An Automated Rack Storage System for Railway Devices and Equipment Using QR Code and Cloud Database Technology

Charm Angel R. Sarong[1], Aaliyah Mikaela A. Ignacio[2], Chrizel R. Guzarin[3], Rhen Jester Valdueza[4], Carlo Jay G. Delizo[5], Sherlie D. Bunag[6], Connie C. Aunario[7], Weellrr D. Martin[8], Julius G. Garcia[9*]

[1-9] *Technological University of the Philippines, Ayala Blvd., Ermita, Manila, Philippines*

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****Correspondence Email:***
julius.tim.garcia@gmail.com

Abstract

This research project aims to develop an automated storage rack system for railway devices and equipment using QR codes and cloud-based database technology. The automated rack system can precisely store railway devices and equipment using the cloud-based QRC/QR Code database. It explores the drawbacks of conventional storage management methods in the railway industry, like lack of order, inefficiency, and security issues. Using QR codes to track and monitor all tools, equipment, and components, the proposed system includes a cloud-based database providing real-time inventory visibility and data analysis capabilities. Additionally, the system features CCTV surveillance for added security level and mobile phone integration to ensure that only you, as the end user, get access. Based on the study's findings, automated storage rack systems promise significant improvements in efficiency, security, and operational effectiveness for railway maintenance.

1. Introduction

The railway industry has benefited from ATO, control centers, and automation of signaling systems. Automated systems for storing and retrieving goods (AS/RS) in warehouses and distribution centres have also been observed. Atypical Insights (2023) observes AS/RS in overcoming maintenance hitches in the railway. Modern technology and a QR code integration system to store, retrieve, and organize components and equipment make operations more efficient and secure.

Other sectors employ automation, but the railway industry has slowly adopted technology, notably for store management systems. Multiple railway sectors, including the Philippines, practice manual store management. Disorganized tools, equipment, and components may hinder resource management, maintenance, and storage.

Warehousing Problems (2019) suggests that poor workflow and excessive labor expenses may promote warehouse chaos. Poor racking design and storage system use may crowd warehouses and prevent new things from being stored. Disorganization and misplacement lead to workers using alternative resources to maintain equipment, tools, and components, which may pose business problems.

According to Patil (2017), modern warehouses have space consumption difficulties. The major cause is sluggish, stagnant, outdated, or enormous inventory. Inefficient storage areas produce stock imbalances due to disorganized equipment and administration. Unauthorized workers accessed the storage rack during depot visits to the Light Maintenance Department of the Light Rail Transit Authority (LRTA), raising concerns about unmonitored store management systems. Bakharev (2024) defined illegal access as evading security to enter a system without workers' approval.

Workplace disorders may harm staff effectiveness and efficiency. Misplaced tools, components, and equipment cost time and pose dangers. Disorganized maintenance staff may use dangerous instruments, endangering themselves and the firm (Creative Safety Supply, n.d.). Indifference and poor morale might impair job productivity and happiness (Mohamed, 2024).

Poor storage management may ruin railway operations. Disorganized storage and lack of monitoring may make retrieving critical materials difficult and inefficient, impeding maintenance and operations. Misallocated or damaged goods and needless equipment acquisitions might cost money (Vörös, 2018). Railway personnel require storage management solutions to operate safely, efficiently, and productively.

The railway industry's tools, equipment, component management, and organization may pose safety and efficiency issues. A secure, structured, automated storage rack system reduces stock discrepancies and inventory disorders. Several Automated Storage and Retrieval Systems (AS/RS) have been developed to increase warehouse efficiency and dependability (Gagliardi et al., 2012). Their railway application, notably tool and equipment management, needs further investigation.

QR codes are crucial for tracking. These codes improve railway accountability and security by tracking tool, component, and equipment use and location. An integrated cloud-based database management system may increase real-time inventory visibility, data analysis, and system administration. This fully automated storage method may improve railway efficiency, security, and operations.

1.1 Literature Review

1.1.1 Railway Maintenance Storage Systems

Safe and reliable railway operations need maintenance. It includes complex electrical and mechanical equipment such as signaling systems, track components, rolling stock, and power supply infrastructure. This equipment must be stored properly to maintain its integrity, lifespan, and availability (PRC Rail Consulting Ltd., n.d.). Maintenance and storage mistakes may lead to higher costs, operational disruptions, and safety issues.

Poor railway equipment maintenance may hasten degradation, operational failures, and breakdowns. This may require costly repairs or replacements and postpone train schedules (Twall, 2023). Poorly maintained equipment might also endanger railway workers and passengers. Failing brakes and signaling systems may cause accidents. Avoiding these problems requires efficient storage management. Poor storage of tools, components, and equipment may make it difficult to find key supplies, delay maintenance, and increase the risk of losing or damaging expensive assets (De Gracia, n.d.). This may hinder maintenance and compromise railway safety and reliability. Manual storage methods may appear appealing due to their low cost and familiarity, but they have drawbacks. Manual storage techniques waste time retrieving items, manage inventory inaccurately, and struggle to maintain structure (Mecalux, 2018). Employees may also be injured while physically manipulating heavy machinery.

1.1.2 Automated Storage Systems

Automated Storage and Retrieval Systems (AS/RS) have transformed warehouse and inventory management by solving the problems of traditional storage methods. These systems automate item storage and retrieval using computers and robots, improving efficiency, accuracy, and safety (AutoStore, 2023). By minimizing manual handling and increasing storage capacity, AS/RS cuts labor costs improve workplace safety and reduces human error. AS/RS technology has advanced significantly since the 1950s. Other automated systems, including vertical lift modules, carousels, mini-load systems, and unit-load systems, have been added to AS/RS, initially designed for pallet storage. This flexibility lets companies tailor storage systems to specific commodities, storage densities, and throughput needs. AS/RS is utilized in production, distribution, retail, and e-commerce. AS/RS ensures component availability for just-in-time manufacturing. Distribution facilities employ AS/RS to improve order fulfillment and logistics. Automation Storage and Retrieval Systems (AS/RS) improve inventory accuracy and customer service for retailers. AS/RS is needed to process large numbers of small orders and accelerate shipping in the fast-growing e-commerce sector (Global Market Report Insights, 2023). AS/RS improves warehouse operations, productivity, and corporate efficiency.

1.1.3 Storage Rack Systems

Many industries use storage rack systems for warehouse management and material storage. They improve space efficiency and make inventory easy to obtain by organizing storage (Patil & Attar, 2016). Various storage rack systems suit different materials, storage densities, and operational needs. Any warehouse or industrial facility must choose the right storage rack system. The optimum solution depends on commodity kind, weight, size, storage density, and access frequency (Cecchi, 2023). Heavy-duty pallet racks are suitable for large items, whereas cantilever racks are best for long or oddly-shaped items. Drive-in racks maximize area but limit accessibility compared to pallet racks. Thorough consideration of these parameters ensures that the chosen storage rack system meets operational demands and improves warehouse efficiency. Storage rack systems optimize space usage, inventory management, and material mobility to raise productivity, save operating costs, and improve warehouse performance.

1.1.4 Automated Storage Rack Systems

Roodbergen and Vis (2009), in their thorough study on ASRS, provided the basic efficiency principles of material handling in multiple moving AS/RS, including the storage rack configurations, retrieval systems, and material handling equipment. Gu et al. (2010) call for such features to be embedded in inventory management systems for efficient working. Their review of where such systems have been fully integrated provides a favorable view that the accuracy and speed of filling orders will improve.

Automated storage systems have proven to have many advantages when it comes to railway maintenance operations. Kumar et al. (2021) argued in their work on the enhancement of the processes of railway maintenance that such systems can significantly decrease time ruining in the retrieval of parts and tools, thus increasing the turn-around periods of the trains. This is made possible through the elimination of storage and retrieval whereby Mattfeld and McGinnis (2003), in their study on the automation of warehouses in the rail sector, noted that human effort and the time taken to search were reduced.

Chang et al. (2010) also illustrate that automatic storage systems can be very cost-effective because they eliminate or reduce manual inventory control's labor requirements and human errors. These solutions improve the effectiveness of storage facilities and enable proper inventory control, which guarantees that required maintenance tools will be on hand when needed, thus boosting work output and improving efficiency.

To build an automated railway equipment storage rack system, hardware and software requirements are necessary. Boysen et al. (2009) outline storage and retrieval systems as having structural elements such as steel cabinets and angle bars and mobility components such as caster wheels. In their study on intralogistics autonomous guided vehicles, Fricke et al., 2015 mention additional elements, including sensors, control systems such as solenoid locks, and CCTV cameras, as relevant for security and monitoring.

Azadeh et al. (2017) have also made it clear the importance of the use of Wi-Fi modules concerning modern day automated storage systems as essential for timely and accurate information transmission as well as for system monitoring. A system administration user interface is denoted by CPU, keyboard, and mouse, whereas control and data management software architecture are denoted by Arduino ide and Google Firebase.

1.1.6 Cloud-based Management System

Automated storage systems' use of cloud database management systems is revolutionizing inventory management in several sectors of industries, especially in the railway industry. Cloud technology has several merits compared to the typical on-premises ones, like providing users with live views of inventories, better analytics features, and better control over the systems (Liu et al.,2022). This means the operations are now more effective, costs are reduced, and decision-making is more precise.

These advantages of cloud-based inventory systems are more pronounced in the railway sector since providing tools, equipment, and components for maintenance and operations needs to be done in time. The ability to provide live pictures helps avoid possible shortages, configure the stocking level, and simplify all procurement issues. In addition, if data can be observed and reports made about the same, it helps to know how often or what times the items are used or purchased, analyze the usage patterns and trends, and make more appropriate managerial decisions concerning inventory and the optimal allocation of resources. The adopted framework of incorporating automated storage with cloud-based data management has the potential to improve the efficiency, security, and operational performance of the railway sector (Sharma et al., 2023).

1.2 Objective of the Study

The study aims to establish a cloud-based automated storage rock system using QR code technology for real-time inventory visibility, data analysis, and system administration to improve railway device and equipment efficiency, security, and operations.

Specifically, the study aimed to:

1. Design a prototype with the following features:
    a. An automated storage rack with QR integration to enhance the storage management system of railway parts and tools.
    b. A closed-circuit television (CCTV) camera to monitor the activities within the automated storage rack.
    c. Mobile Phone to show key information of the user's information.
    d. Cloud Server is used to store the employees' information for real-time monitoring and storage.
    e. Manual bypass lock to access the storage rack in case of power interruption.
2. Fabricate and assemble the prototype per requirements with locally accessible materials.
3. Test and improve the performance of automated rack storage using various inspection methods and evaluate the project's effectiveness.
4. Evaluate the prototype's performance using the TUP standard evaluation tool.

2. Research Methods

2.1 Project Design

The automated storage rack aims to provide a secure and organized storage management system for railway devices and equipment used in rolling stock maintenance within the Light Rail Manila Authority (LRTA) light maintenance department. The system integrates QR code technology, a CCTV camera for real-time monitoring, solenoid locks for enhanced security, and mobile phone integration as a control system for accessing specific compartments.

2.1.1 System Overview

The automated storage rack system comprises three main sections:

1. **Body Section**: Includes the storage rack and compartments.
2. **Monitoring Unit**: Consists of a CCTV camera for security, a computer setup, and a database for logging system activities.
3. **Control Section**: Incorporates QR code tags and a QR code reader for access control.

2.1.2 Isometric and Exploded Views

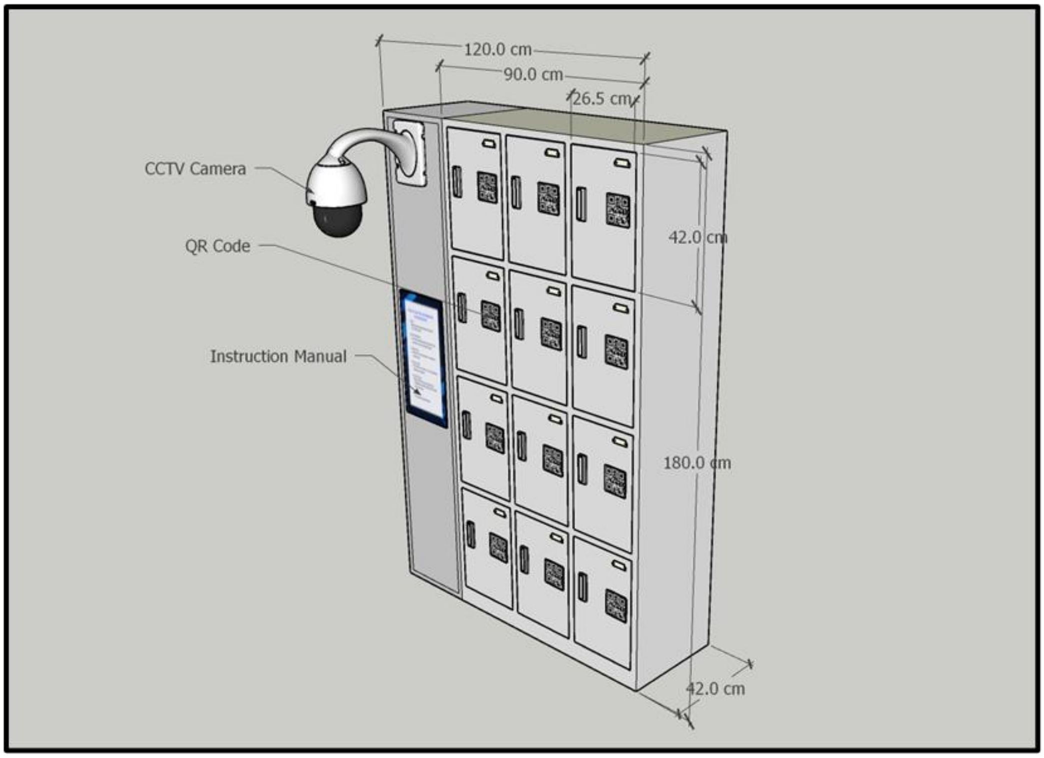

Fig. 1 Isometric View of The Automated Storage Rack

Figure 1 presents an isometric view of the automated storage rack, illustrating the body section with the storage rack, compartments, and QR code. The monitoring unit, including the PTZ CCTV and computer setup, is also shown. Figure 2 provides an exploded view of the system, detailing individual components and their assembly for a comprehensive understanding of its structure and connections.

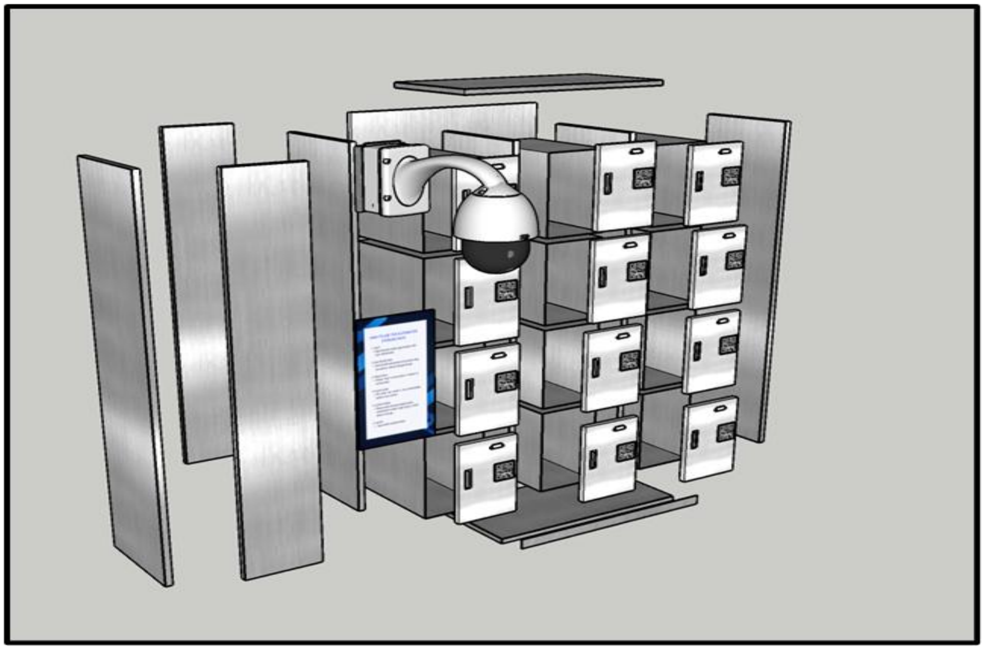
Fig. 2 Exploded View of the Automated Storage Rack

2.1.3 Block Diagram

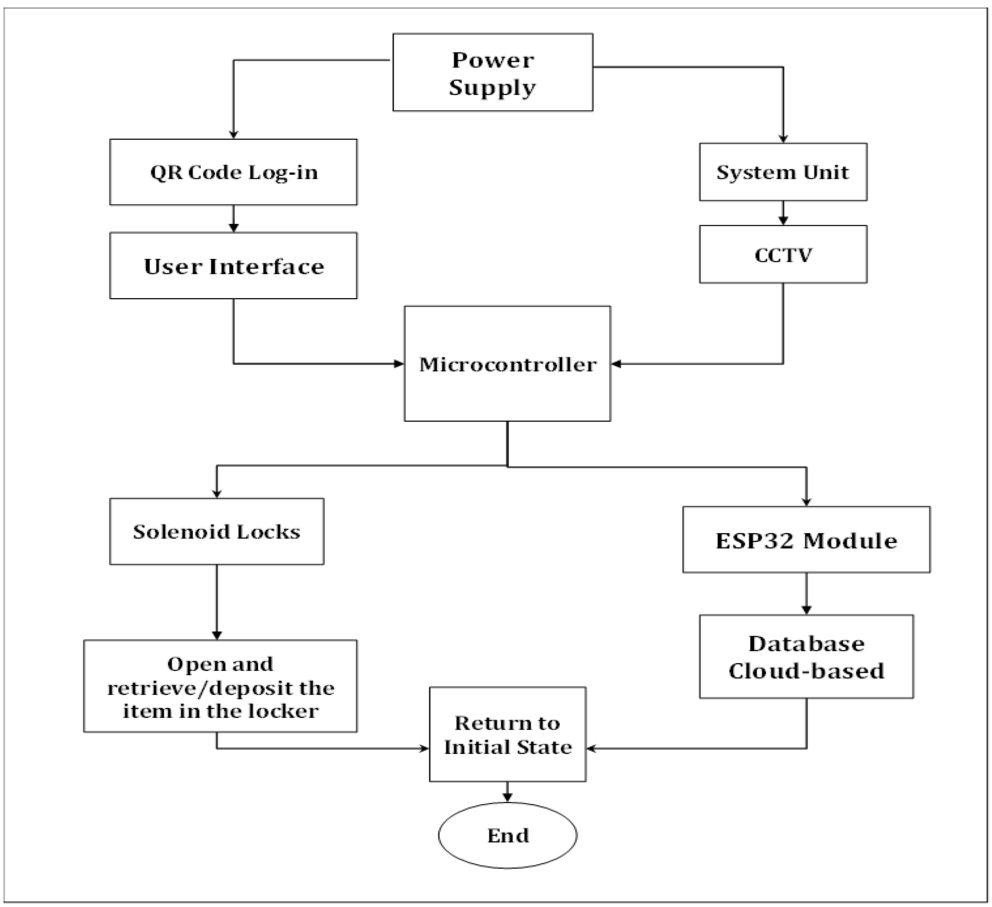

Fig. 3 Process Flow Diagram

Figure 3 displays the block diagram, outlining the process flow for accessing the automated storage rack. This includes power supply, QR code scanning, mobile control system interaction, CCTV monitoring, microcontroller activation of solenoid locks, data logging via ESP32 module, and the system's return to its initial state.

2.2 Development Process
2.2.1 Input-Process-Output Approach

1. **Knowledge Gathering**: Collect information from relevant literature and studies to identify necessary hardware and software components.
2. **Design and Development**: Design and develop the automated storage rack system.
3. **Testing**: Conduct performance tests to ensure all components function according to design specifications.
4. **Evaluation**: Evaluate the system's functionality, workability, durability, and safety.

2.2.2 Fabrication Procedure
The fabrication procedure involves:

1. **Mechanical Assembly**: Use stainless steel to construct the body section, including the storage rack and compartments.
2. **Material Selection**: Utilize stainless steel for the body, frame, and compartment covers.
3. **Component Integration**: Install CCTV cameras, solenoid locks, and other components according to design specifications.

2.3 Operationalization and Testing
2.3.1 Operation

1. Ensure the area around the automated storage rack is clear of obstacles.
2. Power on the automated storage rack and the connected computer setup.
3. Familiarize personnel with the controls and database system.
4. Access compartments by scanning QR codes and logging in through the mobile control system.
5. Retrieve or deposit items and close the compartment door.
6. Repeat the process for accessing additional compartments.

2.3.2 Testing
Testing procedures include:

1. **Preparations**: Ensure a clear operational area and active power supply.
2. **Functional Testing**: Test QR code scanning, control interface functionality, user login, compartment door operation, and monitoring devices.
3. **Performance Testing**: Evaluate QR code reading accuracy, compartment opening speed, solenoid lock functionality, and manual bypass lock operation.
4. **Monitoring System Testing**: Monitor CCTV data, check database accuracy, and test Wi-Fi module functionality.
5. **Documentation**: Record observations, problems, and modifications during testing.
6. **Post-Testing Inspection**: Inspect for damages and address any issues.

2.4 Evaluation
The evaluation will assess functionality, accuracy, performance, and workability by surveying 30 respondents, including engineers, supervisors, and maintenance personnel. It will utilize the Technological University of the Philippines standard evaluation tool and focus on functionality, workability, durability, and safety.

3. Results and Discussion

In industries like railway repair, where tools and equipment are needed quickly, workplace organization and accessibility are critical to productivity. Tools and equipment must be stored systematically (Creative Safety Supply, n.d.). Products must be classified and labeled, locations assigned, and racks, bins, and drawers employed.

Proper storage protects critical railway equipment and helps maintenance crews find and retrieve it quickly, reducing downtime and delays. This is crucial in railways, where even tiny delays may disrupt timetables and operations. An organized workstation makes maintenance easier, decreasing personnel expenses and increasing productivity. Systematic storage improves worker safety. Properly storing tools and equipment can avoid clutter, missing items, and tripping risks. In the railway sector, safety is crucial to avoid major injuries or damage to valuable equipment. Organization and accessibility in tool and equipment storage may increase railway maintenance efficiency, downtime, safety, and production.

Railway maintenance security must be improved to secure important equipment, prevent unauthorized access, and maintain operational integrity. QR code tracking and CCTV surveillance may improve security and efficiency. Bakharev (2024). QR codes help track and monitor tool and equipment usage. Each object may have a QR code to trace its usage, location, and movement by maintenance personnel. This strategy provides rapid visibility into critical assets, reducing misuse, theft, and loss. Inventory management systems may also use QR code data to automate audits, optimize maintenance, and improve accountability.

QR code tracking with CCTV cameras improves security. Strategically placed CCTV cameras in the maintenance department provide entry point surveillance, suspicious activity detection, and security breach-proof. CCTV cameras hinder unauthorized entrance and vandalism. QR code technology and CCTV surveillance allow train maintenance departments to create a secure system that protects assets, enhances accountability, and promotes efficiency. This comprehensive plan protects assets and improves workplace security.

Optimizing processes improves efficiency and productivity in all industries, especially railway maintenance, where timely task execution ensures operational safety and reliability. Optimizing maintenance requires a structured and coherent storage system (D'Souza, 2021). Maintenance workers can quickly identify and get critical tools and equipment from an organized storage system, saving time and effort and speeding up turnaround times.

Efficiency gains ripple across the railway operation. Maintenance efficiency reduces downtime and delays and ensures railway service continuity. This enhances railway efficiency and customer happiness by avoiding disruptions and ensuring timeliness. Optimized processes improve worker safety. Tools and equipment that are easily accessible and organized reduce the likelihood of accidents caused by disorder, misplaced items, or unnecessary workstation movements. Railway safety is crucial due to the potential for serious injuries or expensive equipment damage. Upgrading storage systems and streamlining procedures may improve railway maintenance operations' efficiency, safety, and productivity. This reduces costs, improves reliability, and boosts customer satisfaction.

4. Conclusions

Using QR code technology and a cloud-based database connection, a prototype of an automated railway equipment storage rack system was created, which contains organization, accessibility, security, and workflow efficiency. The design and implementation of such a system enhanced the performance of railway maintenance activities by improving the organization and accessibility of tools and equipment, enhancing security through QR code and CCTV surveillance, improving the workflows, and decreasing the time spent searching for the tools and equipment, enhancing maintenance performance and productivity.

The effectiveness of this automatic storage rack system wirelessly networked with a PC can positively influence the maintenance activities of the railway infrastructure. Reducing chaos can increase safety by limiting misplaced and unnecessary clutter. Streamlining work processes can maintain cost efficiency and enhance productivity. It can enhance accountability and security by inhibiting unnecessary access to tools and monitoring their use. It has also enhanced effectiveness by reducing idle time and allowing for quick maintenance to be performed.

The central limitation of the study was the development of the destructive prototype for assessment, which may not reflect the real-life scenario when undertaken on a larger-scale railway maintenance unit. It is critical to develop other prototypes and further R and D to enhance this system and solve scale issues.

Recommendation

Based on the study's findings and limitations, the following recommendations are made for future research and development:

1. Perform a pilot installation of the automated storage rack system in a railway maintenance environment to evaluate its performance and identify areas for improvement.
2. Consider adding autonomous guided vehicles (AGVs) for material handling and advanced analytics for predictive maintenance.
3. The system's scalability should enable larger inventories and different railway equipment.
4. Perform a cost-benefit analysis to determine whether the automated storage rack system is economically viable in various railway maintenance situations.

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