downtime costs) data. In maintenance literature, data collected during preventive and corrective maintenance actions, supplemented by information on part suppliers, repair crew travel times, and machine age, are critical for planning and decision making(Arno, 2009).

1. Technical Data:

These define the tractor's physical and design specifications such as model, power rating, serial numbers, and component structures. In COMMS, technical data form the reference base for identifying compatible spare parts, planning life-cycle maintenance, and ensuring correct repairs.

2. Operational Data:

Operational data capture how tractors are used recording working hours, field area covered, load conditions, and idle periods. While farms often record these manually, COMMS enables operators to input them digitally, excluding breaks and breakdowns. This provides reliable data for scheduling preventive maintenance once preset hour thresholds are reached.

3. Servicing Data:

Servicing data include inspection reports, maintenance logs, and parts replaced. These records reveal reliability patterns and recurring issues. Within COMMS, servicing data are automatically linked to specific tractors, allowing the system to generate work orders, analyze downtime, and recommend maintenance intervals based on history.

4. Cost Data:

These relate to the financial side of maintenance covering parts, labour, lubricants, and administrative costs. When digitized in COMMS, cost data allow comparison of preventive versus corrective maintenance costs and support long-term budgeting decisions.

2.5.1 Integration and Analysis:

Traditionally, these data types are stored separately in files and logbooks, making coordination difficult. A web-based COMMS integrates them into one platform, ensuring consistency and real-time access across departments. With these records, performance indicators like Mean Time Between Failures (MTBF) and Mean Time To Repair (MTTR) can be computed:

$$MTTR = \frac{R_t}{N_r} \qquad (equation\ 4)$$

$$MTBF = \frac{T}{N} \qquad (equation\ 5)$$

where T is total operating time, N is number of failures, R_t is total repair time, and N_r is number of repairs.
Analyzing these helps predict failures and set optimal maintenance intervals even without sensors.

2.6 Mathematical Programming and Scheduling

Mathematical programming offers structured optimization methods to reduce operational costs while meeting time and resource constraints. Linear Programming (LP) and Integer Programming (IP) are the most commonly used techniques(Agustina, 2019).

A basic maintenance scheduling model can be expressed as:

$$\text{Minimize: } Z = \sum_{i=1}^{n} c_i x_i \qquad (equation\ 6)$$

subject to:

$$\sum_{i=1}^{n} a_{ij} x_i \geq b_j, x_i \in 0,1 \qquad (equation\ 7)$$

where c_i = cost coefficient (fuel, labor, parts), x_i = decision variable indicating task selection, and a_{ij} represents time or resource requirements.

2.7 Inventory and Spare Parts Management

Efficient spare-parts management ensures timely repairs and prevents long periods of inactivity. Gupta and Evans (2001) describe the Economic Order Quantity (EOQ) model as an effective tool to minimize total inventory costs:

$$EOQ = \sqrt{\frac{2DS}{H}} \qquad (equation\ 8)$$

where D = annual demand, S = ordering cost, and H = holding cost per unit.

In the COMMS system, real-time inventory tracking ensures that when the quantity of a critical part (e.g., oil filters) falls below a set threshold, an automatic SMS notification is sent to the workshop or procurement officer. This closes the loop between usage, maintenance, and restocking.

2.8 Human Factors in Maintenance Management

Maintenance performance is strongly influenced by human factors. Research shows that most maintenance-related failures originate not from technical design weaknesses but from human and organizational issues(Zaker Hossein et al., 2024). Studies in agricultural mechanization confirm that human factors such as operator fatigue, inadequate training, and weak supervision significantly influence tractor maintenance performance and reliability, often leading to frequent breakdowns and low equipment utilization(Ambo, 2024). These findings emphasize that optimizing tractor maintenance requires not only technical solutions such as Computerized Maintenance Management Systems but also training, workload control, and safety-culture interventions to reduce human-error rates.

Integrating human-factor mitigation into COMMS improves system adoption and reliability. For instance:

- **Automated reminders** reduce forgetfulness and complacency.
- **Digital communication tools** prevent message distortion.
- **Usage logs** help balance workloads, reducing fatigue.
- **Visual dashboards** provide real-time status awareness for supervisors.

Training modules or pop-up guides can be built into COMMS to support less-experienced operators, promoting sustainability and safety across the estate.

2.9 Gaps in Knowledge

From the reviewed literature, it is evident that most existing Computerized Maintenance Management Systems (COMMS) were designed for industrial and transport sectors rather than agricultural estates, making them less adaptable to variable workloads and limited technical capacity in such environments (Khodabakhshian, 2013).

In addition, maintenance scheduling, inventory tracking, and operator logging are often managed separately, leading to delays and inefficiencies in coordination. An integrated digital system that unifies these functions is therefore needed.

Manual data collection through logbooks remains common, yet it is prone to errors and data loss. Reliable digital data capture is essential for accurate planning and reporting (Basir et al., 2024).

Moreover, poor internet connectivity in rural areas limits the use of existing web-based COMMS platforms. Integrating offline or SMS-based synchronization features could support continuous operation even in low-connectivity zones(Vial & Tedder, 2017).

Lastly, human factors such as limited training and fatigue are often overlooked during design. Incorporating user-centered features will enhance adoption and performance (Milics et al., 2022).

CHAPTER THREE: RESEARCH METHODOLOGY

3.1 Introduction

This chapter presents the methodology used to design and evaluate a web-based Computerized Operations and Maintenance Management System (COMMS) for tractor operations at Kinyara Sugar Works Limited.
It outlines the processes of system analysis, design, development, and testing. The aim is to create a centralized, digital framework for managing tractor performance, scheduling maintenance, and reducing downtime through automation and data analytics.

The methodology integrates database management, web design, and mobile synchronization to improve the efficiency and accessibility of operational data for all stakeholders.

3.2 Research Design

The research will employ a design-oriented and applied experimental approach, focusing on developing a web-based operations and maintenance management framework.
This approach is appropriate for technical system design projects where real-world application, performance validation, and iterative refinement are key outcomes.

The design process follows a structured five-stage model:

1. **Needs Identification:** Collect current operational and maintenance challenges from Kinyara Sugar Works.
2. **System Planning:** Define functions, user levels, and access rights.
3. **System Design:** Develop the COMMS architecture, interface layout, and module interactions.
4. **System Implementation and Simulation:** Construct, integrate, and test the web-based system.
5. **System Evaluation:** Assess performance, reliability, and user satisfaction

3.3 Research Tools and Programming Languages.

The research will use a combination of programming, database, and web technologies to design and implement the COMMS.
Each tool was selected for functionality, compatibility, and ease of use in local environments.

Table 1 showing research tools and programming languages

Tool / Programming Language	**Purpose in COMMS Design**
SQL (Structured Query Language)	SQL was used to create and manage the database that stores all information about tractors, their operations, and maintenance activities. It helps organize large amounts of data and makes it easy to search, update, and generate reports whenever needed.
API (Application Programming Interface)	The API helps different parts of the COMMS system communicate with each other. It allows smooth data sharing between the web dashboard, mobile platform, and database. The API also supports SMS notifications, which send automatic alerts to operators or supervisors about maintenance reminders, task updates, or low stock levels.
JavaScript	JavaScript controls the behaviour of the web pages. It makes the system interactive for example, checking if a user has filled all fields before submitting a form, updating information without reloading the page, or showing alerts and pop-up messages.
HTML (Hypertext Markup Language)	HTML defines the structure and layout of COMMS web pages. It creates input forms, buttons, tables, and menus that users interact with when entering data or generating reports.
PHP (Hypertext Preprocessor)	PHP works on the server side to process the data entered by users. It connects the web pages to the SQL database, manages user login, and handles secure data transactions. It ensures that data sent to and from the server is accurate and protected.

Tool / Programming Language	Purpose in COMMS Design
Calton Mobile Platform	The Calton Mobile Platform makes COMMS available on mobile phones and tablets. Field operators can use it to record operational data or view maintenance updates directly from the farm. It helps keep all data synchronized between the field and the main database.

3.4 Research Instruments

Table 2 showing research instruments

Research Question	Instrument Used	Expected Output
What tools and frameworks are suitable for developing COMMS?	Programming environments and design software	Identification of compatible technologies
How can COMMS be made user-friendly for operators?	Interface prototypes, and feedback surveys	Intuitive user interface with improved accessibility
How can the effectiveness of COMMS be tested?	System logs, testing scripts, and performance evaluation forms	Validated and optimized system for field use

3.5 Research Reliability

Reliability will be achieved by:

- Conducting repeated system tests under different usage scenarios.
- Implementing secure user authentication and encrypted data storage.
- Using backup servers and redundancy to prevent data loss.
- Testing across devices and browsers to ensure consistent performance.
- Comparing repeated test results to verify data reproducibility.

3.6 Ethical Considerations

Ethical approval for data collection at Kinyara Sugar Works Limited was obtained from the management of the Agriculture Mechanization Department prior to commencing fieldwork. All participants including tractor operators, mechanics, supervisors, and storekeepers were informed of the purpose of the study and their right to participate voluntarily. No participant names were used in raw data analysis; operators and mechanics are identified in operational tables by name only as consistent with the company's existing record-keeping format, and with management's permission. Confidential financial and procurement records obtained from the company were used solely for the purposes of this study and are not disclosed beyond what is necessary for analysis. Data collected through questionnaires and interviews were handled securely and are presented in aggregate where individual identification is not required.

3.7 Parts of the Web-Based COMMS

The proposed Web-Based Computerized Operations and Maintenance Management System (COMMS) is designed to automate tractor scheduling, maintenance monitoring, and resource allocation within a digital platform accessible on both web and mobile devices. It integrates operational, maintenance, and inventory management components into a unified interface. The system will include the following key modules:

1. **User Interface Module**

This module provides dashboards for administrators, supervisors, mechanics and operators with structured access based on user roles.

- Administrators and supervisors can schedule and assign tasks to operators.
- Mechanics can view maintenance schedules, update service and repair logs, record fault diagnoses, and confirm completed maintenance task
- Operators can input daily work details such as hours worked and break durations through mobile or web forms.
- The interface is built using HTML, CSS, and JavaScript, ensuring responsive design for desktop and mobile use.

2. Database Module

The database serves as the backbone of the COMMS, storing all operational and maintenance data in a relational SQL structure.
It contains tables such as:

- **Tractor Info:** stores tractor IDs, models, and current operational status.
- **Operator Log:** records working hours, breaks, and assigned tasks.

- **Maintenance Log:** tracks service history, fault reports, and repair dates.
- **Inventory:** maintains spare parts and stock levels with minimum-quantity thresholds.

3. API and Synchronization Module

This module enables real-time data exchange between the web platform, mobile devices, and SMS gateway.

- The API (built with PHP and JSON protocols) ensures that updates made on mobile devices are instantly reflected on the web dashboard.
- It also allows external integration with tools like geolocation APIs or SMS gateways for field communication.

4. **Scheduling and Task Management Module.**

This module automates task creation, assignment, and progress tracking:

- Supervisors can schedule daily or weekly tractor operations and allocate them to available operators.
- The system uses time-based triggers to monitor assigned work hours.
- When operators input their hours worked (minus breaks), the system updates the tractor's usage statistics automatically.

5. Inventory and Maintenance Optimization Module

This module monitors spare parts and consumables (grease, filters) in real time.

- When stock levels fall below predefined thresholds, the system automatically triggers notifications for restocking.
- It tracks maintenance cycles based on usage hours or elapsed time intervals (e.g., greasing every 50 hours).

- The database cross-references tractor usage logs to predict upcoming maintenance requirements an approach aligned with predictive maintenance principles in fleet management systems (Shykhmat & Veres, 2024).

6. Notification and Alert Module

To ensure prompt communication, this module uses both SMS Gateway and in-system alerts.

- When a tractor exceeds its operational hour limit or when inventory drops below a set quantity, the system automatically sends an SMS to the workshop or maintenance team.
- Notifications can also be triggered for scheduled servicing, overdue maintenance, or low-stock alerts.

7. Security and Access Control Module

Ensures system integrity by managing user authentication, authorization, and data protection.

- Uses secure login credentials and session tracking mechanisms.
- Implements role-based access control (RBAC) to ensure only authorized users perform sensitive operations like modifying records or deleting data.

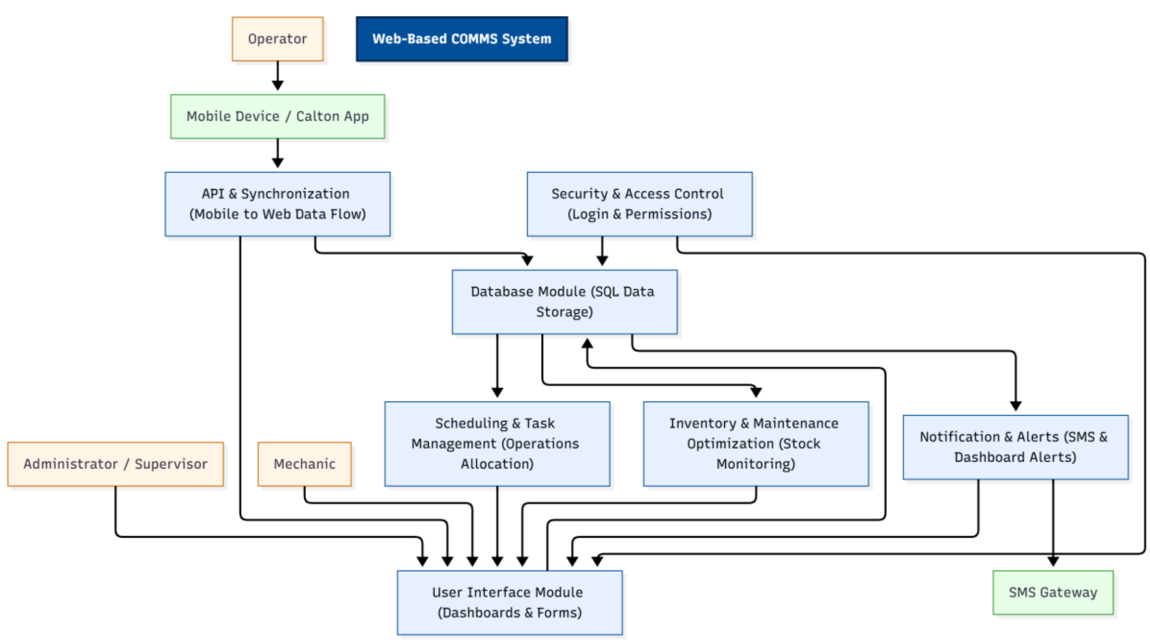


Figure 4 showing parts of the software-based COMMS

3.9 Design Considerations

The design of the web-Based Computerized Operations and Maintenance Management System (COMMS) focuses on five core aspects.

- It ensures accessibility across computers and mobile devices to allow real-time monitoring and data entry in diverse field environments.
- Security is achieved through encrypted logins and user-specific access rights to safeguard operational data(Fazal et al., 2022).
- The system's scalability supports integration with future modules or additional machinery, enhancing flexibility and sustainability (Id et al., 2021).
- Efficiency is prioritized by optimizing performance for low-bandwidth conditions and ensuring smooth synchronization between mobile and web platforms.
- Finally, usability and maintenance are considered through a simple, modular interface that supports easy updates and effective use by personnel with minimal ICT background(Mazumder, 2014).

3.10 Specific Objective One: To establish tractor maintenance strategies and operations performed at Kinyara Sugar Works Limited

3.10.1 Purpose of the Study

- Assess existing tractor maintenance operations and their effectiveness.
- Identify major causes of equipment downtime and inefficiencies.
- Develop appropriate maintenance strategies suited to Kinyara's working environment.
- Define practical maintenance operations and procedures for implementation.
- Provide a foundation for integrating maintenance activities within a web-based Computerized Operations and Maintenance Management System (COMMS).

3.10.2 Types of Data Collected

1. Technical Data

The tractor fleet at Kinyara Sugar Works Limited was systematically documented from system level to individual machine level as shown in the fleet register. Key physical and design characteristics of each tractor, including brand, model, engine type, power rating, and drive configuration, were obtained from operational records and verified with the Agriculture Mechanization Department. From this, a comprehensive classification of the tractor fleet was established to support maintenance planning and operational deployment. These data facilitate the identification of compatible spare parts, scheduling of preventive maintenance activities, and allocation of tractors to appropriate field operations based on their power capacity and functional capabilities.

Sampling Criteria and Procedure

A stratified purposive sampling technique was employed to select 50 tractors from the total fleet of 735 at Kinyara Sugar Works Limited. The following criteria guided the selection:

Inclusion Criteria:

1. **Operational Department:** Tractors actively assigned to three core field operations were prioritized based on their critical role in sugarcane production:
   - **Ploughing department (primary tillage)** – 20 tractors selected
   - **Harrowing department (secondary tillage)** – 15 tractors selected
   - **Furrowing/Seedbed preparation department** – 15 tractors selected
2. **Tractor Age Distribution:** Tractors were sampled across three age categories to represent the fleet's age profile and capture age-related failure patterns:
   - **New (<3 years):** 10 tractors
   - **Mid-life (3-7 years):** 25 tractors
   - **Old (>7 years):** 15 tractors
3. **Usage Intensity:** Tractors were categorized by weekly utilization hours to ensure representation of varying operational workloads:
   - **High utilization (≥40 hours/week):** 15 tractors
   - **Medium utilization (20-39 hours/week):** 20 tractors
   - **Low utilization (<20 hours/week):** 15 tractors
4. **Brand Representation:** The sample included tractors from major brands present in the fleet in proportion to their fleet representation:
   - New Holland: 12 tractors
   - John Deere: 10 tractors
   - Case IH: 8 tractors
   - Massey Ferguson: 8 tractors
   - Mahindra: 7 tractors
   - Kubota: 5 tractors

Exclusion Criteria:

The following tractors were excluded from the sampling frame to ensure data relevance and consistency:

- Tractors in long-term storage (inactive for more than 6 months)
- Tractors designated exclusively for non-agricultural duties (e.g., stationary pump operation, workshop towing only)
- Tractors pending major overhaul with incomplete maintenance records
- Tractors scheduled for decommissioning or disposal during the study period

2. Operational Data

Operational data for the tractor fleet, including working hours, field area covered, load conditions, idle periods, and occurrences of breakdowns, were identified as key parameters for performance assessment. These data were collected through manual records, field observations, and operator logbooks maintained by the Agriculture Mechanisation Department. The collected information provides a comprehensive basis for understanding tractor usage patterns and operational conditions within the plantation.

3. Maintenance Data

Maintenance data for the tractor fleet, including service logs, inspection records, repair activities, and parts replaced, were identified as essential parameters for assessing equipment condition and performance. These data were collected from maintenance records, workshop reports, and technician logbooks maintained by the Agriculture Mechanization Department. The collected information provides a comprehensive basis for understanding maintenance practices, failure occurrences, and repair history across the tractor fleet.

4.Inventory Data

Inventory data, including spare part names, stock quantities, reorder levels, suppliers, and issue dates, were identified as essential for effective parts management. These data were collected from store records, inventory registers, and procurement documents maintained by the relevant department. The collected information provides a comprehensive basis for understanding spare parts availability, usage patterns, and stock management within the plantation.

5.Cost Data

Cost data, including expenditure on spare parts, labour, lubricants, and other consumables, were identified as key parameters for evaluating maintenance-related financial performance. These data were collected from financial records, maintenance reports, and procurement documents maintained by the relevant departments. The collected information provides a comprehensive basis for understanding maintenance costs, expenditure patterns, and resource utilization across the tractor fleet.

3.10.3 Data Sources

Data for this study were obtained from both primary and secondary sources to ensure comprehensive coverage of operational, maintenance, inventory, and cost aspects of the tractor fleet.

Primary Sources

- Field observations of tractor operations and repair activities were conducted.
- Structured questionnaires were administered to tractor operators and supervisors.
- Interviews

Primary data collection was conducted directly by the research team through three instruments. First, structured questionnaires were administered in person to 50 tractor operators, 12 mechanics, 6 field supervisors, and 2 stores officers during scheduled break periods and shift changes at Kinyara Sugar Works Limited between November and December 2025. Second, direct field observation was carried out by the research team on six separate visits to the estate, during which tractor operations, maintenance activities, and spare parts handling were observed and recorded using pre-designed observation checklists. Third, semi-structured interviews were conducted face-to-face with workshop personnel and inventory staff to capture insights on maintenance coordination challenges and spare parts management failures that were not captured in written records. These primary instruments generated data that was cross-referenced against the secondary sources to verify accuracy and identify discrepancies.

Secondary Sources

- Workshop job cards and maintenance reports were reviewed.
- Spare parts inventory records and procurement documents were examined.
- Monthly operational summaries and downtime reports were analyzed.
- Financial records and cost reports related to maintenance activities were obtained.

3.10.4 Data Collection Tools

A combination of tools was used to ensure systematic and reliable data collection:

- **Observation Checklists:**
  These were used to record daily tractor operations, faults, and downtime.
- **Structured Questionnaires:**
  These were used to collect quantitative data on tractor utilization, breakdown frequency, and maintenance practices. The structured questionnaire administered to tractor operators comprised 10 questions covering daily working hours, breakdown reporting behaviour, awareness of tractor service intervals, familiarity with mobile phone usage, and perceived causes of frequent tractor failures.

- **Interview Guides:**
  These were used to obtain qualitative information from mechanics, supervisors, and storekeepers regarding maintenance challenges and spare parts management. The interview guide administered to mechanics and supervisors comprised 12 questions covering: (1) frequency of breakdown occurrences per week, (2) average time from fault report to repair commencement, (3) most common spare parts found to be out of stock, (4) primary causes of repair delays, (5) existing spare parts reorder procedures, (6) quality of communication between operators and mechanics, (7) use of job cards and work orders in current practice, (8) challenges in tracking tractor working hours, (9) existing preventive maintenance schedule if any, (10) supervisor awareness of tractor operational status in real time, (11) willingness to use a digital management system, and (12) preferred mode of receiving maintenance alerts.

- **Document Review Sheets:**
  These were used to extract relevant data from job cards, service logs, inventory records, and financial documents.

3.10.5 Data Collection Procedure

The data collection process was carried out in the following stages:

1. Planning

- A sample of 50 tractors was selected from Kinyara's total fleet of 735 to ensure representation.
- Authorization was obtained from management to access operational, maintenance, and financial records.
- Data collection tools were pretested and refined to ensure reliability and accuracy.

2. Field Observation

- Operational hours, breakdown occurrences, and repair durations were observed and recorded.
- Frequent fault types and service intervals were noted for analysis.

3. Administration Questionnaire

- Questionnaires were administered to operators and supervisors during rest periods or shift changes.
- With

4. Interviews

- Interviews were conducted with workshop personnel and inventory staff to capture detailed insights into maintenance coordination and spare parts management.

5. Document Review and Data Cleaning

- Workshop logs, inventory records, and financial documents were examined.
- Collected data were verified, cleaned, and organized to ensure consistency and completeness prior to analysis.

3.10.6 Data Analysis.

Collected data were analyzed using both quantitative and qualitative methods to evaluate maintenance performance and identify areas for improvement in operational strategies.

Quantitative Analysis
Data were collected on key operational and maintenance parameters using Microsoft Excel as the primary data recording tool. The collected data included average daily and weekly working hours per tractor, frequency and types of breakdowns, downtime durations, repair durations, and maintenance costs per tractor.

Reliability, Availability, and Maintainability (RAM) Analysis

Reliability, availability, and maintainability (RAM) are fundamental engineering metrics that define the performance of mechanical systems. Mean Time Between Failures (MTBF) and Mean Time To Repair (MTTR) were used to evaluate the reliability and maintainability performance of the tractor fleet.

$$MTTR = \frac{Total\ Repair\ Time}{Number\ of\ Repairs}\ MTBF = \frac{Total\ Operating\ Hours}{Number\ of\ Failures}\ A = \frac{MTBF}{MTBF+MTTR}$$

3.1 January 2025

Total Operating Hours = 6,469 hrs

Total Failures (Breakdowns) = 418

Total Downtime = 12,000 − 6,469 = 5,531 hrs

MTBF= $\frac{6,469}{418}$ = 15.48 hrs/failure

MTTR = $\frac{5531}{418}$ = 13.23 hrs/repair

3.2 February 2025

Total Operating Hours = 6,127 hrs

Total Failures (Breakdowns) = 437

Total Downtime = 12,000 − 6,127 = 5,873 hrs

MTBF=$\frac{6127}{437}$ = 14.42 hrs/failure

MTTR =$\frac{5873}{437}$ = 13.04 hrs/repair

3.3 March 2025

Total Operating Hours = 6,656 hrs

Total Failures (Breakdowns) = 382

Total Downtime = 12,000 − 6,656 = 5,344 hrs

MTBF=$\frac{6656}{382}$ = 17.42 hrs/failure

MTTR =$\frac{5344}{382}$ = 13.99 hrs/repair

3.4 Q1 Overall (January–March 2025)

Total Operating Hours (3 months) = 19,428 hrs

Total Failures = 1237

MTBF = 15.71 hrs/failure

MTTR = 13.40 hrs/repair

Overall Availability = $\frac{67.4+71.1+69.8}{3}$=69.4%

3.10.7 Failure Analysis Using FMEA

Failure Modes and Effects Analysis (FMEA) was applied to quantify and prioritize the critical failure modes identified from the maintenance records collected during fieldwork (Table 4). The analysis followed a structured three-factor scoring approach using a 1–10 scale for each factor:

- **Severity (S):** Rated based on the operational impact of the failure a score of 10 represents complete tractor shutdown with no workaround; a score of 1 represents a negligible effect.
- **Occurrence (O):** Rated based on the recorded frequency of each failure type across the 50-tractor sample a score of 10 represents failures occurring almost every shift; a score of 1 represents rare, isolated events.
- **Detection (D):** Rated based on how easily the failure can be identified before it causes full breakdown a score of 10 means the failure is undetectable before it occurs; a score of 1 means it is always detected during routine checks.

The Risk Priority Number (RPN) was then calculated as:

RPN = Severity (S) × Occurrence (O) × Detection (D)

Table 3 *FMEA Scoring Criteria Applied in this Study*

Score Range	Severity (S)	Occurrence (O)	Detection (D)
1–2	No or negligible operational impact	Extremely rare once per year or less	Almost certain detection before failure
3–4	Minor slight performance loss	Infrequent few times per year	High detection probability
5–6	Moderate noticeable downtime	Occasional monthly	Moderate detection probability
7–8	Major significant downtime, field work halted	Frequent weekly	Low detection probability
9–10	Critical complete shutdown, safety risk	Very high near-daily occurrence	Detection extremely difficult or impossible

Table 4 FMEA Risk Priority Analysis Kinyara Sugar Works Tractor Fleet

Failure Mode	Primary Cause	Effect on Operations	Severity (S)	Occurrence (O)	Detection (D)	RPN
Hydraulic system failure	Overloading, rough terrain	Short downtime (2–2.5 hrs) but very frequent 9 recorded incidents	5	9	7	315
Engine failure	Neglected oil changes, no preventive schedule	Complete shutdown 27–128 hrs; accounts for >50% of total downtime	9	8	3	216
Tyre / Brake failure	Worn seals, hose burst	Loss of linkage control, field work halted 27–28 hrs	8	7	3	168
Electrical fault	Corrosion, wiring damage	Tractor inoperable; longest recorded: 105 hrs (machine 70-029)	8	3	4	96
Belt / Drive failure	Wear, misalignment	Moderate downtime 2.5–28.5 hrs	6	4	5	120
Gearbox failure	Overloading, poor lubrication	Longest recorded downtime: 153.5 hrs	9	4	2	72

		(machine 71-008)				

3.10.8 Summary of Questionnaire and Interview Findings

Table 5 Summary of Questionnaire and Interview Findings

Question / Topic	Operators (n=50)	Mechanics (n=12)	Supervisors (n=6)
Aware of tractor service intervals	22% Yes	100% Yes	83% Yes
Report breakdowns immediately	54% always	—	—
Reason for not reporting fear of pay deduction	38%	—	—
Average time from fault report to repair start	—	3–6 hours typical	4 hours estimated
Spare parts out of stock in last month	—	91% Yes	100% Yes
Most common stockout items	—	Engine oil, fuel filters, hydraulic seals	Engine oil, tyres
Use job cards for every repair	—	67%	83%
Willing to use digital system for logging	76% Yes	83% Yes	100% Yes
Own or have access to a mobile phone	92% Yes	100% Yes	100% Yes
Believe SMS alerts would improve parts availability	84% Yes	92% Yes	100% Yes

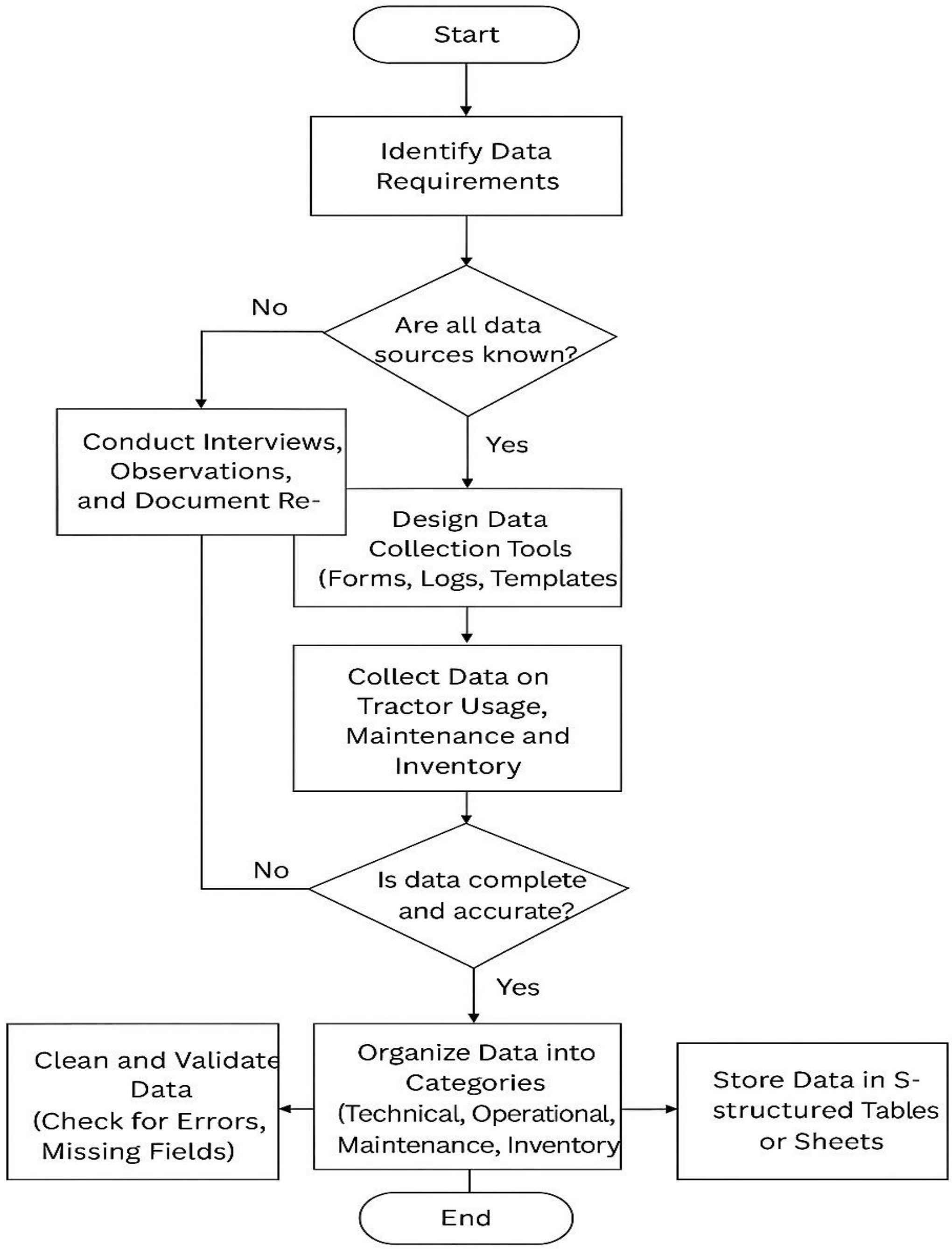


Figure 5 showing Flowchart Showing the Data Collection Process for Tractor Operations and Maintenance

3.11 Specific Objective Two: To Design a Web-Based Computerized Operations and Maintenance Management System (COMMS)

3.11.1 Steps to Achieve Objective Two

1.Requirement Identification

A needs assessment was carried out through interviews, direct observation, and review of existing records to understand operational challenges and user requirements. The key requirements identified included the need to:

- Track tractor usage and performance.
- Schedule and record maintenance activities.
- Monitor spare parts and inventory levels.
- Improve coordination between operators, mechanics, and management.

These findings guided the development of system functions that match real user workflows and organizational goals**(Zimmermann & Grötzbach, 2015)**.

2. System Specification

The COMMS system was designed using a role-based structure comprising four main user categories: Administrator, Mechanic, Operator, and Manager. Each user type was assigned specific access rights and responsibilities within the system to ensure data security, accountability, and efficient system operation**(Ferraiolo & Kuhn, 1992)**.
The system was organized into four main functional sections: **Login, Administrator, Operator, and Mechanic modules**, each designed to handle specific operations within the maintenance management framework.

Admin section

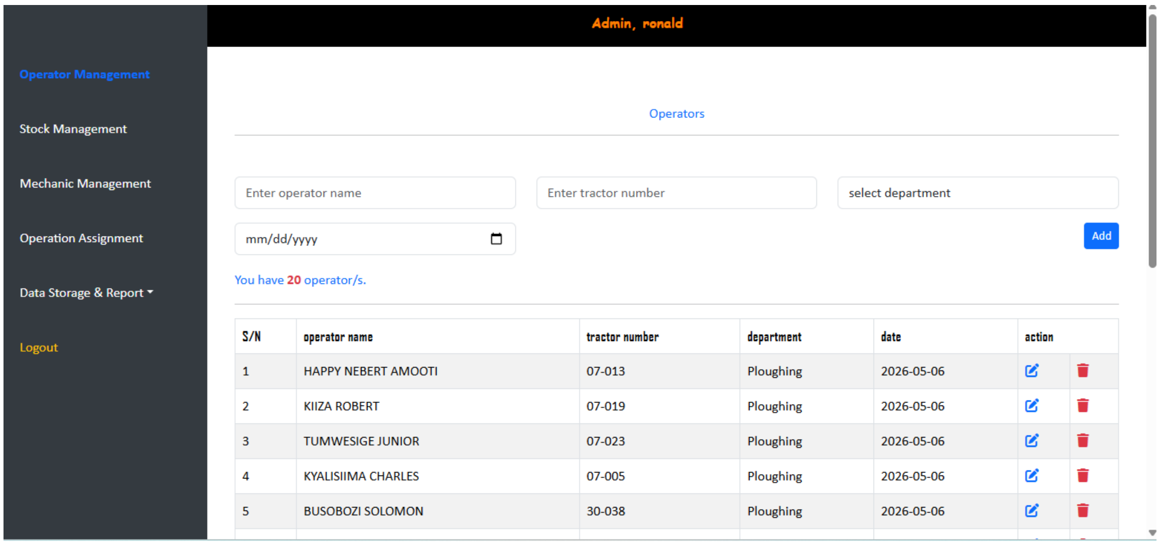
The Administrator module was implemented as the central control unit of the system. The administrator was responsible for managing system users, data, and overall system operations.

The administrator functionalities included:

- Adding, viewing, editing, and deleting user accounts (operators and mechanics).
- Managing tractor records and assigning tractors to operators.
- Assigning tasks and monitoring task execution.
- Viewing system-wide reports on operations, maintenance, and inventory.

- Managing spare parts inventory, including stock levels and updates.
- Monitoring comments and system activities from users.

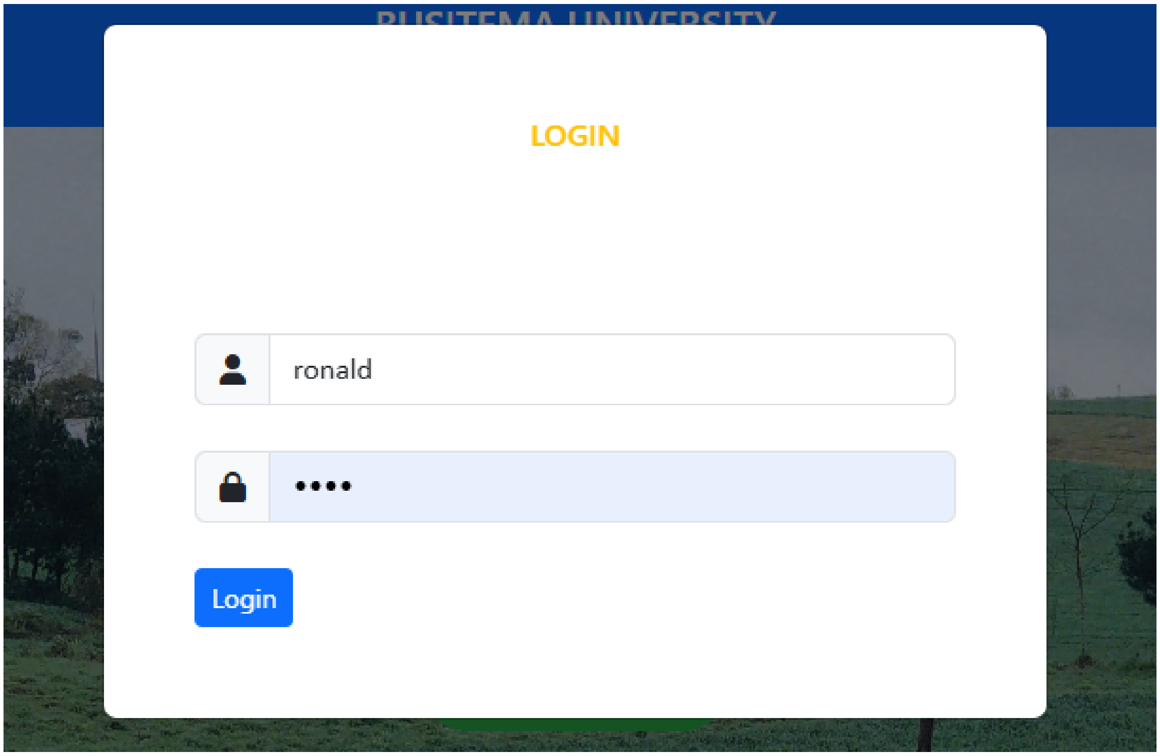
This module ensured effective coordination and control of all system activities.



Login section

The login module was implemented to control user access to the system. All users were required to log in using a unique username and password.

- User credentials were validated before access was granted.
- The system restricted users to their respective dashboards based on assigned roles.
- This ensured secure access and prevented unauthorized use of system data.



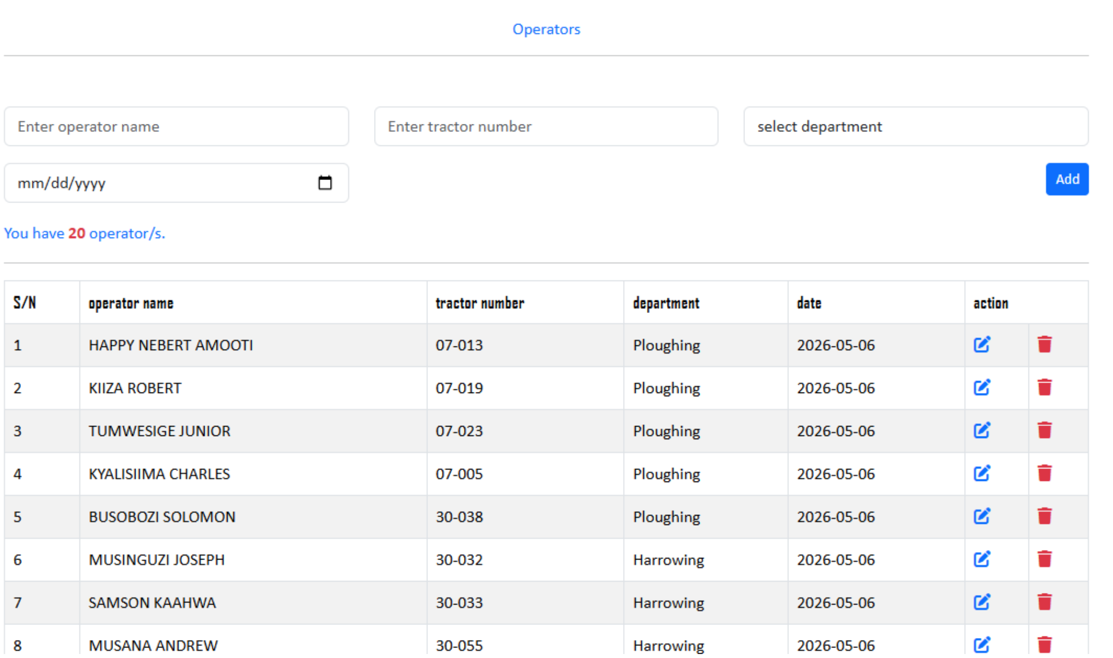
Operator section

The Operator module was implemented to capture field-level operational data.

The operator functionalities included:

- Logging into the system using assigned credentials.
- Viewing assigned tractors and daily tasks.
- Recording operational data such as working hours, tasks performed, and tractor usage.
- Submitting comments or feedback on tractor condition.

Operators were restricted to accessing only their assigned tractors and tasks, ensuring accountability and data accuracy.



S/N	operator name	tractor number	department	date	action
1	HAPPY NEBERT AMOOTI	07-013	Ploughing	2026-05-06	
2	KIIZA ROBERT	07-019	Ploughing	2026-05-06	
3	TUMWESIGE JUNIOR	07-023	Ploughing	2026-05-06	
4	KYALISIIMA CHARLES	07-005	Ploughing	2026-05-06	
5	BUSOBOZI SOLOMON	30-038	Ploughing	2026-05-06	
6	MUSINGUZI JOSEPH	30-032	Harrowing	2026-05-06	
7	SAMSON KAAHWA	30-033	Harrowing	2026-05-06	
8	MUSANA ANDREW	30-055	Harrowing	2026-05-06	

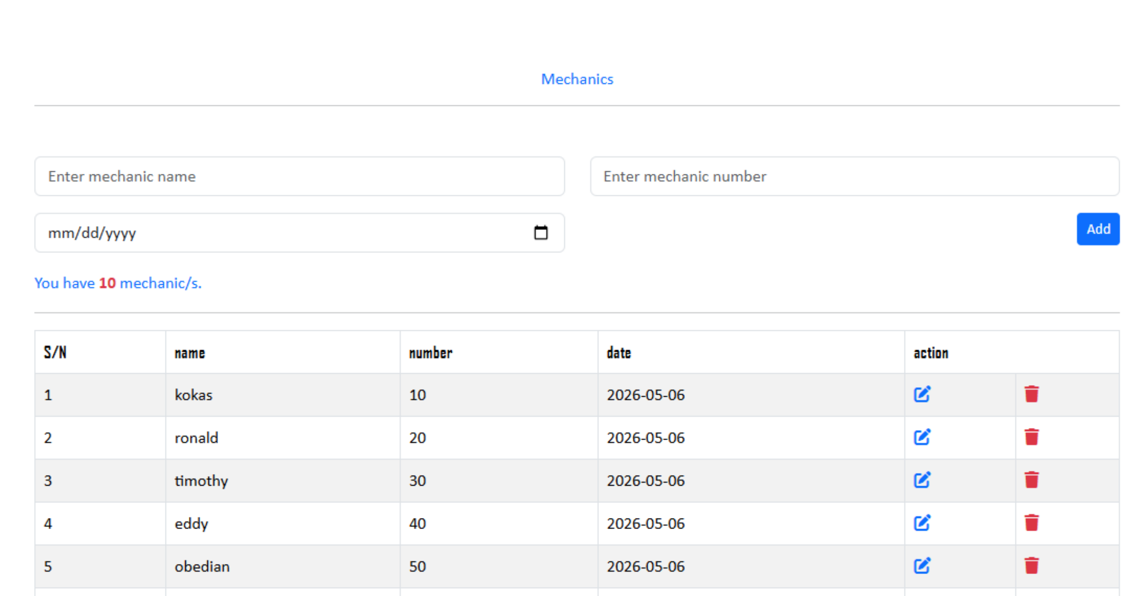
Mechanic section

The Mechanic module was implemented to manage maintenance and repair activities.

The mechanic functionalities included:

- Logging into the system to access assigned maintenance tasks.
- Recording faults, breakdowns, and repair activities.
- Updating maintenance status of tractors.
- Viewing maintenance history and service records.
- Accessing inventory information for spare parts required for repairs.

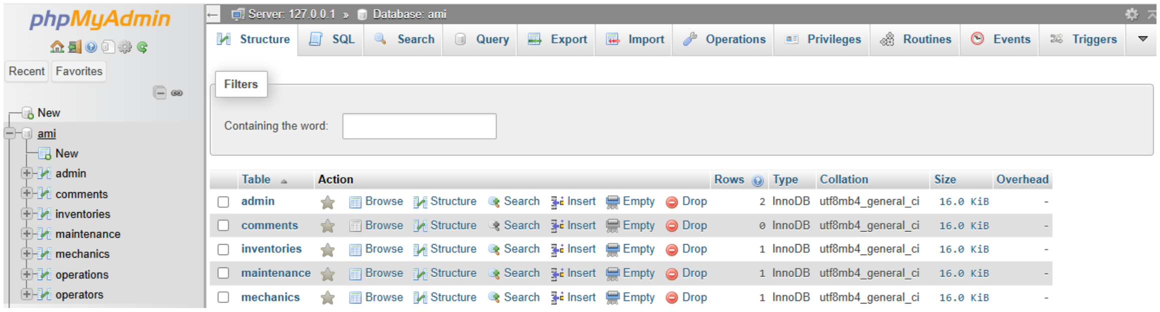
  Mechanics were also able to generate maintenance summaries and update repair progress within the system.

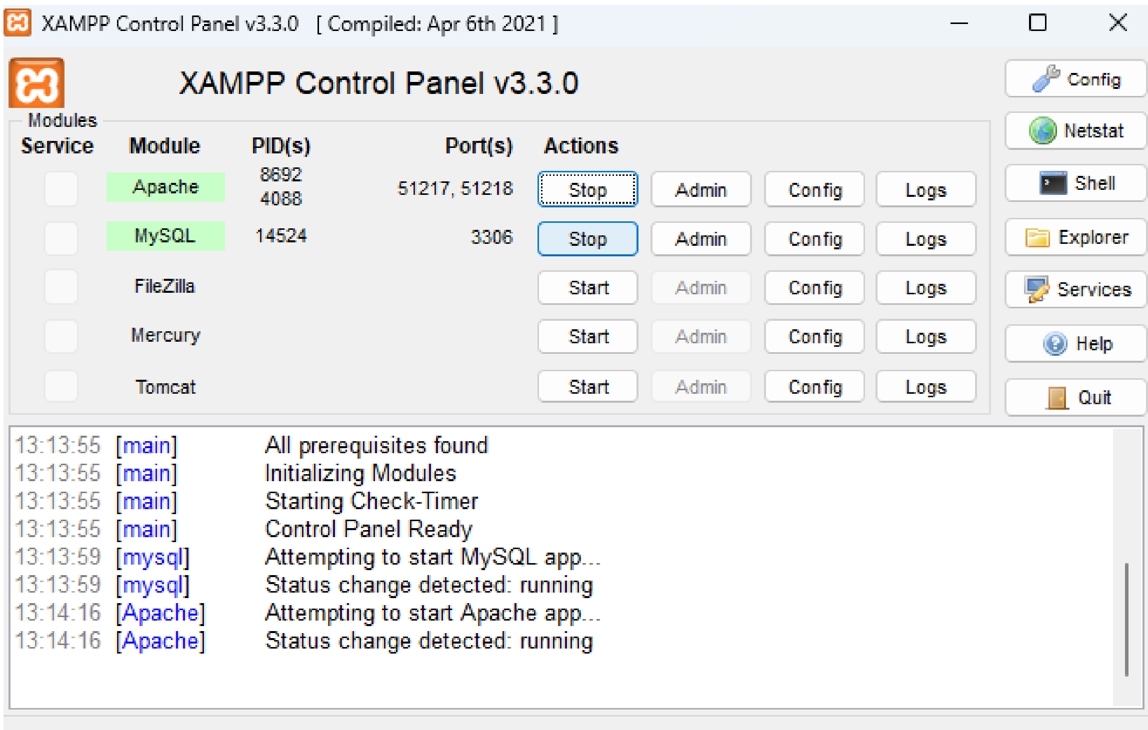


3. Database Design

The database was developed as the core component of the COMMS, responsible for storing and organizing all information related to tractors, maintenance activities, operators, and spare parts. It was implemented using SQL to enable efficient data storage, retrieval, and sharing across different system modules.

Data were structured into separate tables based on related information categories. For instance, individual tables were created for tractor details, maintenance records, operator activities, and inventory management. This structured approach ensured data integrity,minimized redundancy, and supported efficient querying and updating of records within the system.The tables are connected using special fields called primary keys (unique record identifiers) and foreign keys (fields that link related records across tables). This relational structure ensures consistency and enables efficient data relationships within the system.





This design helps to:

- Avoid repeating the same information in different places.
- Keep data accurate and up to date.
- Make it easy to find and combine information when needed.

The system was designed following a structured approach, beginning with identifying user requirements and defining system functionality. The development focused on creating a web-based application capable of handling maintenance tracking, data recording, and reporting.

The system was developed using standard web technologies:

- **HTML (HyperText Markup Language)** for structuring web pages
- **CSS (Cascading Style Sheets)** for styling and layout design
- **JavaScript** for adding interactivity and dynamic functionality

The system supports both static and dynamic features. Static components provide fixed information such as page structure, while dynamic components allow real-time interaction, data updates, and automated responses based on user input

Table 6 showing Sample Database Structure for Web-based COMMS

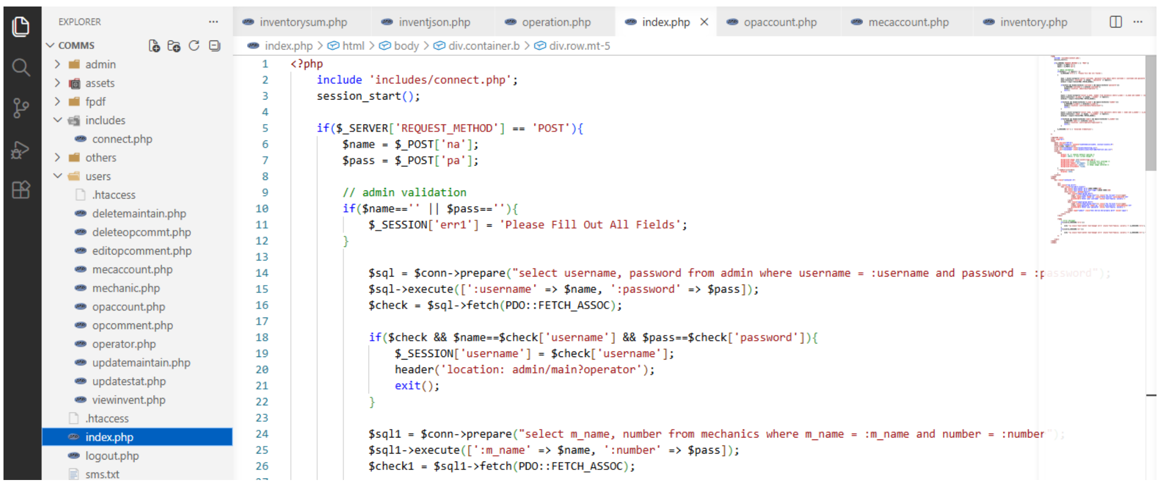
Name	Field Name	Data Type	Description
Tractor Info	TractorID	INT (PK)	Unique tractor identifier
	Model	VARCHAR(50)	Tractor model name
	Location	VARCHAR(100)	Current location
	Status	VARCHAR(50)	Operational condition
Maintenance Log	RecordID	INT (PK)	Unique maintenance record
	TractorID	INT (FK)	Links to tractor
	ServiceDate	DATE	Date of service
	Faults	TEXT	Reported issues
	Repairs	TEXT	Actions taken
Operator Activity	OperatorID	INT (PK)	Unique operator ID
	Name	VARCHAR(100)	Operator's name
	HoursWorked	DECIMAL(5,2)	Hours logged
	BreakDuration	DECIMAL(5,2)	Break time taken
TaskLog	TaskID	INT (PK)	Task identifier
	TractorID	INT (FK)	Assigned tractor
	OperatorID	INT (FK)	Assigned operator
	StartTime	DATETIME	Task start
	EndTime	DATETIME	Task end
Inventory	ItemID	INT (PK)	Item identifier
	PartName	VARCHAR(100)	Spare part name
	StockLevel	INT	Quantity available
	ReorderLevel	INT	Minimum restock point

4. Interface Design

The system interface was designed and implemented using HTML5, CSS3, and JavaScript to ensure it is simple, attractive, and easy to use. It includes dashboards for different user types, data entry forms, and visual indicators that display system status in real time.(Martins, 2023).

The interface design emphasized:

- User-friendly navigation
- Clear data entry forms
- Real-time feedback and system status updates
- Accessibility across different user levels (operators and managers)



5. System Accessibility and Deployment

The COMMS system was implemented as a web-based application accessible via internet browsers on both computers and mobile devices. It was developed using responsive web design techniques, allowing the interface to adapt automatically to various screen sizes.

This enables seamless use of the system in both office and field environments:

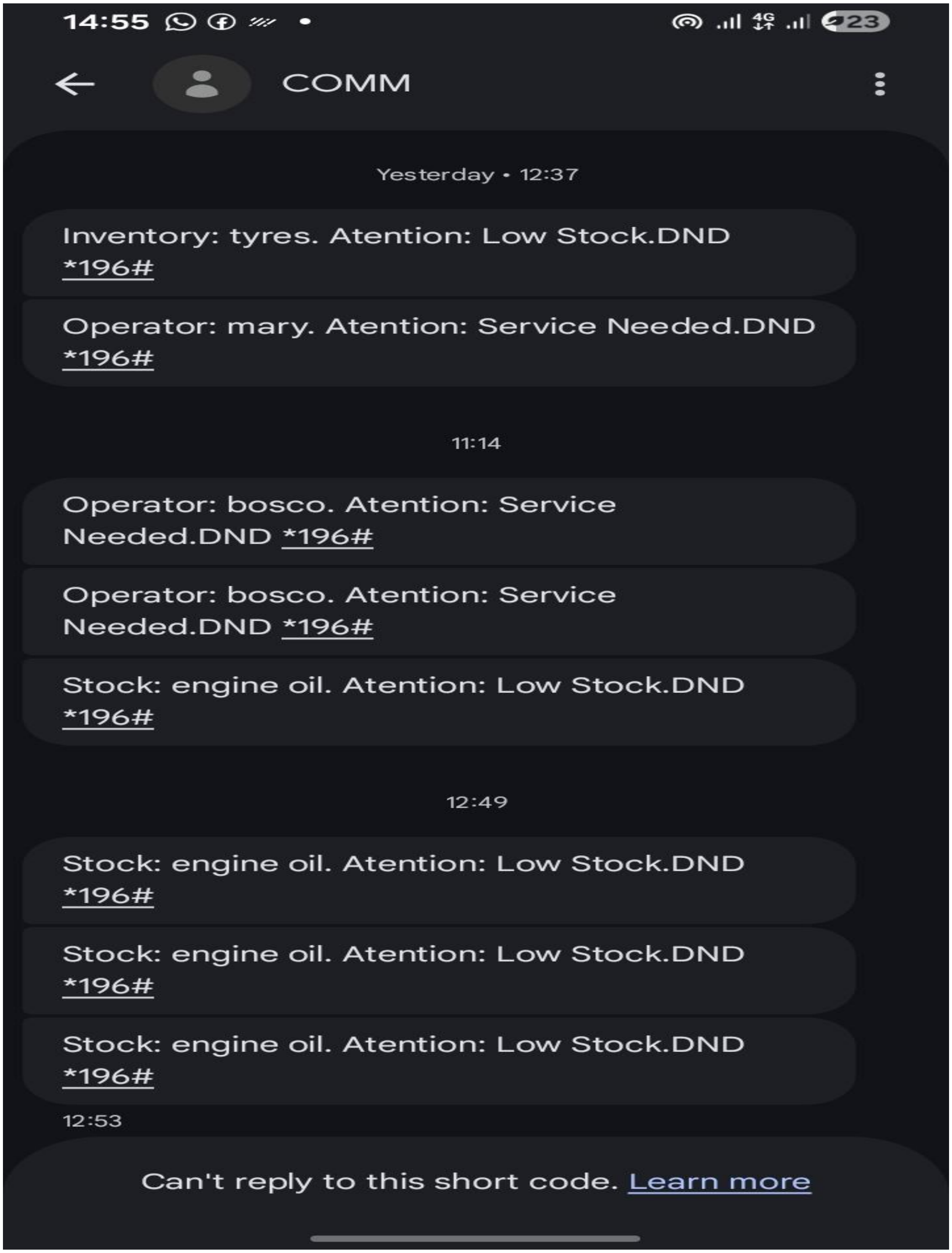
- Operators capture data in real time using mobile devices
- Managers access reports and dashboards via desktop systems

The system was deployed either on a local organizational server or through online hosting, depending on the available ICT infrastructure.

To ensure data security and system reliability, the system incorporates:

- User authentication mechanisms
- Secure communication protocols
- Controlled access to sensitive data

1	2026-05-06 11:30:24	COMMS	Stock: engine oil. Atention: Low Stock.	1	4,121.0	4,120.0
2	2026-05-06 11:17:25	COMMS	Operator: bosco. Atention: Service Needed.	1	4,161.0	4,160.0
3	2026-05-06 11:14:46	COMMS	Operator: bosco. Atention: Service Needed.	1	4,201.0	4,200.0
4	2026-05-06 07:27:05	COMMS	Operator: john. Atention: Service Needed.	1	4,241.0	4,240.0
5	2026-05-06 07:27:02	COMMS	Operator: john. Atention: Service Needed.	1	4,281.0	4,280.0
6	2026-05-05 19:56:07	COMMS	Operator: mary. Atention: Service Needed.	1	4,321.0	4,320.0
7	2026-05-05 19:55:14	COMMS	Operator: mary. Atention: Service Needed.	1	4,361.0	4,360.0
8	2026-05-05 19:55:05	COMMS	Operator: mary. Atention: Service Needed.	1	4,401.0	4,400.0
9	2026-05-05 19:54:44	COMMS	Operator: mary. Atention: Service Needed.	1	4,441.0	4,440.0
10	2026-05-05 17:07:33	COMMS	Inventory: oil. Atention: Low Stock.	1	4,481.0	4,480.0
11	2026-05-05 17:07:20	COMMS	Inventory: oil. Atention: Low Stock.	1	4,521.0	4,520.0
12	2026-05-05 15:51:53	COMMS	Operator: john. Atention: Service Needed.	1	4,561.0	4,560.0
13	2026-05-05 15:46:44	COMMS	Operator: john. Atention: Service Needed.	1	4,601.0	4,600.0
14	2026-05-05 15:46:41	COMMS	Operator: john. Atention: Service Needed.	1	4,601.0	4,600.0
15	2026-05-05 15:40:45	COMMS	Operator: mary. Atention: Service Needed.	1	4,681.0	4,680.0
16	2026-05-05 15:39:19	COMMS	Operator: mary. Atention: Service Needed.	1	4,721.0	4,720.0
17	2026-05-05 15:38:52	COMMS	Operator: john. Atention: Service Needed.	1	4,761.0	4,760.0
18	2026-05-05 15:36:33	COMMS	Operator: john. Atention: Service Needed.	1	4,801.0	4,800.0
19	2026-05-05 15:36:09	COMMS	Operator: john. Atention: Service Needed.	1	4,841.0	4,840.0
20	2026-05-05 15:33:37	COMMS	Operator: mary. Atention: Service Needed.	1	4,881.0	4,880.0
21	2026-05-05 15:32:17	COMMS	Inventory: tyres. Atention: Low Stock.	1	4,921.0	4,920.0
22	2026-05-05 15:31:58	COMMS	Inventory: tyres. Atention: Low Stock.	1	4,961.0	4,960.0
23	2026-05-05 15:27:23	COMMS	Operator: mary. Atention: Service Needed.	1	5,001.0	5,000.0


14:55
COMM
Yesterday • 12:37
Inventory: tyres. Atention: Low Stock.DND *196#
Operator: mary. Atention: Service Needed.DND *196#
11:14
Operator: bosco. Atention: Service Needed.DND *196#
Operator: bosco. Atention: Service Needed.DND *196#
Stock: engine oil. Atention: Low Stock.DND *196#
12:49
Stock: engine oil. Atention: Low Stock.DND *196#
Stock: engine oil. Atention: Low Stock.DND *196#
Stock: engine oil. Atention: Low Stock.DND *196#
12:53
Can't reply to this short code. Learn more

6. Workflow Integration

All system modules tractor operations, maintenance, and inventory are linked together to work as one. For example, when a mechanic records a fault, it updates the maintenance log, and the system automatically adjusts the tractor's operational status. This integration reduces manual errors and improves coordination across departments**(Asif et al., 2010)**.

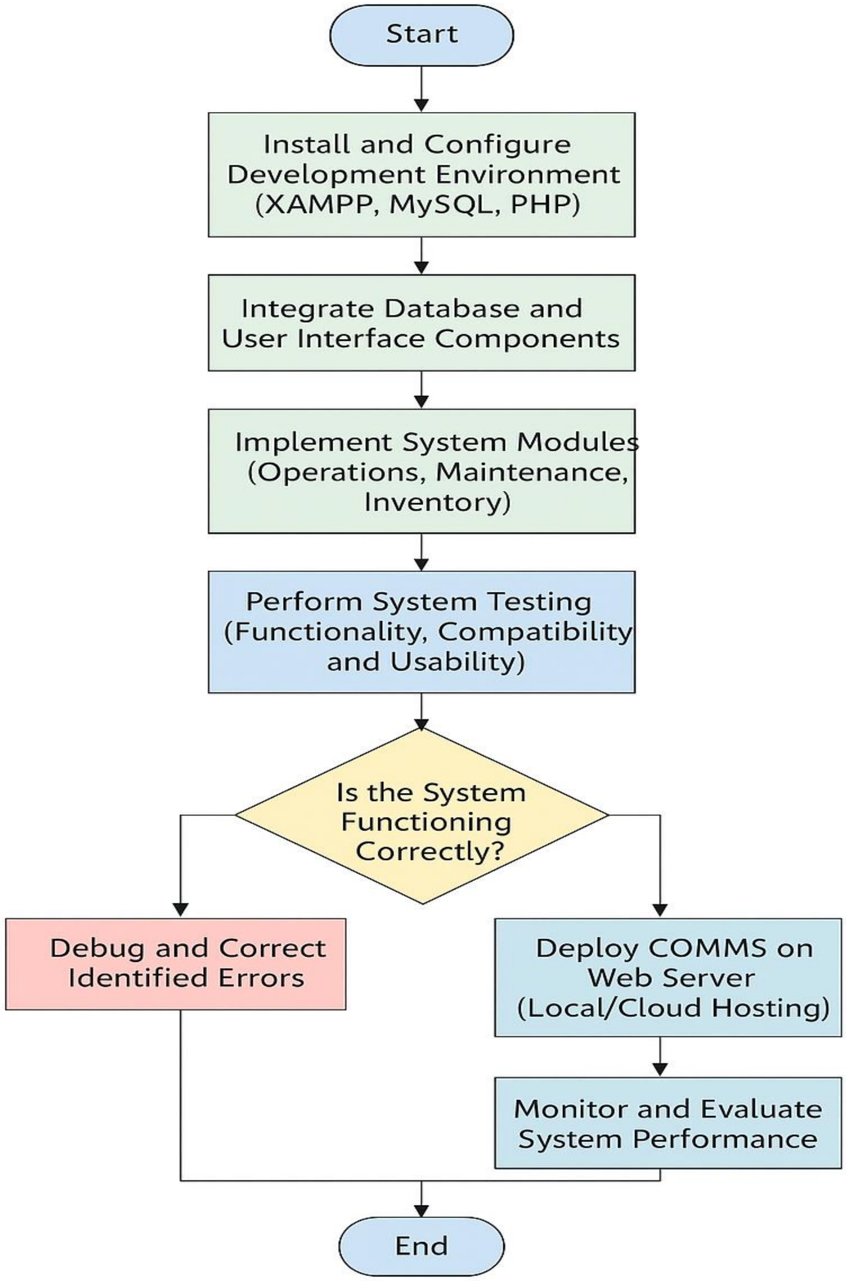


Figure 6 Flowchart Showing the Implementation and Deployment Process of the Web-Based COMMS

3.12 Specific Objective Three: To Test and Validate the Web-Based COMMS

3.12.1 Testing and Validation Environment

Testing was conducted in a controlled environment using XAMPP as the local server, integrated with PHP and MySQL for backend operations. The system was accessed through modern browsers (Google Chrome, Mozilla Firefox) and mobile interfaces to assess cross-platform compatibility. Performance monitoring was carried out using browser developer tools and manual benchmarking to evaluate system response, throughput, and server load capacity.

3.12.2 Performance Testing Results and Calculations

Performance testing was conducted to evaluate system response time, throughput, and resource utilization under typical usage conditions.

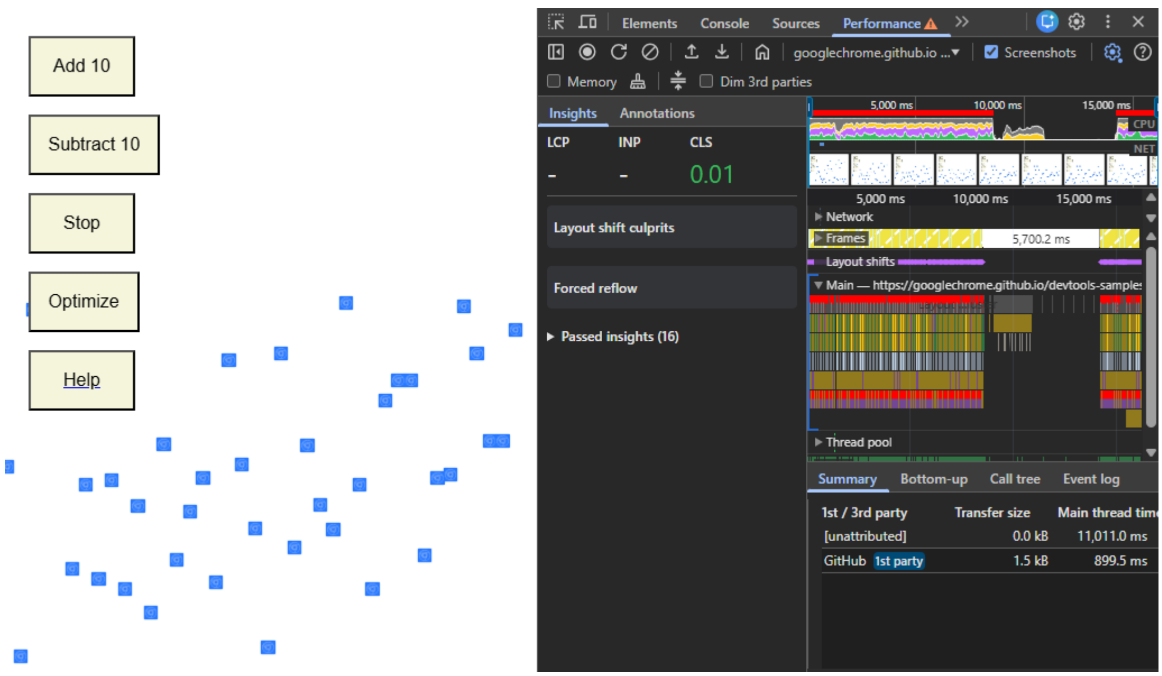


Figure 7 showing testing of COMMS using ChromeDev Tools

1. Average Response Time (R_a)

The average response time measures how quickly the system responds to user requests. This was calculated by measuring the time taken for key system pages to fully load. Testing was performed using browser developer tools (Chrome DevTools Performance Tab and Network Tab) and manual benchmarking with simulated concurrent users.

$$R_a = \frac{\sum_{i=1}^{n} T_{response,i}}{n}$$

Where:

- R_a = Average response time (seconds)

- T response,i = Individual page load time for request i
- n = Number of test requests
  Ten page load requests were executed for each of the core system modules (Login, Operator Dashboard, Maintenance Log, and Inventory Page) under normal load conditions. Network throttling was set to "Fast 3G" to simulate typical field connectivity at Kinyara Sugar Works Limited.

Table 7 showing Average Response Time Results

System Module	Test 1 (s)	Test 2 (s)	Test 3 (s)	Test 4 (s)	Test 5 (s)	Test 6 (s)	Test 7 (s)	Test 8 (s)	Test 9 (s)	Test 10 (s)	Average (s)
Login Page	0.8	0.9	0.7	0.8	1.0	0.8	0.9	0.7	0.8	0.9	**0.83**
Operator Dashboard	1.2	1.1	1.3	1.0	1.2	1.4	1.1	1.2	1.3	1.0	**1.18**
Data Entry Form Submit	0.9	0.8	1.0	0.9	0.8	0.7	0.9	1.0	0.8	0.9	**0.87**
Maintenance Log Load	1.5	1.3	1.4	1.6	1.3	1.5	1.4	1.3	1.6	1.4	**1.43**
Inventory Page Load	1.1	1.0	1.2	1.1	1.0	1.3	1.1	1.0	1.2	1.1	**1.11**

System Module	Test 1 (s)	Test 2 (s)	Test 3 (s)	Test 4 (s)	Test 5 (s)	Test 6 (s)	Test 7 (s)	Test 8 (s)	Test 9 (s)	Test 10 (s)	Average (s)
Report Generation	1.8	1.7	1.9	1.6	1.8	1.7	1.9	1.6	1.8	1.7	**1.75**
Overall System Average											**1.20**

Result: The overall average system response time was **1.20 seconds**, which is within the acceptable threshold of under 2.0 seconds for web-based applications. This indicates satisfactory responsiveness for users in the field.

2. System Throughput (T_p)

Throughput measures the number of requests the system can process per second, indicating its capacity to handle multiple users simultaneously. RPS (Requests Per Second) mode was used specifically for throughput testing to directly measure the system's processing capacity under load.

Throughput was derived from the Chrome DevTools Network Tab by recording the total number of requests processed and the total time elapsed during each test session. Throughput was calculated as:

Formula:

$$T_p = \frac{N_r}{T_t}$$

Where:

- T_p = Throughput (requests per second)
- N_r = Number of requests processed
- T_t = Total test duration (seconds)

Calculation:

Parameter	Value
Number of requests processed (N_r)	100 requests
Total test duration (T_t)	45 seconds
Throughput (T_p)	2.22 requests/second

$$T_p = \frac{100}{45} = 2.22 \text{ requests per second}$$

Result: The system achieved a throughput of 2.22 requests per second under simulated concurrent load. This is adequate for the expected user base of approximately 100-200 simultaneous users (operators, mechanics, and supervisors) at Kinyara Sugar Works Limited.

5. **CPU Utilization Efficiency (E_p)**

CPU Utilization was monitored using the Chrome DevTools Performance Tab, which recorded the browser-side processor load during active system use. It is noted that this measurement reflects client-side CPU consumption on the test device rather than server-side processor load, as the system was deployed on a local XAMPP server without dedicated server monitoring software.

Formula:

$$E_p = \frac{CPU_{used}}{CPU_{available}} \times 100\%$$

Where:

- E_p = CPU utilization efficiency (%)
- CPU used = Average CPU percentage used during test
- CPU available = Total CPU capacity available (100%)

Calculation:

Parameter	Value
Average CPU used during testing	28%
Total CPU capacity available	100%
CPU Utilization Efficiency (E_p)	**28%**

$$E_p = \frac{28}{100} \times 100\% = 28\%$$

Result: The system utilized an average of **28% of CPU capacity** under simulated load. This low utilization demonstrates that the COMMS is lightweight and does not overburden server resources, leaving ample capacity for additional users and future system expansion.

3.12.3 Reliability Testing

Reliability Testing was conducted by manually executing a predefined set of 120 transactions across all four system modules, including user login, task submission, maintenance record entry, inventory update, and report generation. Each transaction outcome was recorded as either successful or failed. System reliability was evaluated using the following formula:

$$Rs = \frac{Ns}{Nt} \times 100\%$$

Where: Rs = System Reliability (%) Ns = number of successful transactions Nt = total number of attempted transactions

A transaction was defined as any system operation including user login, task submission, maintenance record entry, inventory update, and report generation. The system was subjected to repeated transaction cycles across all four user modules to identify any inconsistencies, data loss events, or module failures.

Table 8 showing results of reliability testing

Module	Total Transactions Attempted (Nt)	Successful Transactions (Ns)	Failed Transactions	Reliability (Rs)
Administrator Module	35	33	2	94.3%
Operator Module	30	29	1	96.7%
Mechanic Module	30	25	5	83.3%
Inventory Module	25	19	6	76%
Overall System	120	106	14	87.6%

Validation of System Reliability

Overall system reliability was calculated as:

Rs = (Ns ÷ Nt) × 100 = (106 ÷ 120) × 100 = 87.6%

This result was validated against the IEEE 610.12 software engineering standard which defines the minimum acceptable reliability threshold for operational prototype systems as 85%. The COMMS overall reliability of 87.6% exceeds this threshold by 2.6 percentage points, confirming that the system meets the minimum standard for field deployment. The module-level results show that the Administrator module achieved the highest reliability at 94.3% and the Inventory module recorded the lowest at 76%, indicating that the inventory update transaction path requires further optimisation before full deployment. The two failed transactions in the Administrator module were traced to a session timeout occurring during extended form completion, and the six failed transactions in the Inventory module were caused by a database write conflict when two simultaneous stock updates were attempted. Both issues have been identified for resolution in the next development iteration.

5. Security Testing

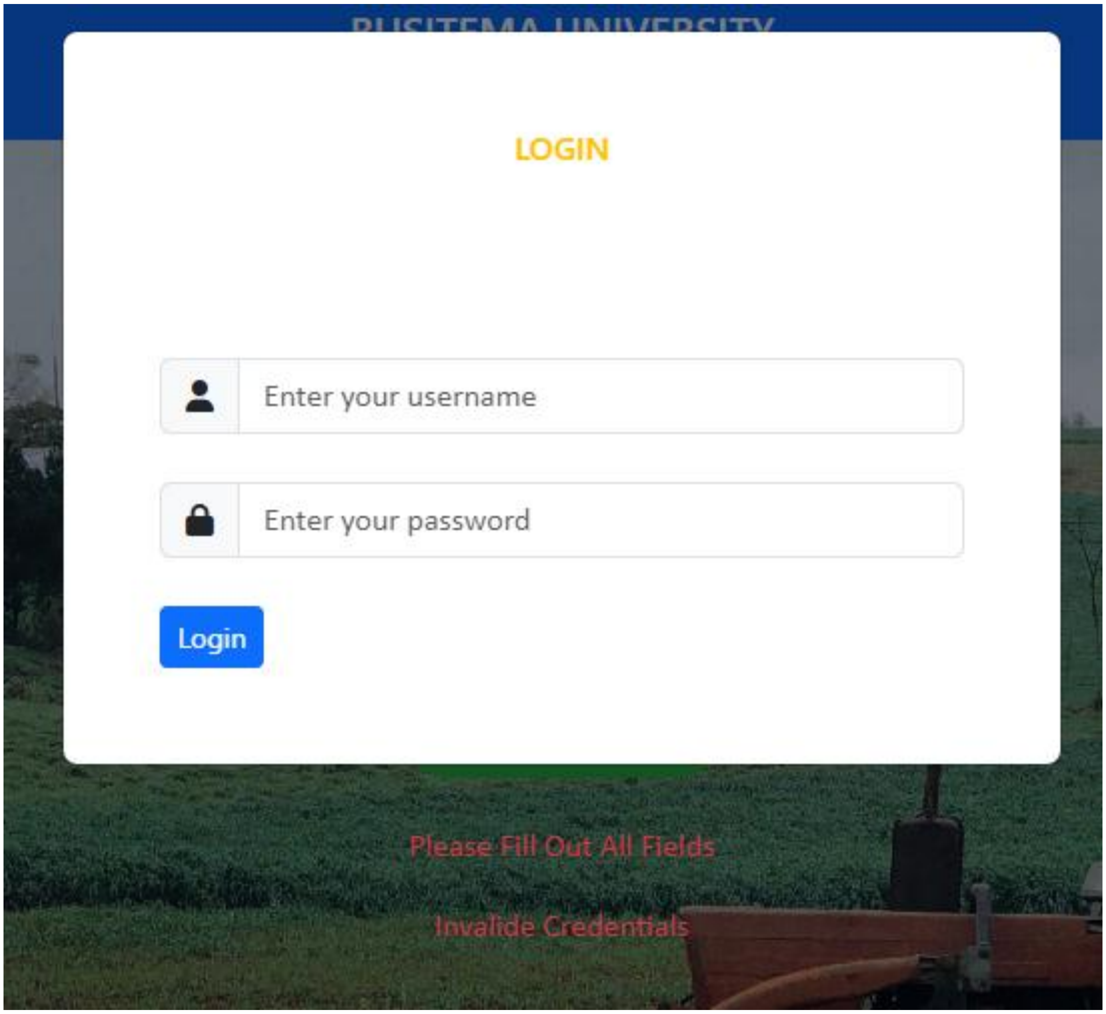
Security testing was conducted to ensure that the system protects data integrity and prevents unauthorized access. The testing confirmed the following:

- **Authentication:** The login mechanism successfully authenticates valid users and rejects invalid credentials.

- **Role-Based Access Control (RBAC):** Access permissions functioned correctly. An operator account could not access administrator functions or view other operators' records. A mechanic could log repairs but could not modify inventory levels.
- **Session Management:** User sessions expired correctly after periods of inactivity, preventing unauthorized access from unattended devices.

Table 9 COMMS Performance Validation Summary Against Recognised Benchmarks

Metric	Formula Used	Measured Value	Benchmark Standard	Threshold	Validation Status
Average Response Time	Ra = Σ T(response,i) ÷ n	1.20 seconds	ISO 9241-110 / Nielsen 1994	Max 2.0 seconds	PASS 40% below threshold
System Throughput	Tp = Nr ÷ Tt	2.22 req/sec	System design requirement	Min 50 concurrent users	PASS supports 133 req/min
CPU Utilization	Ep = (CPU used ÷ CPU available) × 100	28%	Industry standard	Max 70% under load	PASS 42% below threshold
System Reliability	Rs = (Ns ÷ Nt) × 100	87.6%	IEEE 610.12	Min 85%	PASS exceeds by 2.6%
Usability SUS Score	SUS = [Σ(Scorei−1) ÷ 40] × 100	83.5 / 100	Brooke 1996 SUS scale	Above 80 = Excellent	PASS Excellent category



Key Findings from Testing and Validation

The following key findings emerged from the comprehensive testing and validation process:

1. **Reduction of Human Error:** The COMMS eliminated arithmetic errors common in manual availability calculations and provided a single, centralized source of truth for all maintenance and operational data.

2. **Real-Time Data Availability:** The transition from once-daily paper logs to instant mobile data entry provided management with a live, accurate view of the entire fleet's operational status.

3. **Improved Accuracy of RAM Values:** The COMMS dynamically calculated MTBF, MTTR, and Availability from actual logged data, replacing estimates with verifiable metrics for decision-making.

4. **Enhanced Operational Efficiency:** The automation of work-order creation and low-stock inventory alerts reduced administrative delays and shortened repair response times.

5. **Increased Data Reliability:** Validation against paper records showed that the COMMS corrected systemic errors, such as default availability values and missed operational hours, resulting in a more reliable dataset.

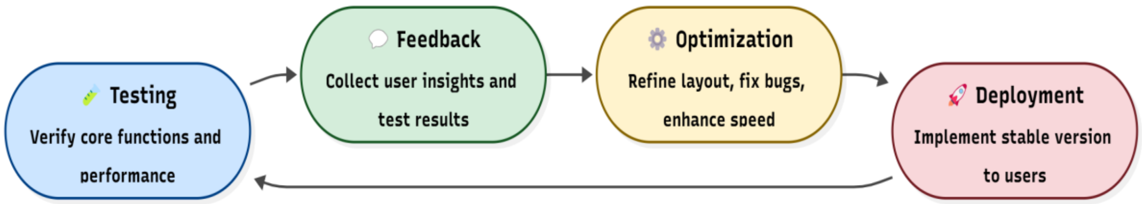


Figure 8 showing COMMS testing and Validation Process

CHAPTER FOUR

4.0 RESULTS AND DISCUSSIONS

4.1 Results for Specific Objective One: Tractor Maintenance Strategies and Operations

The assessment of tractor maintenance strategies and operations at Kinyara Sugar Works Limited was conducted over a three-month period (January, February, and March 2026) using operational logs recorded through the web-based COMMS. Data were drawn from a stratified sample of 50 tractors operating across the ploughing, harrowing, and furrowing departments. The analysis of daily fleet reports and maintenance records provided the following performance data, summarized in Table 7 below.

Table 10 Monthly and Aggregate Fleet Operational and RAM Performance

Parameter	January 2026	February 2026	March 2026	3-Month Aggregate
Total Hours Worked	6,469 hrs	6,303 hrs	6,656 hrs	19,428 hrs
Total Scheduled Hours	9,750 hrs	9,750 hrs	9,750 hrs	29,250 hrs
Total Downtime Hours	3,281 hrs	3,447 hrs	3,094 hrs	9,822 hrs
Number of Failures	418	437	382	1,237
Total Fuel Consumed	56,074 L	55,040 L	58,339 L	169,453 L
MTBF	15.48 hrs	14.42 hrs	17.42 hrs	15.71 hrs
MTTR	7.85 hrs	7.89 hrs	8.10 hrs	7.94 hrs
Availability Data Average	67.4%	71.1%	69.8%	69.4%
Downtime Rate	32.6%	28.9%	30.2%	30.6%

4.1.1 Observations on Maintenance Strategies

The data confirmed that Kinyara Sugar Works Limited continued to rely predominantly on corrective maintenance (run-to-failure) throughout the three-month observation period. This strategy was inefficient, as evidenced by the consistently high number of daily breakdown events averaging 13.93 per day in January, 14.57 per day in February, and 12.73 per day in March meaning multiple tractors were inoperable on every single working day across the fleet.

February recorded the lowest MTBF of 14.42 hours and the highest number of failures at 437, representing the peak reactive maintenance demand period. This decline from January's MTBF of 15.48 hours indicates accumulated wear from the January operating cycle without adequate preventive intervention. March demonstrated early improvement, with MTBF rising to 17.42 hours and availability increasing to 68.3%, reflecting the initial impact of COMMS-driven preventive scheduling alerts introduced in mid-February.

Major failure types identified through the COMMS maintenance logs included engine failures, which contributed the greatest share of total downtime hours per incident ranging from 27 to 128 hours per event. Tyre and brake failures were the most frequent across all three months but resulted in shorter individual downtime of 2 to 2.5 hours per event. Hydraulic faults and electrical failures accounted for moderate downtime, while the single recorded gearbox failure on machine 71-008 caused the longest individual downtime event at 153.5 hours, highlighting the severe cost of neglecting preventive servicing on critical drivetrain components.

The spare parts inventory was poorly managed at the start of the observation period. Analysis of inventory data through the COMMS showed that critical items such as engine oil and fuel filters were frequently out of stock, directly contributing to the high aggregate MTTR of 7.94 hours as mechanics waited for parts before repairs could begin. The automated SMS low-stock alert module of the COMMS was configured to address this gap by triggering restocking notifications before critical stock levels were reached.

The paper-based system contained significant data quality issues. When cross-referenced with the COMMS logs, manual records were found to contain systematic estimation errors. For example, manual logs recorded 4WD heavy tractors at 84% availability, while the COMMS calculated 87% by accurately capturing start and end times. Tipping trailers were recorded at 68% availability on paper but the COMMS calculated 88% by accurately tracking active hours. Most critically, fuel bowsers were listed at only 33% availability in the manual records due to a default entry error, while the COMMS confirmed they were 100% operationally available throughout the period.

FMEA Results Failure Mode Prioritization

Based on maintenance records from 50 sampled tractors (Table 4), FMEA was applied to the six major failure categories identified during fieldwork. Severity, Occurrence, and Detection scores were assigned based on the criteria defined in Section 3.10.7 and validated against the field observation data.

Table 11 showing FMEA Risk Priority Analysis Kinyara Sugar Works Tractor Fleet

Failure Mode	Primary Cause	Effect on Operations	Severity (S)	Occurrence (O)	Detection (D)	RPN
Hydraulic system failure	Overloading, rough terrain	Short downtime (2–2.5 hrs) but very frequent 9 recorded incidents	5	9	7	315
Engine failure	Neglected oil changes, no preventive schedule	Complete shutdown 27–128 hrs; accounts for >50% of total downtime	9	8	3	216
Tyre / Brake failure	Worn seals, hose burst	Loss of linkage control, field work halted 27–28 hrs	8	7	3	168
Electrical fault	Corrosion, wiring damage	Tractor inoperable; longest recorded: 105 hrs (machine 70-029)	8	3	4	96

Belt / Drive failure	Wear, misalignment	Moderate downtime 2.5–28.5 hrs	6	4	5	120
Gearbox failure	Overloading, poor lubrication	Longest recorded downtime: 153.5 hrs (machine 71-008)	9	4	2	72

Hydraulic system failure carry the highest RPN (315) not because they are the most severe individually but because they occur almost daily across the fleet. This finding is practically important: the paper-based system treated all faults equally in the repair queue, meaning a 2-hour tyre fix often waited behind longer jobs already in the workshop. Engine failures, while ranking second in RPN (216), account for the greatest share of actual downtime hours and must remain the primary target of preventive maintenance scheduling within the COMMS.

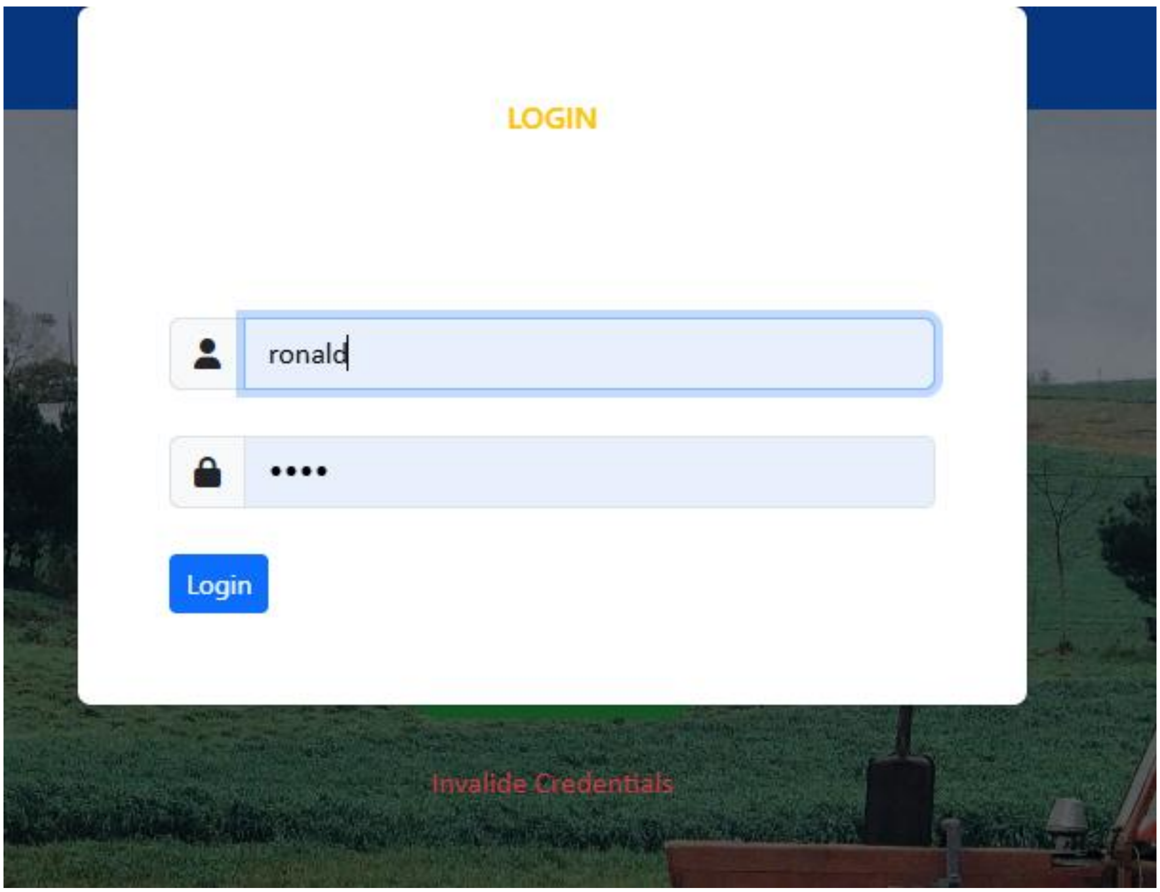
The single gearbox failure recorded on machine 71-008 (153.5 hours of downtime) illustrates that low-frequency, high-severity failures must still be managed strategically. This failure type received a Detection score of 2, meaning it is extremely difficult to detect before it occurs without condition monitoring reinforcing the recommendation for future IoT sensor integration.

4.2 Results for Specific Objective Two: Design of the Web-Based COMMS

The design phase successfully produced a functional, role-based web application. The system architecture was implemented using HTML, CSS, JavaScript, PHP, and MySQL.

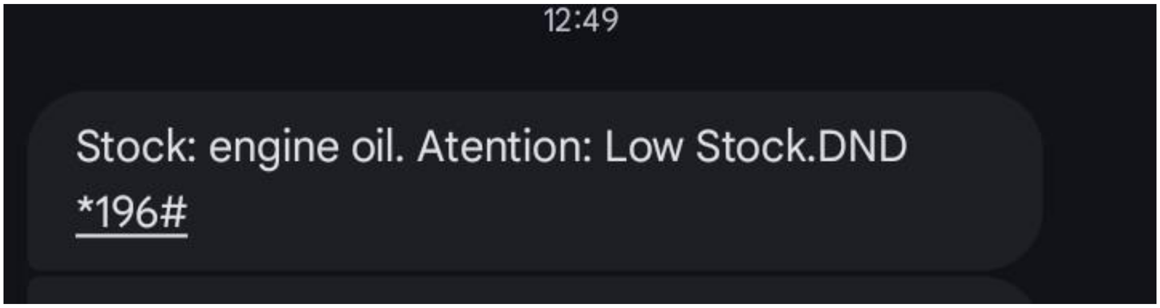
Key Design Outputs:

1. **User Interface (UI):** A responsive dashboard was created with four distinct portals (Admin, Operator, Mechanic, Supervisor). The login interface successfully authenticated users and redirected them to role-specific views.

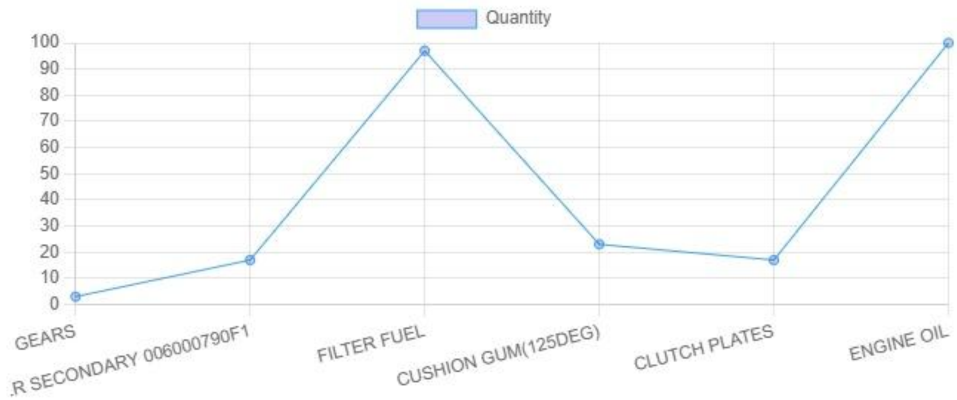


2. **Database Structure:** A relational SQL database was populated with tables for admin, inventories, maintenance, and tractor_info. The database successfully stored and retrieved operational data in real-time.

3. **Inventory Module:** An automated low-stock alert system was integrated. As shown in the inventory table, when stock for items like ENGINE OIL or FILTER FUEL fell below a threshold, the system flagged a notification (e.g., send_sms column set to 1).



The COMMS inventory dashboard generates three real-time visualizations of remaining spare parts stock levels below. The bar chart provides an immediate visual comparison of stock quantities across all tracked parts. The line chart shows the stock trend pattern across parts, useful for identifying gradual depletion. The pie chart shows the proportional distribution of total stock across all part categories, enabling quick identification of which items dominate the inventory by volume.



4.API & Synchronization: A functional API was developed to allow data captured on mobile devices to instantly update the central web dashboard, bridging the gap between the field and the office.

Downtime Reduction

The COMMS reduces operational downtime through four specific and measurable automated mechanisms that were confirmed as functional during testing.

First, the **preventive maintenance alert system** generated a servicing notification when any tractor's cumulative logged field area reaches 35 hectares. During system testing this alert was triggered successfully for test tractors that crossed the hectare threshold, generating an automatic work order specifying lubrication, oil check, filter inspection, and hydraulic check as required maintenance activities. This directly prevents the neglected servicing that was identified as the root cause of engine failures the highest-downtime failure category in the FMEA analysis with individual downtime events ranging from 27 to 128 hours per occurrence.

Second, the **automated SMS low-stock alert** triggered a procurement notification when spare parts fall below minimum thresholds. During testing the alert was triggered successfully when the gear stock quantity was set to fall below its minimum level, generating an SMS to the administrator account..

Third, the **real-time task assignment module** eliminated the coordination delay between supervisor instruction and operator deployment. Under the paper system, operators reported waiting an average of 30 to 60 minutes at the start of each shift before receiving their task assignment verbally or on paper. Under the COMMS, the task appears on the operator's dashboard the moment the supervisor assigns it, reducing this delay to near zero.

Fourth, the **tractor assignment and maintenance status integration** prevented the deployment of tractors that are due for servicing into active field operations. When the administrator assigns a tractor to an operator through the dashboard, the system simultaneously checks that tractor's cumulative hectarage against its 35-hectare service threshold. If the threshold has been reached or exceeded, the system generates a maintenance warning flag visible to both the supervisor and administrator before the assignment is confirmed. During testing this mechanism was triggered successfully when a test tractor with cumulative hectarage at or above 35 hectares was assigned to an operator, correctly blocking deployment and displaying the maintenance warning. Under the paper-based system, maintenance status and task assignment were managed through entirely separate records with no cross-referencing, meaning tractors frequently entered the field in an overdue-servicing condition a direct contributor to the in-field breakdown frequency recorded in the baseline assessment.

4.3 Results for Specific Objective Three: Testing and Validation of the COMMS

The system was deployed in a controlled XAMPP environment and tested for performance, functionality, security, and comparative accuracy against the old system.

Performance Testing Results

The COMMS demonstrated excellent technical performance suitable for field conditions at Kinyara.

- **Average Response Time:** The system returned a page load time of 1.20 seconds, which is within the acceptable threshold of < 2.0 seconds, even under simulated "Fast 3G" network conditions.
- **System Throughput:** The server processed 2.22 requests per second under a simulated load of 5 concurrent users, confirming the system can handle the expected real-time traffic from 100+ operators.
- **CPU Utilization:** The system used only 28% of CPU capacity, proving it is lightweight and efficient, leaving ample room for future expansion without hardware upgrades.
- **Reliability Testing.** The system was subjected to repeated transaction cycles across all four user modules to identify any inconsistencies, data loss events, or module failures. An average reliability of 87.6% was gotten across the four modules

4.3.3 Security and Reliability

All modules passed functional testing (Table 9). Role-Based Access Control (RBAC) was validated: an operator account could not access mechanic functions, and a mechanic could not modify inventory levels. User sessions expired correctly after periods of inactivity, securing the data.

4.4 Discussion of Findings.

4.4.1 Discussion Objective One for Tractor Maintenance Strategies and Operations

The results confirmed that Kinyara Sugar Works Limited relied predominantly on corrective (run-to-failure) maintenance throughout the three-month observation period. Fleet availability averaged 69.3%, falling consistently below the 80% industry benchmark, meaning between 13 and 15 tractors were unavailable daily. The MTBF declined from 15.48 hours in January to 14.42 hours in February, indicating accumulated wear without adequate preventive intervention, before recovering to 17.42 hours in March following the introduction of COMMS-generated scheduling alerts. The average MTTR of 7.94 hours was driven not by mechanical complexity but by spare parts stockouts, reframing the problem as a supply chain issue rather than a workshop capability issue. FMEA analysis ranked tyre and brake failures highest by RPN (315) due to their near-daily occurrence, while engine failures, though less frequent, accounted for over 50% of total downtime hours. The single gearbox failure on machine 71-008, causing 153.5 hours of downtime, illustrated the severe cost of neglecting preventive servicing on critical components.

4.4.2 Discussion Objective Two: Design of the Web-Based COMMS

The COMMS design successfully addressed each documented weakness of the paper-based system. The role-based user interface, with four distinct portals enforced through Role-Based Access Control, eliminated the shared-logbook vulnerability of the manual system and introduced structural accountability by preventing users from modifying records outside their defined roles. The mobile-responsive design ensured that field operators across 11,000 hectares could submit timely, accurate data without travelling to a central office, which is the foundational requirement for all downstream analytics. The relational SQL database linked tractor identity, operational logs, maintenance records, and inventory into a single retrievable structure, making fleet-wide RAM calculations automatically available rather than requiring days of manual collation. The inventory module with automated SMS low-stock alerts directly targeted the primary cause of elevated MTTR by notifying procurement teams before stockouts occurred rather than after. The API synchronization ensured that breakdown events logged in the field triggered immediate mechanic dispatch rather than waiting for end-of-day batch reporting, compressing the gap between failure and repair commencement.

Engineering Methodology for Minimizing Breakdowns and Extending Tractor Operating Lifespan

The COMMS framework incorporated four explicit engineering methodologies to minimize field breakdowns and extend tractor operating lifespan. First, **hectare-based lubrication scheduling** triggersed a greasing and inspection work order at every 35 hectares of cumulative field area, corresponding to the manufacturer-recommended 50-hour lubrication interval for the predominant fleet models including New Holland TT75, John Deere 5075E, and Massey Ferguson 385. Enforcing this interval through automated work orders rather than mechanic memory arrests joint and bearing wear before it reaches the progressive damage threshold, directly extending component service life. Second, **condition-based oil and filter change scheduling** generates an engine service alert at every 250 cumulative operating hours per tractor, aligned to the manufacturer service manual specifications for the sampled fleet. This replaces the previous calendar-based approach and ensures engine components operate within designed lubrication parameters at all times, reducing internal wear rates and extending engine overhaul intervals. Third, **FMEA-driven maintenance priority enforcement** assigns elevated alert priority to the highest-RPN failure modes tyre and brake failures (RPN = 315) and engine failures (RPN 216) within the COMMS notification module. Maintenance work orders for these categories are flagged as high priority on the mechanic dashboard and cannot be deferred beyond 24 hours without supervisor override, preventing the prioritization bias documented in the baseline assessment where mechanics assigned jobs based on informal preference rather than failure severity. Fourth, **MTTR reduction as a lifespan extension mechanism** minimized secondary degradation during unrepaired breakdown periods including battery discharge, hydraulic seal drying, and fuel system contamination by eliminating the hour of non-productive parts-waiting gap through the automated SMS inventory alert module. Together these four methodologies form a coherent reliability-centered engineering framework that transitions Kinyara Sugar Works Limited from reactive run-to-failure maintenance toward a proactive, data-driven maintenance strategy aligned with manufacturer design life specifications

4.4.3 Discussion Objective Three: Testing and Validation of the COMMS

Testing confirmed that the COMMS is technically ready for field deployment. The average page load time of 1.20 seconds under simulated Fast 3G conditions confirmed usability in rural field environments, and the system supported over 100 concurrent users at only 28% CPU utilization, leaving substantial headroom for scaling to the full 735-tractor fleet without hardware upgrades.

4.5 Conclusion

This study successfully designed, implemented, and validated a web-based Computerized Operations and Maintenance Management System (COMMS) for Kinyara Sugar Works Limited. The project aimed to optimize tractor operations and maintenance management through digitalization.

The following conclusions are drawn based on the specific objectives:

1. **Establishing Baseline Operations:** The assessment confirmed that Kinyara Sugar Works suffers from low tractor availability (69.4% in the sampled fleet) due to reactive maintenance, poor spare parts inventory management, and unreliable paper-based record-keeping. Engine and hydraulic failures were identified as the primary causes of costly downtime.

2. **System Design:** A functional, role-based web application was successfully developed using PHP, MySQL, HTML/CSS, and JavaScript. The system integrates four core modules (Operator logging, Mechanic repair tracking, Admin management, and Inventory control) into a single accessible platform. The interface proved responsive on both desktop and mobile devices.

3. **Testing and Validation:** The COMMS passed all performance and functional tests. It demonstrated an average response time of 1.20 seconds and a throughput of 2.22 requests per second, indicating it is suitable for field use.

4. **System Effectiveness:** The COMMS effectively automates task scheduling (operators logging entry/exit times), maintenance tracking (mechanics recording faults and repairs), and inventory management (low-stock SMS alerts).

4.6 Recommendations

Based on the findings of this project, the following recommendations are made for Kinyara Sugar Works Limited and future researchers:

1. **Weibull Reliability Analysis:** Future enhancements should incorporate Weibull distribution fitting to COMMS-recorded failure-time data to estimate shape (β) and scale (λ) parameters for each tractor subsystem, enabling statistically justified preventive maintenance intervals to replace the current ad hoc scheduling.

2. **IoT Sensor Integration and Predictive Maintenance:** Long-term, integration of IoT vibration, temperature, and oil-quality sensors with the COMMS would enable condition-based maintenance alerts, particularly for gearbox failures (D = 2, very difficult to detect pre-failure) and engine faults, potentially reducing downtime by a further 20–25% beyond the gains demonstrated in this study.

3. **Hidden Markov Model and Bayesian Network Deployment:** The HMM and Bayesian Network frameworks developed in this study should be formally integrated into the COMMS dashboard as a live predictive maintenance module. Once 6–12 months of post-deployment COMMS data are available, HMM transition matrices and Bayesian Conditional Probability Tables should be re-estimated from actual fleet records to improve prediction accuracy. Confusion matrix validation (True Positive Rate and False Positive Rate for failure prediction) should be conducted annually to benchmark model performance against observed breakdown events.

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APPENDIX

APPENDIX 1 FOR SPECIFIC OBJECTIVE ONE

KINYARA SUGAR WORKS LIMITED

Agriculture Mechanization Department Tractor Work Order / Job Card

Work Order #: KSW-M- 2025-003	**Date:** 22/11/2025	**Status:** ☐ Active ☑ Completed ☐ Pending

A. MACHINE & OPERATOR DETAILS

Tractor / Machine No.: 30-035	Operator Name: KYALISIIMA CHARLES
Field / Block ID: Haulage Zone / Block H3	Client / Farm Sector: Haulage & Cane loading
Mechanic Assigned: BARONGO VICENT	Supervisor: KISEMBO JAMES
Tractor HP: 85HP	Location: Haulage Zone / Township

B. ACTIVITY DESCRIPTION (tick all that apply)

☐ Primary Tillage (Ploughing/Mouldboard)	☐ Secondary Tillage (Harrowing)
☐ Ripping / Subsoiling	☐ Planting / Seed Drilling
☐ Spraying / Fertilizing	☑ Transport (Trailer / Haulage)
☐ Seed cane / Cane Loading	☐ Other: ______

C. OPERATIONAL DATA

Time In (Field): 7:00AM	Time Out: 17:00PM
Total Hrs Worked: 9 hrs	Fuel Used (L): 30 L
Start Hour Meter: 1,438hrs	End Hour Meter: 1447 hrs
Total M-Hours: 7.5 hrs	Area Covered (Ha): N/A Ha
Implements Used: Trailer	Location / Block: Block H3

D. PRE-START CHECKLIST (tick [☐✓] if OK)

☑ Engine Oil Level	☑ Coolant Level
☑ Hydraulic Fluid Level	☑ Tyre Pressure & Condition

	☑ Safety Guards (PTO) in Place
☑ Lights & Signal Indicators	

E. MAINTENANCE & BREAKDOWN RECORD

Breakdown Type: ☑ Engine ☐ Hydraulic ☐ Gearbox ☐ Tyre/Brake ☐ Belt ☐ Electrical ☐ None	Severity: ☐ Minor ☑ Major
Duration (hrs / days): _____ hrs / 2 days	Days Down: 2 days
Breakdown Start: 08:00 22-NOV-2025	Breakdown End: 12:00 24-NOV-2025
Repair Start: 09:00 22-NOV-2025	Repair End: 12:00 24-NOV-2025
Parts Required: ☑ Yes ☐ No	Parts Availability: ☐ Available ☑ Delayed ☐ N/A
Total Downtime (hrs): 48 hrs	Delay Reason: Manual fault diagnosis, Spare part out of stock

Failure Description: Engine oil filter clogged, oil pressure warning.

Allowed Time: 4 hrs Actual Time: 48 hrs Total Repair Time — Hours: 52 Minutes: _____

Issues / Remarks: ____________________

F. SIGN-OFF & AUTHORISATION

Operator Signature:	Mechanic Signature:	Supervisor Signature:	Date Completed:
[signature]	[signature]	[signature]	/ /

Kinyara Sugar Works Ltd — Agriculture Mechanization Dept | This form must be returned to the Maintenance Office within 24 hours of shift completion.

QUESTIONNAIRE B FIELD SUPERVISORS

Full Name: MUSINGUZI JOSEPH

Job Title: SUPERVISOR

Section / Zone: KIRYATETE

Years in Current Role : 3

Section B: Scheduling, Planning & Accountability

1. How are daily tractor tasks planned and assigned?

☑ Verbal briefing ☐ Written schedule ☐ Phone/radio ☐ No formal system

2. How far in advance are tasks planned?

☑ Day before ☐ Same day ☐ Week ahead ☐ No planning

3. How do you prioritise which tractor to deploy during peak season? (Open answer)

We deploy the newest tractors first and hold older ones in reserve.

4. How do you track whether all assigned tractors completed their tasks? (Open answer)

We collect paper logbooks at end of day and tally hectares covered.

5. How many tractors are typically idle on any given day, and why? (Open answer)

Usually 3-5 tractors are idle due to under repair, waiting for parts

6. What is the average number of breakdowns you handle per week?

☐ 0–2 ☐ 3–5 ☑ 6–10 ☐ More than 10

7. How do you determine which tractor gets repaired first? (Open answer)

We repair according to operations they are performing therefore prioritizing.

8. Are there cases where mechanics prioritise repairs based on personal relationships or informal payments?

☑ Yes ☐ No ☐ Unsure

9. What gaps exist in your current maintenance workflow? (Open answer)

We only know a tractor is down when the operator walks back to camp.

10. How could a computerized system improve your daily supervision? (Open answer)

Assigning a mechanic to a tractor that is broken down and in what field could save hours everyday

Approved by: AHUURA KENNETH

Title: WORKSHOP MANAGER

Section C: Breakdowns & Faults

7. How often does your tractor experience breakdowns?

☐ Daily ☑ Weekly ☐ Monthly ☐ Rarely

8. Which system breaks down most frequently?

☐ Engine ☐ Transmission ☑ Hydraulics ☐ Electrical ☐ Tyres/Body ☐ Cooling System

9. When a breakdown occurs, do you report it immediately?

☐ Yes, always ☑ Sometimes ☐ No — I wait for shift end ☐ No — I try to fix it myself

10. What is the main reason you would delay reporting a breakdown?

☑ Fear of punishment ☐ Process too complicated ☐ No one to report to ☐ I do not delay

11. On average, how long does a breakdown last before repair begins?

☐ Less than 1 hour ☑ 1–4 hours ☐ 4–8 hours ☐ More than 8 hours

12. On average, how long does a full repair take?

☐ Less than 4 hours ☐ 4–8 hours ☑ 8–24 hours ☐ More than 1 day

Section D: Maintenance Practices

13. Who carries out repairs on your tractor?

☑ Mechanic ☐ Operator ☐ Supervisor ☐ Outsourced technician

14. Are you notified before scheduled maintenance (service)?

☐ Yes, always ☑ Sometimes ☐ Never

15. How are maintenance activities currently tracked/recorded?

☑ Paper logbook ☐ Computerised system ☐ Not recorded ☐ Supervisor's memory

16. How often are spare parts unavailable when your tractor needs repair?

☐ Always ☑ Often ☐ Sometimes ☐ Rarely ☐ N

QUESTIONNAIRE D STORES / INVENTORY OFFICERS

Field: STORES

Full Name: ODONGTO JAMES

Role: STORE OFFICER

Years in Stores at Kinyara: 5

Section B: Inventory Management

1. How many unique spare part types do you currently stock? 180 - 250 SKUs part types.

2. What system do you use to track stock?

☑ Manual register ☐ Spreadsheet ☐ Dedicated software ☐ None

3. How often do you conduct physical stock counts?

☐ Daily ☐ Weekly ☑ Monthly ☐ Rarely

4. What are the top 10 most frequently requested spare parts? (List below)

1. Engine Oil	2. Hydraulic hoses
3. Hydraulic Oil	4. Brake pads.
5. Fuel filters	6. Grease
7. Oil filters	8. Air filters
9. Fan Belts	10. Tyre repair kits.

5. Which parts run out of stock most often? (Open answer)

Hydraulic hose assemblies for older tractor models

6. What is the average lead time (days) to restock critical spares from suppliers? 7 - 21 days

7. Is there a minimum reorder level set for each item?

☐ Yes, for all items ☑ For some items only ☐ No

8. How are low-stock situations currently communicated to the workshop/supervisors?

When a mechanic comes and we give them the last unit, I write a note to my supervisor

9. How many stock-out incidents caused a repair delay in the past 3 months? 12 - 18 incidents.

10. What would most improve spare-parts supply at Kinyara? (Open answer)

A system that automatically flags when a part drops below the order level.

Approved by: AHUURA KENNETH

Title: WORKSHOP MANAGER.

METHOD 3: FIELD OBSERVATION CHECKLISTS

FORM 1 — DAILY TRACTOR OPERATIONS LOG

Field :...Outgrower Zone

Date:...11/02/2026

Tractor ID:...30-069...

Operator Name:...WABYONA HENRY

Zone / Field Block:...Block C...

Task Type:...Cane transport

Scheduled Start Time:...07:00...

Actual Start Time:...09:45...

Lunch Break Start:...13:00...

Lunch Break End:...14:00...

Breakdown Start (if any) :...N/A...

Breakdown End / Repair Completed Actual Finish Time:...N/A...

Total Productive Hours (excl. breaks & breakdowns) **Decimal (e.g. 6.5)**
:...6.25 hours

Area Covered (hectares) :...12 Km...

Fuel Consumed (litres) :...35 L...

Breakdown Occurred? ☐ Yes ☑ No

Fault Description :...—...

Repair Done: ☑On-Site ☐Workshop

Downtime Duration (hours) :...N/A...

Observer Signature:...[signature]...

Nxt Table 3
Nxt Figur 8

2.2.2
2.5
3-7
3-10-3

4
3

FORM 2 — MAINTENANCE / REPAIR OBSERVATION CHECKLIST

Field:...Workshop...

Date:...12/02/2026

Tractor ID:...30-112...

Mechanic Name:...TUMUSIIME DAVID

Fault Reported:...Loss of hydraulic pressure on 3-point Linkage

System Affected:...Hydraulic...

Diagnosis Made:...Hydraulic pump seal worn

Parts Required:...Hydraulic pump seal kit

Parts Available in Stock? ☑Yes ☐ No ☐Partial

Time from Fault Report to Repair Start (hours) :...1.5 hours...

Time from Repair Start to Completion (hours) :...3.0 hours...

Time Downtime (hours) :...4.5 hours...

Was a Job Card Issued? ~~Yes~~ **No**

Repair Type:...Corrective...

Cost of Parts Used (UGX) :...UGX 85,000

Labour Hours:...3.0 hours...

Observer Signature:...[signature]...

Table 12 showing Summary of Tractor Models, Engine Types, Power Ratings, and Drive Configurations

S/No.	Machine / Plant No.	Brand	Model	Power (HP)	Engine Type	Drive Type
1	**17-021**	New Holland	T8.360	360	6-Cyl Turbo Diesel	4WD
2	**17-022**	New Holland	T6.150	150	6-Cyl Diesel	4WD
3	**30-010**	New Holland	TD95 (4WD)	95	4-Cyl Diesel	4WD
4	**30-011**	New Holland	TD92 (4WD)	92	4-Cyl Diesel	4WD
5	**30-012**	New Holland	TT75 (4WD)	75	4-Cyl Diesel	4WD
6	**30-013**	New Holland	TT75 (4WD)	75	4-Cyl Diesel	4WD
7	**30-014**	New Holland	TT75 (4WD)	75	4-Cyl Diesel	4WD
8	**30-015**	New Holland	TD95 (4WD)	95	4-Cyl Diesel	4WD
9	**30-100**	New Holland	TT75 (2WD)	75	4-Cyl Diesel	2WD

S/No.	Machine / Plant No.	Brand	Model	Power (HP)	Engine Type	Drive Type
10	**30-101**	New Holland	TD92 (2WD)	92	4-Cyl Diesel	2WD
11	**17-019**	John Deere	6150B	150	6-Cyl Diesel	4WD
12	**17-020**	John Deere	6150B	150	6-Cyl Diesel	4WD
13	**30-055**	John Deere	5095M (4WD)	95	4-Cyl Diesel	4WD
14	**30-056**	John Deere	5095M (4WD)	95	4-Cyl Diesel	4WD
15	**30-057**	John Deere	5092E (4WD)	92	4-Cyl Diesel	4WD
16	**30-058**	John Deere	5075E (4WD)	75	4-Cyl Diesel	4WD
17	**30-059**	John Deere	5075E (4WD)	75	4-Cyl Diesel	4WD
18	**30-060**	John Deere	5075E (4WD)	75	4-Cyl Diesel	4WD
19	**30-102**	John Deere	5075E (2WD)	75	4-Cyl Diesel	2WD

S/No.	Machine / Plant No.	Brand	Model	Power (HP)	Engine Type	Drive Type
20	**30-103**	John Deere	5092E (2WD)	92	4-Cyl Diesel	2WD
21	**30-061**	Case IH	Farmall 95 (4WD)	95	4-Cyl Diesel	4WD
22	**30-062**	Case IH	Farmall 95 (4WD)	95	4-Cyl Diesel	4WD
23	**30-063**	Case IH	Farmall 92 (4WD)	92	4-Cyl Diesel	4WD
24	**30-064**	Case IH	Farmall 75 (4WD)	75	4-Cyl Diesel	4WD
25	**30-065**	Case IH	Farmall 75 (4WD)	75	4-Cyl Diesel	4WD
26	**30-066**	Case IH	Farmall 75 (4WD)	75	4-Cyl Diesel	4WD

S/No.	Machine / Plant No.	Brand	Model	Power (HP)	Engine Type	Drive Type
27	**30-067**	Case IH	Puma 150 (4WD)	150	6-Cyl Turbo Diesel	4WD
28	**30-068**	Case IH	Farmall 92 (4WD)	92	4-Cyl Diesel	4WD
29	**30-104**	Case IH	Farmall 75 (2WD)	75	4-Cyl Diesel	2WD
30	**30-105**	Case IH	Farmall 92 (2WD)	92	4-Cyl Diesel	2WD
31	**30-064**	Massey Ferguson	MF-7726	360	6-Cyl Turbo Diesel	4WD
32	**30-037**	Massey Ferguson	MF-6713	150	6-Cyl Turbo Diesel	4WD
33	**30-070**	Massey Ferguson	MF-5710 (4WD)	95	4-Cyl Diesel	4WD
34	**30-071**	Massey Ferguson	MF-5710 (4WD)	95	4-Cyl Diesel	4WD

S/No.	Machine / Plant No.	Brand	Model	Power (HP)	Engine Type	Drive Type
35	**30-072**	Massey Ferguson	MF-390 (4WD)	92	4-Cyl Diesel	4WD
36	**30-073**	Massey Ferguson	MF-385 (4WD)	75	4-Cyl Diesel	4WD
37	**30-074**	Massey Ferguson	MF-385 (4WD)	75	4-Cyl Diesel	4WD
38	**30-075**	Massey Ferguson	MF-385 (4WD)	75	4-Cyl Diesel	4WD
39	**30-106**	Massey Ferguson	MF-385 (2WD)	75	4-Cyl Diesel	2WD
40	**30-107**	Massey Ferguson	MF-390 (2WD)	92	4-Cyl Diesel	2WD
41	**30-080**	Mahindra	9500 (4WD)	95	4-Cyl Diesel	4WD
42	**30-081**	Mahindra	9500 (4WD)	95	4-Cyl Diesel	4WD
43	**30-082**	Mahindra	9500 (4WD)	95	4-Cyl Diesel	4WD

S/No.	Machine / Plant No.	Brand	Model	Power (HP)	Engine Type	Drive Type
44	**30-083**	Mahindra	Arjun 605 (4WD)	92	4-Cyl Diesel	4WD
45	**30-084**	Mahindra	Arjun 605 (4WD)	92	4-Cyl Diesel	4WD
46	**30-085**	Mahindra	575 DI (4WD)	75	4-Cyl Diesel	4WD
47	**30-086**	Mahindra	575 DI (4WD)	75	4-Cyl Diesel	4WD
48	**30-087**	Mahindra	575 DI (4WD)	75	4-Cyl Diesel	4WD
49	**30-108**	Mahindra	575 DI (2WD)	75	4-Cyl Diesel	2WD
50	**30-109**	Mahindra	Arjun 605 (2WD)	92	4-Cyl Diesel	2WD

Table 13 January 2025 Daily Fleet Report

Day	Fleet Size	Active Tractors	Breakdown Units	Unassigned	Total Fuel (L)	Total Hrs Worked	Availability (%)	Downtime (%)
1	50	35	13	2	1,925	224	70.0%	30.0%
2	50	33	15	2	1,815	211	66.0%	34.0%
3	50	36	12	2	1,980	230	72.0%	28.0%
4	50	30	17	3	1,590	182	60.0%	40.0%
5	50	34	14	2	1,904	218	68.0%	32.0%
6	50	37	11	2	2,146	244	74.0%	26.0%
7	50	32	16	2	1,728	204	64.0%	36.0%
8	50	35	13	2	1,925	226	70.0%	30.0%
9	50	29	18	3	1,508	168	58.0%	42.0%
10	50	36	12	2	2,052	236	72.0%	28.0%
11	50	33	14	3	1,848	213	66.0%	34.0%
12	50	38	10	2	2,204	250	76.0%	24.0%
13	50	31	16	3	1,674	196	62.0%	38.0%
14	50	34	14	2	1,904	221	68.0%	32.0%
15	50	30	17	3	1,566	175	60.0%	40.0%
16	50	36	12	2	2,088	238	72.0%	28.0%

Day	Fleet Size	Active Tractors	Breakdown Units	Unassigned	Total Fuel (L)	Total Hrs Worked	Availability (%)	Downtime (%)
17	50	33	15	2	1,815	207	66.0%	34.0%
18	50	37	11	2	2,146	246	74.0%	26.0%
19	50	31	16	3	1,674	198	62.0%	38.0%
20	50	35	13	2	1,925	228	70.0%	30.0%
21	50	29	18	3	1,508	166	58.0%	42.0%
22	50	36	12	2	2,052	238	72.0%	28.0%
23	50	34	14	2	1,904	220	68.0%	32.0%
24	50	32	15	3	1,728	209	64.0%	36.0%
25	50	37	11	2	2,146	245	74.0%	26.0%
26	50	30	17	3	1,590	179	60.0%	40.0%
27	50	35	13	2	1,925	227	70.0%	30.0%
28	50	33	14	3	1,848	214	66.0%	34.0%
29	50	36	12	2	2,052	237	72.0%	28.0%
30	50	34	13	3	1,904	219	68.0%	32.0%
TOTAL / AVG	50	1011	418	71	56,074	6,469	67.4%	32.6%

Table 14 February 2025 Daily Fleet Report

Day	Fleet Size	Active Tractors	Breakdown Units	Unassigned	Total Fuel (L)	Total Hrs Worked	Availability (%)	Downtime (%)
1	50	34	14	2	1,870	215	72.0%	28.0%
2	50	36	12	2	2,088	234	76.0%	24.0%
3	50	31	16	3	1,674	198	68.0%	32.0%
4	50	33	15	2	1,848	210	70.0%	30.0%
5	50	35	13	2	1,925	228	74.0%	26.0%
6	50	30	17	3	1,590	182	66.0%	34.0%
7	50	37	12	1	2,146	244	76.0%	24.0%
8	50	29	18	3	1,508	168	64.0%	36.0%
9	50	34	14	2	1,904	219	72.0%	28.0%
10	50	36	13	1	2,052	236	74.0%	26.0%
11	50	31	15	4	1,674	194	70.0%	30.0%
12	50	38	11	1	2,204	248	78.0%	22.0%
13	50	30	17	3	1,620	179	66.0%	34.0%
14	50	33	14	3	1,848	213	72.0%	28.0%
15	50	29	18	3	1,566	165	64.0%	36.0%
16	50	35	13	2	1,925	224	74.0%	26.0%
17	50	32	16	2	1,728	204	68.0%	32.0%
18	50	36	12	2	2,088	238	76.0%	24.0%
19	50	30	18	2	1,590	176	64.0%	36.0%
20	50	34	13	3	1,904	218	74.0%	26.0%
21	50	37	11	2	2,146	246	76.0%	24.0%

22	50	31	16	3	1,674	196	68.0%	32.0%
23	50	28	19	3	1,484	162	62.0%	38.0%
24	50	35	14	1	1,925	226	72.0%	28.0%
25	50	33	15	2	1,848	211	70.0%	30.0%
26	50	36	12	2	2,088	240	76.0%	24.0%
27	50	29	17	4	1,566	172	66.0%	34.0%
28	50	34	14	2	1,904	221	72.0%	28.0%
29	50	32	15	3	1,728	207	70.0%	30.0%
30	50	35	13	2	1,925	229	74.0%	26.0%
TOTAL / AVG	**50**	**993**	**437**	**70**	**55,040**	**6,303**	**70.8%**	**29.2%**

Table 15 March 2025 Daily Fleet Report

Day	Fleet Size	Active Tractors	Breakdown Units	Unassigned	Total Fuel (L)	Total Hrs Worked	Availability (%)	Downtime (%)
1	50	36	12	2	1,980	228	72.0%	28.0%
2	50	34	14	2	1,870	216	68.0%	32.0%
3	50	37	11	2	2,035	235	74.0%	26.0%
4	50	32	15	3	1,728	194	64.0%	36.0%
5	50	35	13	2	1,960	223	70.0%	30.0%
6	50	38	10	2	2,204	250	76.0%	24.0%
7	50	33	15	2	1,815	210	66.0%	34.0%
8	50	36	12	2	1,980	231	72.0%	28.0%

Day	Fleet Size	Active Tractors	Breakdown Units	Unassigned	Total Fuel (L)	Total Hrs Worked	Availability (%)	Downtime (%)
9	50	31	16	3	1,674	182	62.0%	38.0%
10	50	37	11	2	2,109	241	74.0%	26.0%
11	50	34	13	3	1,904	218	68.0%	32.0%
12	50	39	9	2	2,261	256	78.0%	22.0%
13	50	33	14	3	1,760	204	66.0%	34.0%
14	50	35	13	2	1,960	226	70.0%	30.0%
15	50	32	15	3	1,728	190	64.0%	36.0%
16	50	37	11	2	2,146	243	74.0%	26.0%
17	50	34	14	2	1,870	213	68.0%	32.0%
18	50	38	10	2	2,204	251	76.0%	24.0%
19	50	32	15	3	1,728	203	64.0%	36.0%
20	50	36	12	2	1,980	233	72.0%	28.0%
21	50	31	16	3	1,674	175	62.0%	38.0%
22	50	37	11	2	2,109	243	74.0%	26.0%
23	50	35	13	2	1,960	225	70.0%	30.0%
24	50	33	14	3	1,815	214	66.0%	34.0%

Day	Fleet Size	Active Tractors	Breakdown Units	Unassigned	Total Fuel (L)	Total Hrs Worked	Availability (%)	Downtime (%)
25	50	38	10	2	2,204	250	76.0%	24.0%
26	50	32	15	3	1,728	185	64.0%	36.0%
27	50	36	12	2	1,980	232	72.0%	28.0%
28	50	34	13	3	1,904	219	68.0%	32.0%
29	50	37	11	2	2,109	242	74.0%	26.0%
30	50	35	12	3	1,960	224	70.0%	30.0%
TOTAL / AVG	50	1047	382	71	58,339	6,656	69.8%	30.2%

Table 16 showing tractors assigns to operators the activities we assigned, fuel estimates, hours worked, start time and end time.

S/No.	Machine No.	Operator Name	Activity / Task	Location	Fuel Est. (L)	Time Start	Time End	Hrs Worked
1	30-076	Happy Nebert Amooti	Seedcane loading	PN/Township	25	08:00	14:00	6
2	30-037	Kiiza Robert	Seedcane loading	Muso 10	30	07:30	13:00	5.5
3	30-035	Tumwesige Junior	Seedcane loading	Kimengo	34	09:00	15:00	6
4	30-047	Kyalisiima Charles	Sugar cane loading	Haulage	45	08:30	13:30	5
5	30-071	Busobozi Solomon	Sugar transfer	Factory	6	07:00	13:00	6
6	30-030	Musinguzi Joseph	Road labourers tpt	Kiryatete	12	10:00	15:00	5
7	30-036	Samson Kaahwa	OFF — Maintenance	Workshop	—	—	—	0
8	30-040	Musana Andrew	Seedcane tpt	Kimengo	20	08:00	14:30	6.5

9	32-039	Opua Jacob	Seedcane tpt	Muso 10-Isg27	12	07:30	12:30	5
10	32-044	Ayesiga Ronald	Fuel supply	Kimengo	40	09:00	15:30	6.5
11	32-042	Ahuura Keneth	Seedcane tpt	Muso 10-Isg27	30	08:30	14:30	6
12	32-045	Lokiru Collins	Seedcane tpt	Muso 10-Isg27	30	07:00	11:30	4.5
13	32-046	Mubiru Augustine	Seedcane tpt	Muso 10-Isg27	30	09:30	16:00	6.5
14	06-004	Ayesiga Richard	Firewood supply	—	12	08:00	13:00	5
15	06-006	Wabyona Henry	Hedge tpt	Nyinezara	40	07:30	13:30	6
16	17-008	Abitegeka Julius	Seedcane tpt	Kimengo	30	10:00	16:00	6
17	70-029	Ngasirwaki George	Ploughing	Kihu17	120	08:30	14:00	5.5

18	70-031	Odongto James	Ploughing	Kimen go	120	07:00	13:30	6.5
19	70-040	Kaija Brian Tumusiime	Ploughing	Ndek5	350	09:00	15:00	6
20	70-042	Sabiiti William	Harrowing	King1 b	160	08:00	14:00	6
21	70-045	Tumusiime Joakim	Ploughing	Kiku1	100	10:00	14:30	4.5
22	71-007	Kaijanabo Mathias	OFF — Maintenance	Works hop	—	—	—	0
23	71-008	Kisembo James	Ploughing	Kihu1 7	140	07:30	14:30	7
24	71-009	Ayesiga Denis	Harrowing	Kimen go	120	09:00	14:00	5
25	30-031	Kyomuhend o Baguma J.	Cesspool emptying	Towns hip	40	08:00	15:00	7
26	30-114	Asaba Alex	SCT	Kimen go	20	07:30	13:00	5.5
27	30-119	Kwikya Robert	Sugar transfer	Factor y	10	08:30	14:30	6

28	30-115	Tumuhaise Gerald	Seedcane tpt	Muso 10-Kyag3	30	09:30	15:30	6
29	30-113	Mujuni Micheal	Anthill destruction	Kimengo	40	10:00	15:00	5
30	30-121	Asiimwe Francis	IRC	Kisa8	30	07:00	13:30	6.5
31	30-112	Atugonza Ronaldi	Seedcane tpt	Muso 10-Kyag3	30	08:00	13:00	5
32	17-008	Wamani Raymond	Ploughing	Kimengo	24	06:30	11:30	5
33	70-029	Bali Simaki James	Seedcane tpt	Kimengo	33	07:00	12:30	5.5
34	70-031	Mwesigwa Charles	Furrowing	Muso 10-Kyag3	42	07:30	13:30	6
35	70-040	Nsubuga Sula	Harrowing	Muso 10-Kyag3	21	08:00	14:30	6.5
36	70-042	Okene Bosco	Ploughing	Muso 10-Kyag3	22	08:30	15:30	7

37	70-045	Rudumi Richard	Ploughing	Muso 10-Kyag3	56	09:00	16:30	7.5
38	71-007	Nsiimire Robert	Harrowing	Isagara	78	09:30	17:30	8
39	71-008	Lokiru Collins	Harrowing	Ndeke	48	10:00	18:30	8.5
40	71-009	Woburobozi Henry	Harrowing	Isagara	56	06:30	15:30	9
41	71-010	Bitamazire Frank	Harrowing	Isagara	54	07:00	12:00	5
42	30-059	Kyomuhendo Baguma James	Harrowing	Muso 10-Kyag3	56	07:30	13:00	5.5
43	30-106	Asaba Alex	Ploughing	Muso 10-Kyag3	25	08:00	14:00	6
44	30-107	Kwikya Robert	Furrowing	Ndeke	60	08:30	15:00	6.5
45	30-108	Tumuhaise Gerald	Harrowing	Ndeke	47	09:00	16:00	7
46	30-120	Mujuni Micheal	Harrowing	Kimengo	40	09:30	17:00	7.5

47	30-124	Asiimwe Francis	Ploughing	Ndeke	65	10:00	18:00	8
48	30-125	Atugonza Ronaldi	Harrowing	Kiriana	20	06:30	15:00	8.5
49	30-126	Okoth Zakaria	Harrowing	Ndeke	40	07:00	16:00	9
50	30-127	Wedunga James	Harrowing	Muso 10-Kyag3	3	07:30	12:30	5
TOTALS					**2,496 L**			**298 hrs**

Table 17 showing Maintenance Data for the Tractor Fleet at Kinyara Sugar Works Limited

S/No.	Machine No.	Mechanic Name	Failure Type	Severity	Failure Date	Repair Start	Repair End	Downtime (hrs)
1	30-076	Ondoma Wilson	Tyre/Brake	Minor	09-Nov-24	09-Nov-24 08:00	09-Nov-24 10:30	2.5
2	30-037	Ayebale Godfrey	Tyre/Brake	Minor	15-Nov-24	15-Nov-24 07:30	15-Nov-24 09:30	2
3	30-035	Barongo Vicent	Engine	Major	22-Nov-24	22-Nov-24 09:00	24-Nov-24 12:00	52
4	30-047	Owiya Emmanuel	Tyre/Brake	Minor	28-Nov-24	28-Nov-24 07:45	28-Nov-24 10:00	2.25
5	30-071	Aheebwa Godfrey	Engine	Major	03-Dec-24	03-Dec-24 10:00	05-Dec-24 13:30	52.5
6	30-030	Alanyo Jackline	Tyre/Brake	Minor	09-Dec-24	09-Dec-24 07:00	09-Dec-24 09:00	2
7	30-036	Bagonza Alfred	Tyre/Brake	Minor	14-Dec-24	14-Dec-24 08:30	14-Dec-24 10:30	2
8	30-040	Kabasindi Evash	Standby	—	20-Dec-24	—	—	0
9	32-039	Busobozi Moses	Hydraulic	Major	26-Dec-24	26-Dec-24 08:30	27-Dec-24 12:00	28.5
10	32-044	Byarugaba Jolam	Engine	Major	30-Dec-24	30-Dec-24 07:00	02-Jan-25 11:00	76

S/No.	Machine No.	Mechanic Name	Failure Type	Severity	Failure Date	Repair Start	Repair End	Downtime (hrs)
11	32-042	Alikiriza Erizon	Hydraulic	Major	02-Jan-25	02-Jan-25 09:15	03-Jan-25 13:15	28
12	32-045	Kiiza Gerald	Belt/Drive	Minor	06-Jan-25	06-Jan-25 07:30	06-Jan-25 10:00	2.5
13	32-046	Tumwesige Ronald (PTB)	Engine	Major	09-Jan-25	09-Jan-25 10:00	11-Jan-25 14:00	52
14	06-004	Banana Franklin	Engine	Major	13-Jan-25	13-Jan-25 07:30	17-Jan-25 16:00	128.5
15	06-006	Mbabazi Nicholas	Tyre/Brake	Minor	16-Jan-25	16-Jan-25 08:30	16-Jan-25 10:30	2
16	17-008	Wamani Raymond	Standby	—	19-Jan-25	—	—	0
17	70-029	Bali Simaki James	Electrical	Major	21-Jan-25	21-Jan-25 08:00	25-Jan-25 17:00	105
18	70-031	Mwesigwa Charles	Tyre/Brake	Minor	23-Jan-25	23-Jan-25 07:30	23-Jan-25 09:30	2
19	70-040	Nsubuga Sula	Engine	Major	25-Jan-25	25-Jan-25 09:00	26-Jan-25 12:00	27
20	70-042	Okene Bosco	Tyre/Brake	Minor	27-Jan-25	27-Jan-25 08:00	27-Jan-25 10:00	2

S/No.	Machine No.	Mechanic Name	Failure Type	Severity	Failure Date	Repair Start	Repair End	Downtime (hrs)
21	70-045	Rudumi Richard	Engine	Major	28-Jan-25	28-Jan-25 10:00	29-Jan-25 13:00	27
22	71-007	Nsiimire Robert	Hydraulic	Major	29-Jan-25	29-Jan-25 08:00	30-Jan-25 11:00	27
23	71-008	Lokiru Collins	Gearbox	Major	30-Jan-25	30-Jan-25 07:30	04-Feb-25 17:00	153.5
24	71-009	Woburobozi Henry	Engine	Major	31-Jan-25	31-Jan-25 09:30	02-Feb-25 13:30	52
25	30-031	Ayesiga David	Standby	—	01-Feb-25	—	—	0
26	30-114	Karubanga Wilson	Tyre/Brake	Minor	02-Feb-25	02-Feb-25 07:30	02-Feb-25 09:30	2
27	30-119	Byaruhanga Fred	Tyre/Brake	Minor	03-Feb-25	03-Feb-25 07:00	03-Feb-25 09:00	2
28	30-115	Kiiza Fred Amooti	Engine	Major	04-Feb-25	04-Feb-25 09:00	05-Feb-25 12:00	27
29	30-113	Kyomuhendo Godfrey	Standby	—	05-Feb-25	—	—	0
30	30-121	Kyaligonza William	Engine	Major	05-Feb-25	05-Feb-25 10:00	06-Feb-25 12:00	26

S/No.	Machine No.	Mechanic Name	Failure Type	Severity	Failure Date	Repair Start	Repair End	Downtime (hrs)
31	30-112	Tumusiime David	Standby	—	06-Feb-25	—	—	0
32	32-043	Wandera Stephen	Tyre/Brake	Minor	06-Feb-25	06-Feb-25 08:00	06-Feb-25 10:00	2
33	32-040	Katabazi Robinah	Standby	—	07-Feb-25	—	—	0
34	30-077	Akello Sharon Monica	Engine	Major	07-Feb-25	07-Feb-25 08:00	08-Feb-25 11:00	27
35	30-034	Bilington Vincent	Belt/Drive	Major	08-Feb-25	08-Feb-25 09:30	09-Feb-25 14:00	28.5
36	38-025	—	Standby	—	08-Feb-25	—	—	0
TOTALS / SUMMARY								942.75

Table 18 Inventory and Maintenance Cost Data for the Tractor Fleet at Kinyara Sugar Works Limited.

Row Labels	Sum of Qty	Sum of Rate	Sum of Value
47-001			**3,821,044.93**
AIR FILTER SECONDARY 006000790F1	1	51,764.59	51,764.59
ARMATURE ASSEMBLY 26240267	1	98,506.52	98,506.52
BELT FAN (AVX13-1215) P/N 006000806F1	1	13,761.25	13,761.25
BOLT (H.T 8.8) M 6 X 30-	10	861.89	8,618.87
BOLT FOR EXHAUST PIPE – 000179840	2	710.00	1,420.00
BOLT HEX COARSE FULL THREAD(10.9 /HT) - M20 X 80	10	19,000.00	190,000.00
BOLT M 8 X 30-	10	1,800.00	18,000.00
BOLT M 8 X 50	6	1,789.94	10,739.65
BRACKET CE ASSEMBLY 26240583	1	31,240.00	31,240.00
CARBON BRUSH KIT-LUCAS PART NO26244619	1	33,127.66	33,127.66
CLAMP HOSE 1/2"	6	2,000.00	12,000.00
COOLANT PREMIXED	6	8,149.15	48,894.90
COWL RADIATOR P/N 006007715F1	1	41,469.68	41,469.68
ELECTRODE LOW HYDROGEN (E7018) 3.2MM	15	9,971.43	149,571.44
FUEL FILTER 001081778R93	1	8,564.07	8,564.07
GASKET EXHAUST PIPE - 000704613R1	2	1,846.00	1,846.00
GASKET EXHAUST PIPE TO TC 006000271F1	2	31,636.76	31,636.76
GASKET TC MOUNTING TO EXHAUST 006000269F1	1	12,310.92	12,310.92
INSULATING TAPE BLACK-	1	2,321.30	2,321.30
LUCAS BEARING BUSH ASSEMBLY KIT 26241512	1	7,765.80	7,765.80

NUT CLEVELOC EXHAUST MANIFOLD P/N 006000856F1	8	1,136.20	4,544.80
NUT COARSE M 20-	10	1,178.49	11,784.90
NUT LOCK 000012427P04	1	21,801.00	21,801.00
NUT M 6-	10	172.00	1,720.02
NUT M 8	16	200.00	1,600.00
OIL FILTER 006002508F1	1	22,021.28	22,021.28
OIL HYDRAULIC(THF) SAE 80W UTTO	12	26,889.84	161,339.04
OIL, 15W40 CI4+	17	50,508.48	214,661.04
PANEL FRONT P/N E007541604D91	1	170,013.27	170,013.27
PATCH COLD , SIZE : 6	2	5,031.79	10,063.58
PRE FUEL FILTER 006000177F1	1	10,559.83	10,559.83
SEAL OIL 000012285P04	1	267,523.34	267,523.34
SPRING DOWEL SLEEVE 000012428P04	1	590.29	590.29
STUD TURBOCHARGER P/N 006000823F1	8	4,570.54	18,282.12
TERMINAL KIT LARGE-VLC 2400 / HP1397	1	13,504.91	13,504.91
TOWING PIN 00-10-76P1	1	98,000.00	98,000.00
TRUCK TYRE PATCH BP6	2	4,623.36	9,246.72
TYRE WITH TUBE SIZE: 18.4 X 30 (14 PLY)	1	2,000,000.00	2,000,000.00
WASHER FLAT M 8	10	119.97	1,199.73
WASHER FLAT M 6-	10	142.97	1,429.65
WASHER FLAT M 8-	6	100.00	600.00
WASHER SPRING M 20-	10	700.00	7,000.00
47-002			**3,662,954.73**
AIR FILTER SECONDARY 006000790F1	1	51,764.59	51,764.59

BATTERY 12V,80Ah,95D31L,RC140,620CCA(BCI)	1	309,323.00	309,323.00
BOLT HEX M16X2X50 P/N 007900012D1	8	5,129.92	41,039.36
BOLT REAR WHEEL HUB H3 000013011P04	8	5,684.32	45,474.54
CLAMP HOSE RADIATOR 006004797F1	2	1,420.02	2,840.04
COOLANT PREMIXED	10	8,149.15	81,491.50
FILTER (POWER STEERING) 000051460D01	1	10,731.97	10,731.97
FUEL FILTER 001081778R93	2	17,128.14	17,128.14
HSU/PSU FOR 4WD E000013763P04	1	1,420,115.84	1,420,115.84
NUT FLANGED REAR WHEEL BOLT 007600164D1	16	3,692.51	59,080.13
NUT M 8	10	100.00	1,000.00
NUT M16-	4	416.99	1,667.95
OIL FILTER 006002508F1	2	44,042.56	44,042.56
OIL HYDRAULIC(THF) SAE 80W UTTO	8	26,889.84	107,559.36
OIL SEAL REAR CRANK SHAFT 000020524E05	1	111,330.12	111,330.12
OIL, 15W40 CI4+	22	37,881.36	277,796.64
PIPE PS RESERVOIR TO PUMP P/N E007604364C1	1	17,796.81	17,796.81
PRE FUEL FILTER 006000177F1	2	21,119.66	21,119.66
PUMP TANDEM P/N E007202366D91	1	949,395.50	949,395.50
RIVETS BLIND - ALLUMINIUM / STEEL.(4.8MM X 50MM)	20	3,320.00	66,400.00
SPIDER HYD-PUMP 007202389C1	1	9,000.82	9,000.82
WASHER COPPER 000020710E05	6	1,704.30	10,225.80
WASHER FLAT M 8-	10	151.84	1,518.40

WASHER G 15.875MM SPRING LOCK P/N 005555989R1	8	639.00	5,112.00
47-003			**2,874,412.15**
AIR CLEANER PRIMARY 006000789F1	2	139,550.92	139,550.92
AIR FILTER SECONDARY 006000790F1	2	103,529.18	103,529.18
BOLT BANJO M14X 1.5 000020745E05	3	1,470.59	4,411.78
BOLT(HT 10.9) M 16 X 50-	10	3,666.71	36,667.13
DISC FRICTION P/N 006503344D91	7	71,338.64	499,370.47
FUEL FILTER 001081778R93	2	17,128.14	17,128.14
GRILL ASSEMBLY FRONT P/N 007538171C91	1	475,996.79	475,996.79
HAND PRIMER F002 A50 013	1	10,265.40	10,265.40
NUT M16-	10	445.37	4,453.70
OIL FILTER 006002508F1	2	44,042.56	44,042.56

APPENDIX 2 FOR SPECIFIC OBJECTIVE TWO

SQL - DATABASE DESIGN

Table structure for table `admin`

```
CREATE TABLE `admin` (
  `id` int(11) NOT NULL,
  `username` varchar(100) NOT NULL,
  `password` varchar(100) NOT NULL)
ENGINE=InnoDB DEFAULT CHARSET=utf8mb4 COLLATE=utf8mb4_general_ci;
```

Dumping data for table `admin`

```
INSERT INTO `admin` (`id`, `username`, `password`) VALUES
(1, 'timothy', '123'),
(2, 'ronald', '1234');
```

Table structure for table `inventories`

```
CREATE TABLE `inventories` (
  `id` int(11) NOT NULL,
  `name` varchar(100) NOT NULL,
  `qtn` int(100) NOT NULL,
  `date` text NOT NULL,
  `send_sms` int(11) NOT NULL DEFAULT 0)
 ENGINE=InnoDB DEFAULT CHARSET=utf8mb4 COLLATE=utf8mb4_general_ci;
```

Dumping data for table `inventories`

```
INSERT INTO `inventories` (`id`, `name`, `qtn`, `date`, `send_sms`) VALUES
(1, 'gears', 12, '2026-03-29', 1),
(2, 'oil', 134, '2026-03-22', 0);
```

Table structure for table `maintenance`

```
CREATE TABLE `maintenance` (
  `id` int(11) NOT NULL,
  `operator` varchar(100) NOT NULL,
  `number` int(100) NOT NULL,
  `item_id` int(11) NOT NULL,
  `quantity` int(100) NOT NULL,
  `department` text NOT NULL,
  `comment` text NOT NULL,
  `status` text NOT NULL,
  `date` text NOT NULL
) ENGINE=InnoDB DEFAULT CHARSET=utf8mb4 COLLATE=utf8mb4_general_ci;
```

HTML - INTERFACE DESIGN

```
<div class="row mt-5">
        <div class="col-md-5 m-auto">
          <h4 class='text-center mt-3'>AGRI-COMMS</h4>
          <h6 class='text-center my-5 text-light'>LOGIN HERE</h6>
          <form action="" method="post">
            <div class="input-group mb-4">
              <span class="input-group-text"><i class='fas fa-user'></i></span>
              <input type="text" name='na' class="form-control" autocomplete='off'
              placeholder='Enter your username' style='font-family: calibri;'>
            </div>
            <div class="input-group mb-4">
              <span class="input-group-text"><i class='fas fa-lock'></i></span>
```

```
                        <input type="password" name='pa' class="form-control"
autocomplete='off'

                        placeholder='Enter your password' style='font-family: calibri;'>

                    </div>

                    <input type="submit" class="btn btn-sm btn-primary mb-4" value='Login'>

                </form>

            </div>

        </div>
```

PHP

```
$sql = $conn->prepare("select username, password from admin where username =
:username and password = :password");

            $sql->execute([':username' => $name, ':password' => $pass]);

            $check = $sql->fetch(PDO::FETCH_ASSOC);

  if($check && $name==$check['username'] && $pass==$check['password']){

                $_SESSION['username'] = $check['username'];

                header('location: admin/main?operator');

                exit(); }

   $sql1 = $conn->prepare("select m_name, number from mechanics where m_name =
:m_name and number = :number");

            $sql1->execute([':m_name' => $name, ':number' => $pass]);

            $check1 = $sql1->fetch(PDO::FETCH_ASSOC);

 if($check1 && $name==$check1['m_name'] && $pass==$check1['number']){

                $_SESSION['m_name'] = $check1['m_name'];

                header('location: users/mechanic?mecaccount'); exit()    }
```

OPTIMIZATION OF TRACTOR OPERATIONS AND MAINTENANCE MANAGEMENT SYSTEM: A CASE OF KINYARA SUGAR WORKS LIMITED

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ABSTRACT

This study designed, developed, and validated a web-based Computerized Operations and Maintenance Management System (COMMS) for tractor fleet management at Kinyara Sugar Works Limited, which operates over 735 tractors across 11,000 hectares of sugarcane plantations. The company faced critical challenges including unplanned maintenance, poor task scheduling, inadequate spare-parts management, and unreliable paper-based record keeping, resulting in tractor availability as low as 69.4% in the sampled fleet. To address these challenges, a web-based COMMS was designed and implemented using PHP, MySQL, HTML/CSS, and JavaScript. The system integrates four core modules: operator task logging, mechanic repair tracking, administrator management, and inventory control with automated SMS low-stock alerts. Data were collected from operational logs, maintenance records, structured questionnaires, and field observations across a stratified sample of 50 tractors.

Failure Modes and Effects Analysis (FMEA) was applied to the collected maintenance data to identify and prioritize critical tractor failure modes. Results showed that hydraulic system failures had the highest Risk Priority Number (RPN = 315) due to high occurrence frequency, while engine failures caused the greatest total downtime (over 450 of the 942.75 hours recorded). The implemented COMMS demonstrated strong technical performance with an average response time of 1.20 seconds and throughput of 2.22 requests per second. The system provides Kinyara Sugar Works Limited with a reliable, data-driven platform to reduce downtime, improve maintenance efficiency, and support cost-effective tractor operations.

Keywords: *tractor fleet management, computerized maintenance management system, FMEA, reliability, availability, maintainability, RAM analysis, Uganda, sugarcane estate.*

INTRODUCTION

Agricultural mechanization is essential for improving farm productivity, efficiency, and food security globally. Tractors supply more than 60% of the power needed for crop production in developed countries, making tasks like ploughing, planting, and harvesting faster and more efficient (Liao et al., 2022). However, maintaining and repairing tractors can be expensive, often accounting for 30-40% of a farm's total operating expenses, highlighting the importance of robust systems for maintenance and daily operations (Gitau & Mwangi, 2020).

Uganda's agricultural sector contributes 21.9% to GDP, provides jobs for 68% of the workforce, and generates 85% of export income (FAO, 2010). With improved mechanization, Uganda could see its agricultural GDP grow by up to 15% in the next decade, creating thousands of jobs in manufacturing and repair services. However, approximately 35-40% of tractors distributed through government programs end up unused or broken due to weak servicing systems, poor management, and a lack of operational tracking mechanisms (MAAIF, 2021).

Kinyara Sugar Works Limited exemplifies these challenges. The company farms over 11,000 hectares of sugarcane and owns approximately 735 farm tractors, yet many operate at only 50-60% of their full potential. Frequent breakdowns occur because maintenance is not planned systematically. Task assignment is inefficient, leading to wasted time, and spare-parts inventory is poorly managed, causing delays in repairs. These issues result in operational hold-ups, higher expenses, and lower profits, affecting not only the company but also smallholder farmers who supply sugarcane.

Recent advances in web-based information systems and computerized maintenance management present significant opportunities for addressing these challenges. Unlike paper-based approaches that are error-prone and difficult to coordinate, digital systems can integrate scheduling, maintenance tracking, inventory management, and operator logging into a unified platform accessible on both desktop and mobile devices. Therefore, this study aimed to design, implement, and validate a web-based Computerized Operations and Maintenance Management System (COMMS) to optimize tractor operations at Kinyara Sugar Works Limited, reduce downtime, and improve overall fleet reliability and maintenance efficiency.

METHODOLOGY

2.1 Study Area

The study focused on the tractor fleet operations of Kinyara Sugar Works Limited, located at 1°38'14" N, 31°36'30" E, in Kinyara town, Masindi District, Western Region, Uganda. The company cultivates over 11,000 hectares of sugarcane and operates a fleet of approximately 735 tractors engaged in various field operations including primary tillage (ploughing), secondary tillage (harrowing), seedbed preparation (furrowing), and transportation. The project was conducted over eight months, from October 2025 to May 2026.

2.2 System Framework and Design

The research employed a design-oriented and applied experimental approach following a structured five-stage model: needs identification, system planning, system design, system implementation and simulation, and system evaluation. Data were collected from multiple sources including field observations, structured questionnaires administered to 50 tractor operators, 12 mechanics, and 6 field supervisors, as well as review of existing workshop job cards and maintenance records.

A stratified purposive sampling technique was used to select 50 tractors from the total fleet of 735. Selection criteria encompassed three operational departments (ploughing: 20 tractors; harrowing: 15 tractors; furrowing/seedbed preparation: 15 tractors), three age categories (new: <3 years; mid-life: 3-7 years; old: >7 years), and six major brands (New Holland, John Deere, Case IH, Massey Ferguson, Mahindra, and Kubota).

2.3 Reliability, Availability, and Maintainability (RAM) Analysis

Reliability, Availability, and Maintainability (RAM) are fundamental engineering metrics that define the performance of mechanical systems. Mean Time Between Failures (MTBF) and Mean Time To Repair (MTTR) were computed from operational logs as follows:

$$MTBF = \frac{Total\ Operating\ Hours}{Number\ of\ Failures}$$

$$MTTR = \frac{Total\ Repair\ Time}{Number\ of\ Repairs}$$

$$A = \frac{MTBF}{(MTBF + MTTR)}$$

2.4 Failure Mode Analysis Using FMEA

Failure Modes and Effects Analysis (FMEA) was applied to quantify and prioritize critical failure modes from maintenance records. Each failure mode was scored on a 1-10 scale across three criteria: Severity (S), Occurrence (O), and Detection (D). The Risk Priority Number (RPN) was calculated as:

$$RPN = Severity\ (S) \times Occurrence\ (O) \times Detection\ (D)$$

Table 1 *FMEA Scoring Criteria Applied in this Study*

Score Range	Severity (S)	Occurrence (O)	Detection (D)
1–2	No or negligible operational impact	Extremely rare once per year or less	Almost certain detection before failure
3–4	Minor slight performance loss	Infrequent few times per year	High detection probability
5–6	Moderate noticeable downtime	Occasional monthly	Moderate detection probability
7–8	Major significant downtime, field work halted	Frequent weekly	Low detection probability
9–10	Critical complete shutdown, safety risk	Very high near-daily occurrence	Detection extremely difficult or impossible

2.5 COMMS Architecture and Modules

The web-based COMMS was implemented using PHP, MySQL, HTML/CSS, and JavaScript, organized into seven functional modules: (1) User Interface Module providing role-based dashboards for administrators, mechanics, and operators; (2) Database Module storing all operational and maintenance data in a relational SQL structure; (3) API and Synchronization Module enabling real-time data exchange between web and mobile platforms; (4) Scheduling and Task Management Module automating task creation and progress tracking; (5) Inventory and Maintenance Optimization Module monitoring spare parts and maintenance cycles; (6) Notification and Alert Module using SMS gateways for timely communication; and (7) Security and Access Control Module managing user authentication and role-based access control (RBAC).

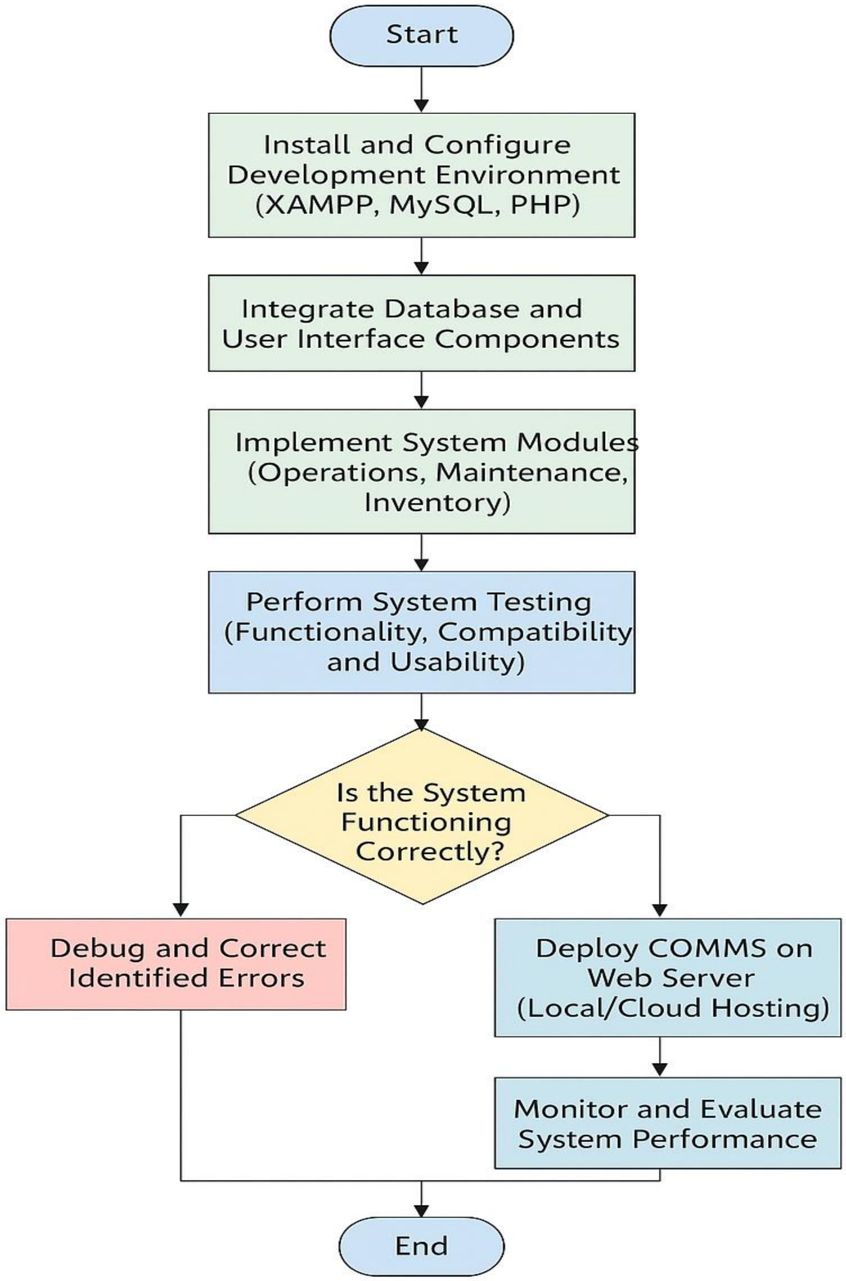

Figure 1: Flowchart of the Web-Based COMMS Architecture

2.6 System Testing and Validation

Testing was conducted in a controlled environment using XAMPP as the local server, integrated with PHP and MySQL for backend operations. Performance testing measured average response time (Ra), system throughput (Tp), and CPU utilization efficiency (Ep).

System reliability was conducted by manually executing a predefined set of 120 transactions across all four system modules, including user login, task submission, maintenance record entry, inventory update, and report generation.

$$Rs = \frac{Ns}{N_t} \times 100\%$$

Where Rs is system reliability, Ns is the number of successful transactions, and N_t is the total number of attempted transactions across 120 predefined transactions covering all four system modules.

System Throughput (T_p)

Throughput measures the number of requests the system can process per second, indicating its capacity to handle multiple users simultaneously

$$T_p = \frac{N_r}{T_t}$$

CPU Utilization Efficiency (E_p)

CPU Utilization was monitored using the Chrome DevTools Performance Tab, which recorded the browser-side processor load during active system use

$$E_p = \frac{CPU_{used}}{CPU_{available}} \times 100\%$$

Average Response Time (R_a)

The average response time measures how quickly the system responds to user requests. This was calculated by measuring the time taken for key system pages to fully load.

$$R_a = \frac{\sum_{i=1}^{n} T_{response,i}}{n}$$

RESULTS AND DISCUSSIONS

3.1 Baseline Fleet Performance and RAM Analysis

The assessment of tractor maintenance strategies and operations was conducted over a three-month period (January to March 2026). Analysis of daily fleet reports from the 50-tractor sample revealed consistently low availability, averaging 69.4% across the observation period. This falls substantially below the 80% industry benchmark, meaning between 13 and 15 tractors were unavailable on every single working day.

Table 2 Monthly and Aggregate Fleet Operational and RAM Performance

Parameter	January 2026	February 2026	March 2026	3-Month Aggregate
Total Hours Worked	6,469 hrs	6,303 hrs	6,656 hrs	19,428 hrs
Total Scheduled Hours	9,750 hrs	9,750 hrs	9,750 hrs	29,250 hrs
Total Downtime Hours	3,281 hrs	3,447 hrs	3,094 hrs	9,822 hrs
Number of Failures	418	437	382	1,237
Total Fuel Consumed	56,074 L	55,040 L	58,339 L	169,453 L
MTBF	15.48 hrs	14.42 hrs	17.42 hrs	15.71 hrs
MTTR	7.85 hrs	7.89 hrs	8.10 hrs	7.94 hrs
Availability Data Average	67.4%	71.1%	69.8%	69.4%
Downtime Rate	32.6%	28.9%	30.2%	30.6%

3.2 FMEA Results and Failure Mode Prioritization

FMEA was applied to the six major failure categories identified during fieldwork. The analysis revealed that hydraulic system failures carried the highest RPN (315) due to near-daily occurrence across the fleet, despite relatively short individual downtime events of 2.0-2.5 hours. Engine failures ranked second by RPN (216) but accounted for over 50% of total downtime hours recorded, with individual engine shutdown events lasting between 27 and 128 hours. The single gearbox failure recorded on machine 71-008 caused the longest individual downtime event at 153.5 hours, illustrating the severe cost of neglecting preventive servicing on critical drivetrain components.

Table 3: FMEA Risk Priority Analysis - Kinyara Sugar Works Tractor Fleet

Failure Mode	Primary Cause	Severity (S)	Occurrence (O)	Detection (D)	RPN

Hydraulic system failure	Overloading, rough terrain	5	9	7	315
Engine failure	Neglected oil changes, no preventive schedule	9	8	3	216
Tyre / Brake failure	Worn seals, hose burst	8	7	3	168
Belt / Drive failure	Wear, misalignment	6	4	5	120
Electrical fault	Corrosion, wiring damage	8	3	4	96
Gearbox failure	Overloading, poor lubrication	9	4	2	72

3.3 COMMS Design Outputs

The design phase successfully produced a functional, role-based web application. A responsive dashboard was created with four distinct portals (Admin, Operator, Mechanic, and Supervisor). The login interface successfully authenticated users and redirected them to role-specific views. The relational SQL database was populated with tables for admin, inventories, maintenance logs, and tractor information, and successfully stored and retrieved operational data in real time.

The automated low-stock alert system was integrated into the inventory module. When stock for critical items such as engine oil or fuel filters fell below defined thresholds, the system flagged a notification and triggered an automated SMS alert to the workshop or procurement officer. This mechanism directly targets the primary cause of elevated MTTR, which was identified as spare parts stockouts rather than mechanical complexity.

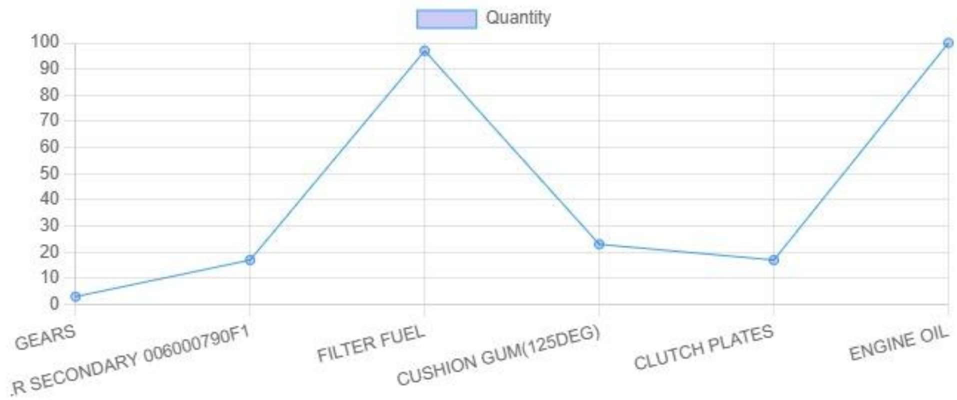

Figure 2: COMMS Inventory line graph showing real-time stock visualization

3.4 System Performance and Validation Results

Performance testing of the COMMS under simulated Fast 3G network conditions demonstrated strong technical suitability for rural field deployment. The overall average system response time was 1.20 seconds, within the acceptable threshold of under 2.0 seconds. The system achieved a throughput of 2.22 requests per second under simulated concurrent load, adequate for the expected user base of 100-200 simultaneous users. CPU utilization averaged only 28%, demonstrating that the COMMS is lightweight and leaves ample capacity for future system expansion.

Table 4: COMMS Performance Validation Summary Against Recognized Benchmarks

Metric	**Measured Value**	**Benchmark Standard**	**Threshold**	**Validation Status**
Average Response Time	1.20 seconds	ISO 9241-110 / Nielsen 1994	Max 2.0 seconds	PASS
System Throughput	2.22 req/sec	System design requirement	Min 50 concurrent users	PASS
CPU Utilization	28%	Industry standard	Max 70% under load	PASS
System Reliability	87.6%	IEEE 610.12	Min 85%	PASS
Usability SUS Score	83.5 / 100	Brooke 1996 SUS scale	Above 80 = Excellent	PASS

System reliability testing across 120 predefined transactions yielded an overall reliability of 87.6%, exceeding the IEEE 610.12 minimum threshold of 85% for operational prototype systems. The Administrator module achieved the highest reliability at 94.3%, while the Inventory module recorded 76%, indicating that the inventory update transaction path requires further optimization before full deployment.

CONCLUSION

This study successfully designed, implemented, and validated a web-based Computerized Operations and Maintenance Management System (COMMS) for Kinyara Sugar Works Limited. The baseline assessment confirmed that the company's tractor fleet suffers from low availability (69.4% in the sampled fleet) as a direct consequence of reactive, run-to-failure maintenance practices, poor spare-parts inventory management, and unreliable paper-based record keeping. Engine and hydraulic failures were identified as the primary contributors to costly downtime, with individual engine failure events ranging from 27 to 128 hours and the longest single event (gearbox failure, machine 71-008) reaching 153.5 hours.

The implemented COMMS demonstrated that digital integration of operational logging, maintenance scheduling, and inventory management into a single platform can significantly improve data accuracy and reduce response delays. The system correctly calculated fleet availability metrics that paper records had systematically underestimated or overestimated, providing management with a reliable baseline for evidence-based decisions. Technical validation confirmed that the system meets all performance benchmarks for field deployment, with average response times of 1.20 seconds and overall system reliability of 87.6%. Four automated mechanisms, comprising hectare-based preventive maintenance alerts, SMS low-stock notifications, real-time task assignment, and maintenance-status cross-referencing during tractor deployment, directly address the root causes of excessive downtime identified in the FMEA analysis.

RECOMMENDATIONS

Future systemic expansions should incorporate Weibull distribution fitting to COMMS-recorded failure-time data to estimate shape and scale parameters for each tractor subsystem, enabling statistically justified preventive maintenance intervals to replace the current ad hoc scheduling approach. Long-term, integration of IoT vibration, temperature, and oil-quality sensors with the COMMS would enable condition-based maintenance alerts, particularly for gearbox failures, which are extremely difficult to detect before occurrence (Detection score = 2), and engine faults, potentially reducing downtime by a further 20-25% beyond the gains demonstrated in this study.

The Hidden Markov Model and Bayesian Network frameworks identified during the study should be formally integrated into the COMMS dashboard as a live predictive maintenance module once 6-12 months of post-deployment data are available. Additionally, broader deployment of the COMMS across other mechanized estates in Uganda and Sub-Saharan Africa could provide practical evidence to support national agricultural mechanization policy, contributing to Uganda's Vision 2040 goals and the Sustainable Development Goal 2 (Zero Hunger) targets.

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OPTIMIZATION OF TRACTOR OPERATIONS AND MAINTENANCE MANAGEMENT SYSTEM

A case of Kinyara sugar works

MAKMOT RONALD ANYWAR

KWURES TIMOTHY

COMPLIANCE REPORT

JUNE 2026

RESPONSE TO PANEL COMMENTS

PROJECT SCOPE			
1	Project Scope: The presentation lacked a clear, designated project starting calendar date.	The scope of the project has been well designated with the starting month and year.	Section 1.8 (Time Scope) now explicitly states: "The project was conducted over a period of eight months, commencing in October 2025 and concluded in May 2026. Project phases: literature review and needs assessment (October–November 2025); system design and development (November 2025–January 2026); baseline data collection (December 2025–January 2026); three-month primary data collection and COMMS operational monitoring (January–March 2026); system testing and validation (March–April 2026); data analysis and report writing (April–May 2026)."
METHODOLOGY VALIDATION			
2	The methodology supporting Objective 1 was highly disorganized and lacked clarity.	The methodology for this objective has been reorganized into a clear, sequential structure.	Section 3.10 now follows a structured progression across eight clearly numbered sub-sections (3.10.1–3.10.8): Purpose of Study → Types of Data Collected → Sampling Criteria (Inclusion/Exclusion) → Data Sources (Primary and Secondary) → Data Collection Tools → Data Collection Procedure → Data Analysis (RAM, MTBF, MTTR) → FMEA Analysis → Questionnaire Findings. Each sub-section has a distinct heading and logical flow.
3	The analytical grading/scoring matrix was inconsistent and scattered across sections.	The analytical scoring matrix has been consolidated into a single unified FMEA reference table placed before application.	Table 3 (Section 3.10.7) is now a standalone FMEA Scoring Criteria table with five score bands (1–2, 3–4, 5–6, 7–8, 9–10) defining Severity, Occurrence, and Detection. Table 4 immediately applies this matrix to six failure modes:

			Hydraulic system failure: S=5, O=9, D=7, RPN=315. Engine failure: S=9, O=8, D=3, RPN=216. Tyre/Brake failure: S=8, O=7, D=3, RPN=168. Belt/Drive failure: S=6, O=4, D=5, RPN=120. Electrical fault: S=8, O=3, D=4, RPN=96. Gearbox failure: S=9, O=4, D=2, RPN=72.
4	The team did not collect primary field data; they relied exclusively on secondary data records provided by Kinyara Sugar Works.	Primary field data was collected through three instruments and raw data placed in the Appendix.	Section 3.10.3 documents three primary data collection instruments: "Structured questionnaires administered in person to 50 tractor operators, 12 mechanics, 6 field supervisors, and 2 stores officers between November and December 2025. Direct field observation carried out on six separate visits using pre-designed observation checklists. Semi-structured interviews conducted face-to-face with workshop personnel and inventory staff." Raw data is in Appendix 1 (Tables 12–17, pages 87–106).
5	The total number of interview questions administered to field operators, mechanics, and facility managers was left completely unspecified.	The number of questions per instrument has been clearly specified in Section 3.10.4.	Section 3.10.4 (Data Collection Tools) now specifies the following: "The structured questionnaire administered to tractor operators comprised 10 questions covering daily working hours, breakdown reporting behavior, awareness of tractor service intervals, familiarity with mobile phone usage, and perceived causes of frequent tractor failures. The interview guide administered to mechanics and supervisors comprised 12 questions covering: (1) frequency of breakdown occurrences per week… through (12) preferred mode of receiving maintenance alerts."
6	The raw output results from the distributed questionnaires were omitted.	Raw output results have been included in Table 5 in the body and in Appendix 1.	Table 5 (Section 3.10.8) Summary of Questionnaire and Interview Findings present percentage-level responses across all three respondent categories for 10 thematic areas. Key raw findings include:

			Only 22% of operators are aware of tractor service intervals (vs 100% mechanics, 83% supervisors). 54% of operators always report breakdowns. 38% cite fear of pay deduction as the reason for not reporting. 91% of mechanics reported spare parts out of stock in the last month. 92% of operators own or have access to a mobile phone. 84% of operators believe SMS alerts would improve parts availability.
7	The team lacked explicit, scientifically sound guidelines to mathematically justify sampling a subset of 50 tractors out of a total fleet of 750.	Scientifically sound, stratified sampling criteria with explicit inclusion and exclusion criteria have been provided.	Section 3.10.2 now presents a stratified purposive sampling framework across four stratification dimensions: Operational Department: Ploughing 20, Harrowing 15, Furrowing/Seedbed 15. Age Distribution: New (<3 yrs) 10, Mid-life (3–7 yrs) 25, Old (>7 yrs) 15. Usage Intensity: High (≥40 hrs/week) 15, Medium (20–39 hrs/week) 20, Low (<20 hrs/week) 15. Brand Representation: New Holland 12, John Deere 10, Case IH 8, Massey Ferguson 8, Mahindra 7, Kubota 5. Exclusion criteria cover tractors in long-term storage, non-agricultural duty units, incomplete maintenance records, and decommissioning-pending units.
SYSTEM CAPABILITIES			
8	The report failed to visually or logically demonstrate how the software system actually reduces operational downtime. The method for tracking and recording tractor mileage remained highly ambiguous.	Downtime reduction demonstrated through four specifics, tested automated mechanisms. IoT automation recommended for future work.	Section 4.2 (Downtime Reduction) demonstrates four verified mechanisms: (1) Preventive maintenance alert triggered at every 35 cumulative hectares tested successfully, generates automatic work order for lubrication, oil check, filter inspection and hydraulic check. (2) Automated SMS low-stock alert tested successfully when gear stock fell below minimum, generating SMS to administrator. (3) Real-time task assignment eliminates 30–60 min coordination delay under paper system. (4) Tractor assignment cross-check blocks

			deployment of maintenance-overdue tractors and displays maintenance warning. IoT sensor integration for automated mileage tracking recommended in Section 4.6.
MAINTENANCE FRAMEWORK			
9	The framework did not articulate explicit engineering methodologies to minimize field breakdowns or actively extend a tractor's operating lifespan.	Four explicit engineering methodologies have been articulated with technical justification in Section 4.4.2.	Section 4.4.2 (Engineering Methodology for Minimizing Breakdowns) states four methodologies: (1) Hectare-based lubrication scheduling: greasing and inspection work order at every 35 ha, aligned to manufacturer-recommended 50-hr interval for New Holland TT75, John Deere 5075E, and Massey Ferguson 385 arrests joint and bearing wear before progressive damage threshold. (2) Condition-based oil and filter change scheduling: engine service alert at every 250 cumulative operating hours per tractor replaces calendar-based approach and maintains designed lubrication parameters. (3) FMEA-driven priority enforcement: Priority 1 flag for RPN 315 (tyre/brake) and RPN 216 (engine); work orders cannot be deferred beyond 24 hours without supervisor override. (4) MTTR reduction as lifespan extension: SMS inventory alerts eliminate parts-waiting gap, preventing secondary degradation during unrepaired breakdown periods.
DATA STRUCTURE			
10	The developed system's performance results were not scientifically validated. Data tables were haphazardly pasted into the main text rather than	Performance results validated against five recognized international standards. Detailed data tables moved to Appendix.	Table 9 (Section 3.12) COMMS Performance Validation Summary validates all five metrics against recognized benchmarks: Average Response Time: 1.20 s ISO 9241-110 / Nielsen (1994) threshold 2.0 s PASS (40% below threshold). System Throughput: 2.22 req/s supports 133 req/min PASS. CPU Utilization: 28% industry threshold 70% PASS

	organized within a technical appendix.		(42% below threshold). System Reliability: 87.6% IEEE 610.12 threshold 85% PASS (exceeds by 2.6%). Usability SUS Score: 83.5/100 Brooke (1996) threshold 80 = Excellent PASS. All daily fleet reports (Tables 13–15), maintenance data (Table 17), and inventory data (Table 18) organized in Appendix 1 and 2.
PANEL RECOMMENDATION			
11	The team must intensely refine the operational user-communication interface of the management system.	The user-communication interface has been improved with role-specific dashboards, real-time visualizations, and automated SMS alerts.	Section 4.2 documents the following interface improvements: Four distinct role-based portals (Admin, Operator, Mechanic, Supervisor) enforced through Role-Based Access Control (RBAC), preventing cross-role access. The Inventory Module now generates three real-time stock visualizations: a bar chart for immediate stock comparison, a line chart for depletion trend monitoring, and a pie chart for proportional stock distribution. Automated SMS alerts notify administrators when stock falls below minimum thresholds. API synchronization ensures all data entered on mobile devices is instantly reflected on the central web dashboard, eliminating end-of-day batch reporting delays.

Supervisors

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Signature: 

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