INTERNATIONAL JOURNAL OF ACADEMIC RESEARCH IN BUSINESS & SOCIAL SCIENCES

Vol 14, Issue 12, (2024) E-ISSN: 2222-6990

Optimizing Hospital Bed Management System with Iot

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To Link this Article: http://dx.doi.org/10.6007/IJARBSS/v14-i12/24355 DOI:10.6007/IJARBSS/v14-i12/24355

Published Date: 29 December 2024

Abstract

Effective management of hospital beds is considered one of the key factors in providing timely and efficient health services in response to growing patient demand. This paper describes the concept of utilizing the Internet of Things (IoT) for managing hospital bed assignments and utilization to minimize various issues related to bed management, such as patient flow, bed availability, and resource allocation. The initiative seeks to enhance current bed management practices using IoT technologies by embedding real-time data acquisition and monitoring. Traditional bed management systems rely on manual updates, which lead to delays in patient movement data and misallocations, such as assigning occupied beds to newly arriving patients. The proposed project thus offers a bed management solution that reduces errors and enhances patient care by providing healthcare administrators with a real-time view of current bed occupancy. The proposed system improves bed management decisions, facilitates better patient flow, and streamlines resource allocation within hospitals through the deployment of sensor networks and predictive analytics. Results obtained from the system's operation have been encouraging, showing significant improvements in minimizing patient waiting times and optimizing hospital operations overall.

Keywords: Hospital Bed Management, Bed Occupancy, Internet of Things, Proof of Concept, Patient Flow Optimization

Introduction

Hospital bed management systems is vital to the seamless operation of a hospital. Management of hospital beds plays an important role in maintaining proper patient flow and utilization of resources for overall operational efficiency in hospitals (Lee et al., 2021). Conventionally, bed management has been performed manually, which creates many inefficiencies, delayed admissions, long waiting times, and inability to manage varying patient demands. Such management of hospital beds still faces a number of problems: lack of real-time bed visibility, ineffective communication among departments, inability to prioritize

patient admissions according to urgency of treatment, inability to forecast bed demand, and inefficient discharge planning, which results in overcapacity or shortages of beds in hospitals (Hammer et al., 2022). The hospital bed management systems address these challenges through leveraging technology for streamlining bed allocation, improving coordination between various departments, and enhancing the flow of patients. An effective system enables a real-time bed occupancy monitoring system, followed by automated allocation according to the need and severity of the patients. It offers integrations with electronic health records, enabling seamless information flow, data-driven insights to optimize bed utilization effectively, and so on (Siverskog & Henriksson, 2022). In integration, IoT-based technology is transforming the landscape of healthcare management. IoT-enabled hospital bed management systems represents a new approach in bed optimization with a view to ensuring better patient care and managing the workflow at the hospital. The IoT-based systems facilitate collections, analysis, and dissemination of information on time, thus rendering a sea change in the concept of hospital administrations (Yeh et al., 2021). The integration of IoT with hospital bed management systems will meet the challenges through an efficient collection of information and smooth communication amongst beds, medical equipment, and health professionals. IoT sensors embedded in beds and connected medical devices connect in real time with data on bed occupancy, patients' vital signs, and device status. Conclusively, this would make automated decision-making for bed allocation possible, predict demand patterns, and therefore allow equipment maintenance proactively. The current project deals with the design of an IoT-integrated hospital bed management systems, which would be suitable for modern health care needs. Thus, such objectives are to analyze the bed management-related challenges existing in most of the present healthcare facilities, design an IoT-based architecture for hospital bed management systems, develop a prototype system integrated with IoT sensors, deploy the system in a simulated hospital environment, and assess its effectiveness in optimizing bed allocation and improving clinical care for the patients (Borges et al., 2020).

Research Background

The reviewed literature on hospital bed management systems reveals various approaches aimed at improving hospital efficiency, patient flow, and resource allocation. Iadanza, Luschi, and Ancora (2018) present a web-based application designed to optimize bed allocation by integrating patient interaction data, admission status, and personnel information. The system seeks to reduce outliers and diversions while minimizing the length of hospital stays. Although the proposed system is innovative, the paper lacks empirical evidence to support its effectiveness in real-world scenarios. Furthermore, it does not adequately address the challenges of integrating such a system into existing hospital infrastructure or training staff to use it.

Abedian et al. (2014) introduce a dynamic bed management system that provides real-time updates on bed availability, particularly focusing on intensive care unit (ICU) and critical care unit (CCU) beds. This system is designed to optimize the distribution of patients across hospitals. While it addresses critical care needs, the paper lacks sufficient technical details and empirical testing to support its broad implementation. The scalability of the system and its potential challenges, such as network reliability and system integration, are not thoroughly explored.

Thomas et al. (2013), focus on the development of a decision support tool that uses a mixed-integer programming approach to optimize bed assignments in dynamic hospital environments. This tool integrates real-time patient data with hospital resources to improve bed assignment efficiency. The system's application at Mount Sinai Medical Center adds credibility, but the paper falls short in discussing the human factors involved in its implementation, such as staff adoption and training. Additionally, the sustainability of the system in evolving hospital environments is not fully addressed.

Noonan et al. (2019), provide a comprehensive review of bed management practices, examining operational, procedural, and decision-support approaches to improve hospital efficiency. While the review covers a broad range of methods, it is more descriptive than analytical and lacks critical evaluation of the success rates of the methods reviewed. The paper does not provide actionable recommendations or empirical evidence on the effectiveness of these practices, limiting its usefulness for decision-makers seeking proven solutions.

In a more recent paper, Noonan et al. (2013), present the development of a bed management system designed to replace outdated paper-based methods. The system captures patient-hospital interactions in real-time, providing up-to-date information on bed status and improving patient throughput. Although the system shows promise, the paper does not offer comprehensive testing data or discuss challenges related to staff adoption of the new technology. Like many hospital IT solutions, resistance from staff accustomed to traditional methods could pose a barrier to successful implementation.

While these previous work provide valuable insights into various approaches to hospital bed management, many of the proposed solutions still require real-world validation. Key challenges such as user adoption, system integration, and long-term sustainability need to be addressed to ensure these systems can effectively improve hospital efficiency and patient outcomes.

Methodology

Conventional hospital bed management, as illustrated in Figure 1, starts when a patient is admitted either from the emergency department, clinic, or other wards in the same hospital. First, the ward staff or nurses call the bed management system to determine availability of the bed. It will then access the bed management system and identify an appropriate, available bed within a specific ward. After this confirmation of bed availability, the nurses will contact the administrative department. Once the administrative team has assigned the patient to an available bed, the bed allocation is updated in the system. The bed assignment then follows up with transportation of the patient by either nursing or transport staff to the assigned bed.

After the admission, the nurses record all the patient's information, like their previous and current medical history, and transfer that to the administration department to complete the formalities of record keeping. The doctors and the nurses, depending on the condition of the patient, monitor their condition by noting down the various critical and important changes during their stay in the hospital. As the patient's health improves, the doctor evaluates whether the patient is ready for discharge. Following approval of the discharge, the patient is given instructions on post-discharge care, including medication schedules and follow-up

appointments, and the nurse completes the required documentation. The nurse alerts the cleaning crew to sanitise the now-empty bed and updates the system after the patient leaves the hospital. The bed management cycle is finished when the nurse notifies the administrative department that the bed is ready for use, having cleaned and readied it for the next patient.

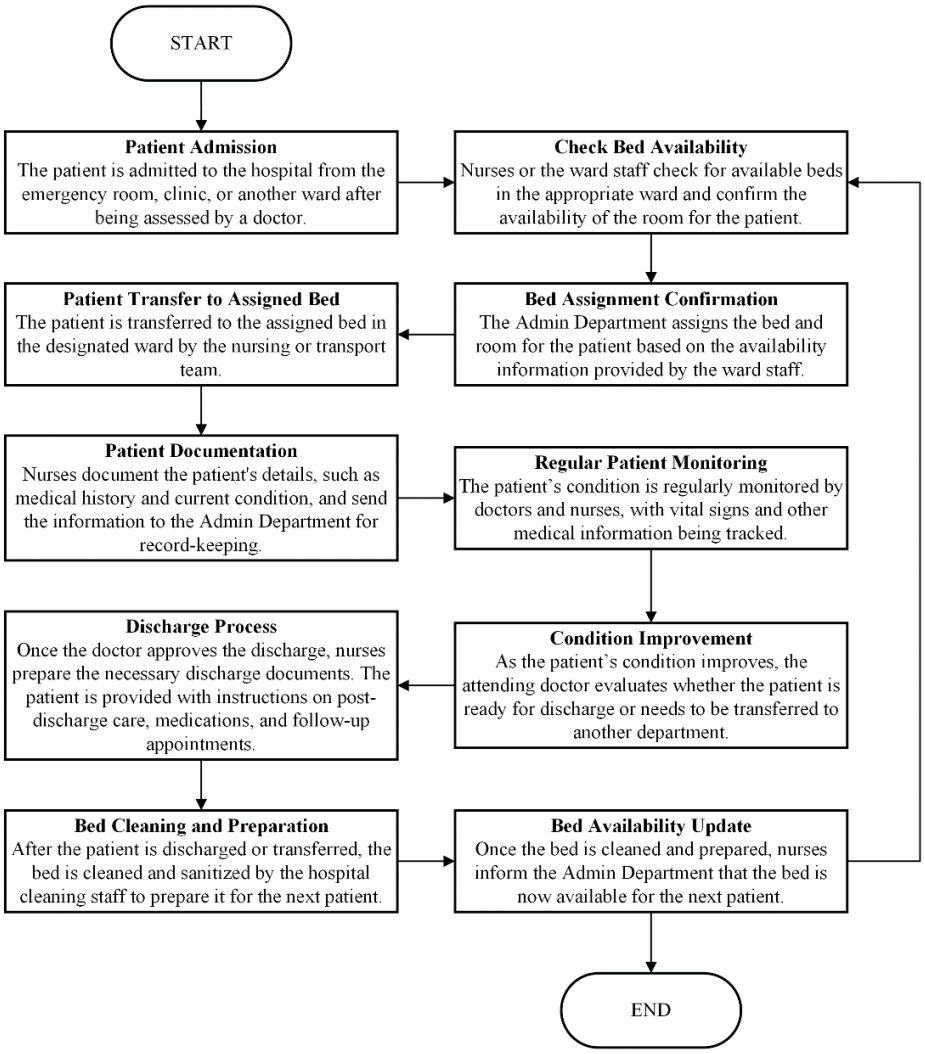

Figure 1: Typical bed management process

Figure 2 illustrates the proposed IoT-based hospital bed management system, which automates the steps involved in patient admission, bed assignment, and bed preparation. The process begins with a patient being admitted to the hospital from the emergency room, clinic, or another ward after being assessed by a doctor.

The next step involves checking bed availability, where the nurses or ward staff use the bed management system to identify available beds in the appropriate ward. The system confirms the availability of the room for the patient.

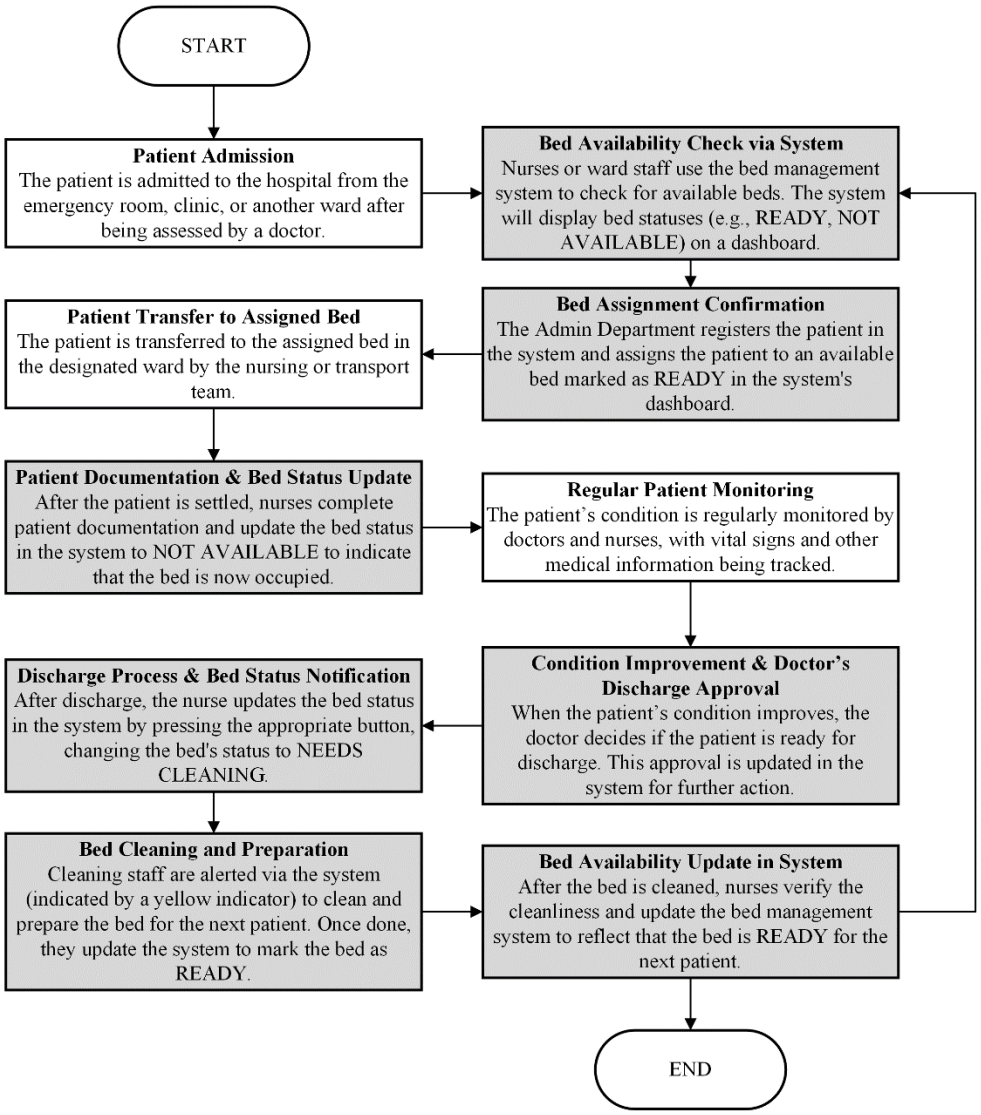

Figure 2: Proposed concept of optimized bed management process

Once a bed is identified, the bed assignment is confirmed by the Admin Department, who assigns the patient to a bed and room using the real-time system information. The patient is then transferred to the assigned bed by the nursing or transport team. Following the patient's transfer, the nurse completes the patient documentation, recording important details such as medical history and current condition. This information is sent to the Admin Department for record-keeping. During the patient's stay, regular patient monitoring takes place. The patient's condition is regularly checked by doctors and nurses, who track vital signs and other medical information to ensure proper care.

As the patient's condition improves, the doctor evaluates whether the patient is ready for discharge. When the patient is deemed fit for discharge, the discharge process is initiated. Nurses prepare the necessary discharge documents, and the patient is informed about post-discharge care, medication, and follow-up appointments. Once the patient is discharged or transferred, the nurse updates the system to notify the cleaning staff that the bed requires cleaning and preparation. The bed is cleaned and sanitized by the hospital cleaning staff, ensuring it is ready for the next patient. Finally, the bed availability update is triggered once

the bed is cleaned and prepared. Nurses inform the Admin Department that the bed is now available for the next patient, completing the cycle.

The proposed hospital bed management system can be effectively developed using a combination of sensors and cloud based IoT technology to automate the process of bed availability updates and cleaning notifications.

To validate the proposed concept, a scaled-down prototype was developed by setting up two hospital rooms, each equipped with two beds. The IoT system utilized ESP32 microcontrollers, various sensors, and LED indicators to monitor bed occupancy. Blynk served as the cloud interface, providing real-time data visualization and control. This setup allows for efficient monitoring of bed availability and occupancy, effectively demonstrating the functionality of the IoT system in a hospital-like environment. The setup is shown in Figure 3 while the Blynk interface is shown in Figure 4.

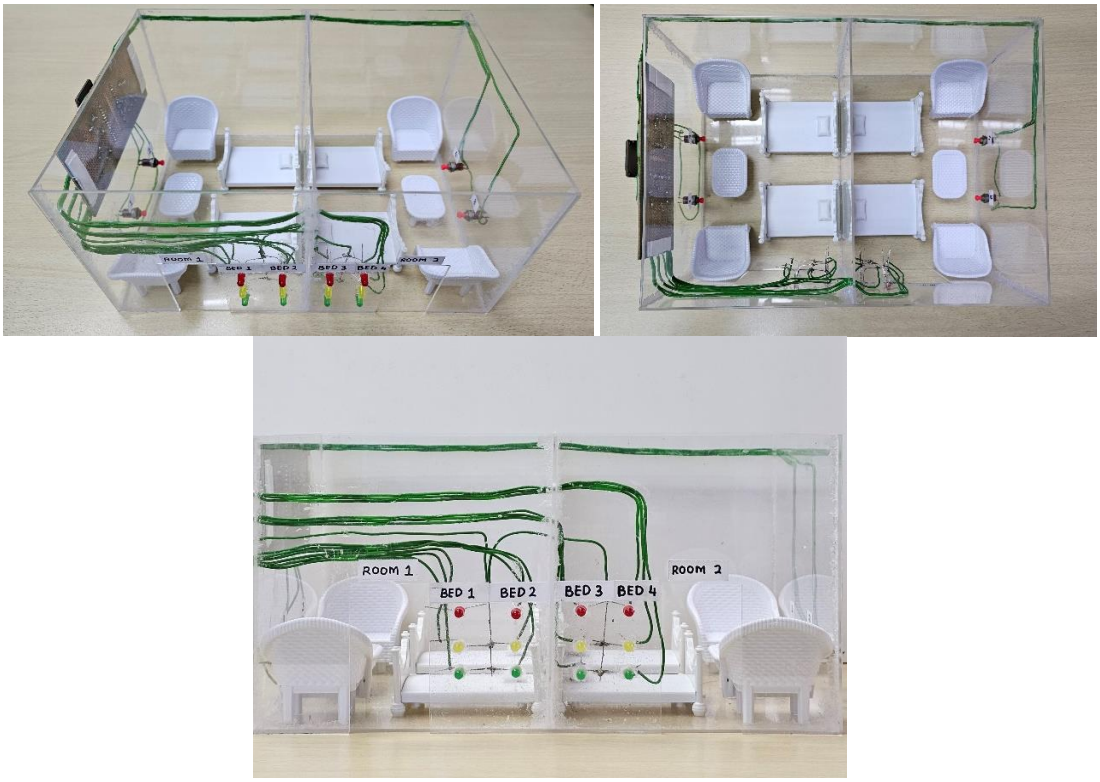

Figure 3: Scaled-down prototype

Figure 4: IoT dashboard view

By integrating sensors to detect bed occupancy and cleanliness status and using a cloud platform to manage real-time data and notifications, the system can ensure efficient communication between nursing, administrative, and cleaning staff. This approach will enhance the overall bed management process by reducing delays and improving patient flow. The results of this system's implementation and its impact on hospital efficiency will be analyzed in the next part of the study, providing a comprehensive evaluation of its effectiveness.

Results and Analysis

In this section, the time efficiency of the typical system will be compared with that of the IoT system in four situations. The focus will be on patient flow, from the moment the patient is moved to a bed until discharge. The goal of the analysis is to demonstrate that the IoT system offers better time efficiency compared to the old system.

Monitoring Bed Occupancy for Patient Transfers

In the typical system when the administrator needed to monitor bed occupancy, the administration department relied on nursing staff to manually compile a list of hospital rooms with occupied beds. This information was crucial for preparing patient transfers from the ICU, as it helped determine how many beds were available for incoming patients. However, this manual process could be time-consuming and susceptible to delays.

On the other hand, the IoT system significantly improves this process by enabling the administration department to monitor bed occupancy through a real-time IoT dashboard. The dashboard displays bed statuses using simple red or green indicators to show whether a bed is occupied or available, as shown in Figure 5 and 6. This automated system eliminates the need for manual checks and reporting, allowing administrators to efficiently track bed availability and better prepare for patient transfers from the ICU. The real-time monitoring ensures that the information is always current, enhancing decision-making and operational efficiency in the hospital.

Figure 5: Dashboard indicating occupied and available beds

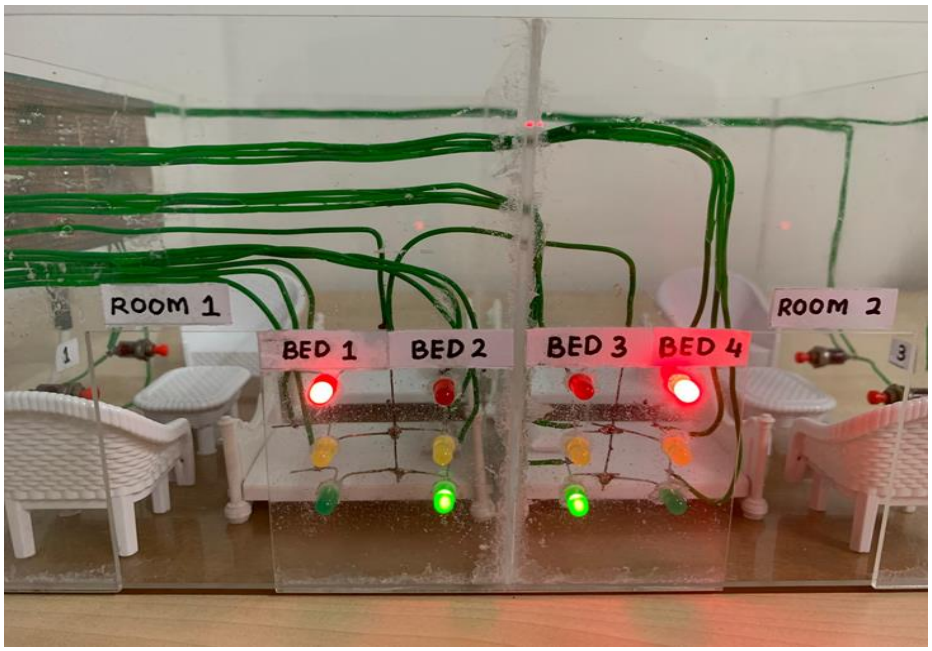

Figure 6: Prototype system indicating occupied and available beds

Transferring Patients from ICU to Normal Ward

In a typical hospital process, when patients in the ICU have stabilized and are ready to be transferred to a normal ward, the goal is to free up ICU beds for incoming critical cases. In the earlier system, the ICU department would notify the administration department of the patients ready for transfer. The administration department would then instruct the nursing staff to manually search for an available bed in the normal ward. Once the staff nurses identified an empty bed, they would relay the information back to the administration, which

would then notify the ICU department of the available rooms and bed numbers. This manual communication process often introduced delays in bed assignment.

With the IoT system, this process is more efficient. The ICU department still informs the administration of patients ready for transfer, but instead of relying on manual checks, the administration department consults the IoT system dashboard. The dashboard displays real-time bed availability using green indicators for available beds, allowing the administration to quickly identify which beds are ready to accommodate new patients, as shown in Figure 7 and 8. Once an empty bed is found, the administration department promptly informs the ICU of the available room and bed, streamlining the transfer process and reducing response time. This real-time approach minimizes delays and ensures smoother patient flow from the ICU to the normal ward.

Figure 7: Dashboard indicating available beds

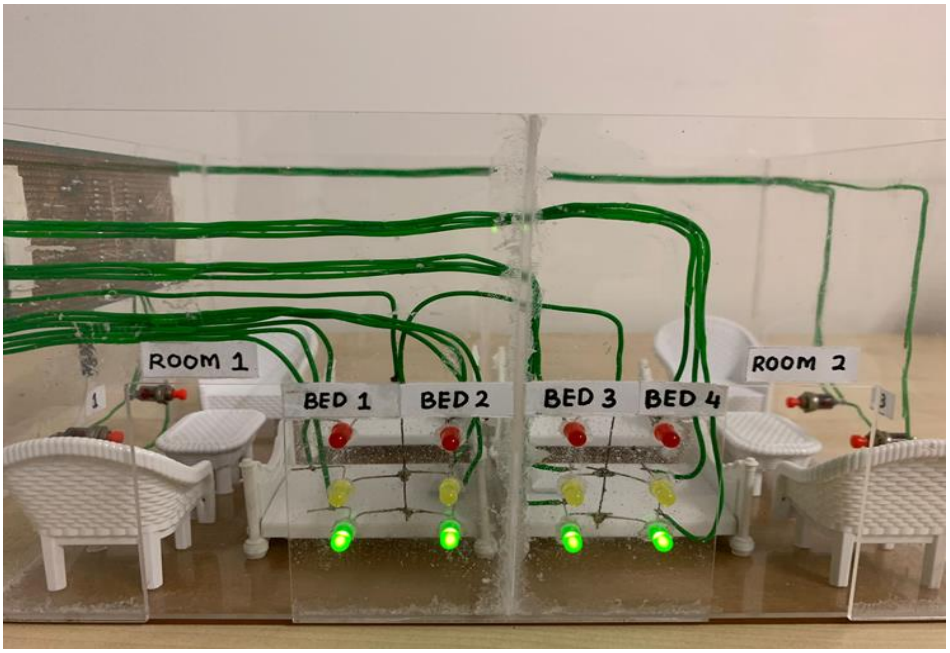

Figure 8: Prototype system indicating available beds

Bed Cleaning and Availability Post-Discharge

When a patient in the normal ward has been diagnosed in good health and receives approval from the doctor for discharge, the bed they vacate becomes empty but cannot be immediately reassigned to a new patient. In the previous system, once the patient leaves, the nursing staff manually instructs the cleaning staff to sanitize the bed. Thorough cleaning is necessary to prevent any risk of infection for future patients. This manual process, however, relies on timely communication between nurses and cleaning staff, which may cause delays in making the bed available for new admissions.

In the IoT system, once the patient leaves the bed, the nursing staff presses a button that triggers a yellow indicator light, signaling that the bed is now empty but not yet ready for use, as shown in Figure 9 and 10. This status is visible to the department admin on the IoT dashboard, who is alerted to notify the cleaning staff to sanitize the bed. This automated notification system streamlines the bed cleaning process, ensuring that the bed status is accurately tracked in real-time and the cleaning staff is alerted promptly, reducing delays and improving bed turnover efficiency.

Figure 9: Dashboard indicating beds needing cleaning

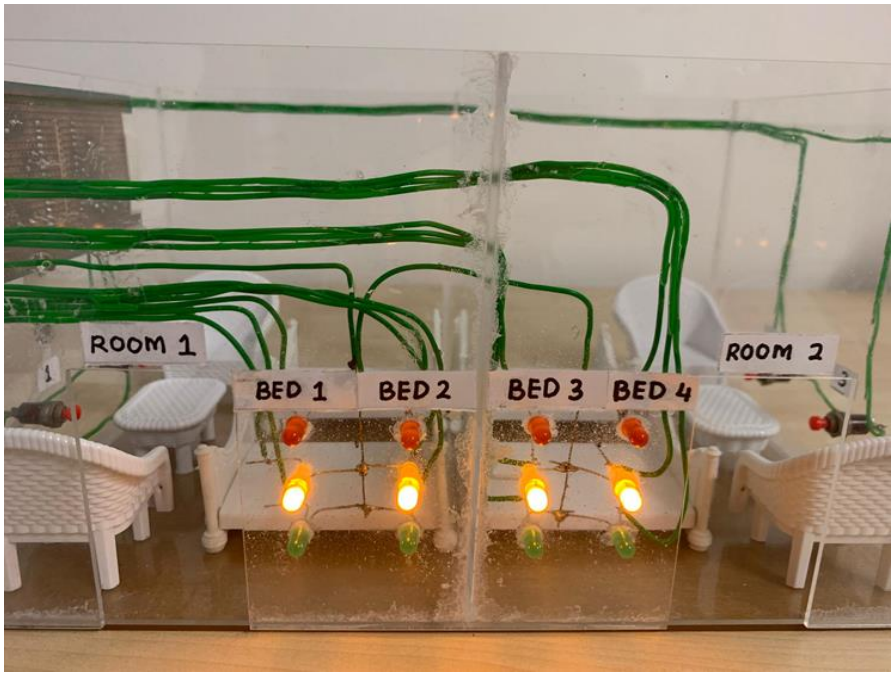

Figure 10: Prototype system indicating beds needing cleaning

Bed Readiness Notification After Cleaning

After the cleaning staff has sanitized a bed, it must be marked as ready for use by a new patient. In a typical system, the cleaning staff would manually inform the nursing staff that the bed is clean and ready. The nurses would then relay this information to the administration department, which would update their records to reflect that the bed is available for a new patient. This manual process, involving multiple steps of communication, could potentially cause delays in making the bed available for new admissions.

In the IoT system, the process is streamlined and automated. Once the cleaning is complete, the cleaning staff simply presses a button, which triggers a green indicator on the system dashboard. This green light signals in real-time that the bed is ready for use. The administration department can instantly see this status update on the IoT dashboard, eliminating the need for manual communication and ensuring the bed is made available for new patients without delay. This automation improves operational efficiency and optimizes bed turnover times.

Comparison of Time Efficiency between Systems

As shown in Table 1, the analysis of time efficiency is conducted based on the situations described in the previous section. The purpose of this comparison is to determine whether the IoT system demonstrates superior time efficiency compared to the previous system.

Table 1
Time comparison between typical and IoT systems

Situation	Typical system	IoT system	Percentage Improvement
4.1	60-120 minutes	2-5 minutes	95%
4.2	30 minutes	2-5 minutes	83%
4.3	5-10 minutes	2-5 minutes	50%
4.4	5-10 minutes	2-5 minutes	50%

In Situation 1, where bed occupancy monitoring is required, the time taken in a typical system ranged from 60 to 120 minutes, while the IoT system reduced this to 2-5 minutes, reflecting a significant 95% improvement. Situation 2 which involves transferring patients from the ICU to the normal ward shows the typical system required approximately 30 minutes to locate an available bed and complete the transfer process, whereas the IoT system reduced this time to 2-5 minutes, resulting in an 83% improvement in efficiency. In Situation 3, after a patient is discharged, the typical system required 5-10 minutes to inform the cleaning staff and track bed availability. In contrast, the IoT system reduced this process to 2-5 minutes, leading to a 50% improvement. Finally, in Situation 4, after bed cleaning, the previous system took 5-10 minutes to inform the administration that the bed was ready for the next patient. The IoT system streamlined this process to 2-5 minutes, yielding another 50% improvement in time efficiency.

These results demonstrate that the IoT system significantly enhances time efficiency across various scenarios compared to the previous manual system, ensuring faster response times and more effective bed management processes.

Conclusion and Future Work

In conclusion, the implementation of an IoT system significantly enhances time efficiency compared to the traditional manual system. The real-time monitoring and data collection capabilities of IoT streamline the process of tracking bed occupancy, reduce human errors, and enable quicker decision-making. This improvement is especially critical in high-demand areas like ICU transfers, where timely and accurate information can have a direct impact on patient care and overall hospital operations. Therefore, adopting IoT technology not only boosts operational efficiency but also contributes to better patient outcomes and more effective resource management in healthcare settings.

The future development of the IoT bed management system should focus on scalability and adaptability, ensuring it can meet the diverse needs of various hospital environments. To achieve this, the system should be designed using a modular framework, allowing for the easy addition or removal of components based on the specific requirements of each hospital. For example, plug-and-play modules for bed occupancy sensors, patient monitoring devices, and administrative tools can be integrated seamlessly, enabling hospitals to scale the system up or down without major disruptions.

Additionally, comprehensive training programs will be essential to ensure the successful adoption and utilization of the IoT system by hospital staff. These programs should be tailored to the varying roles and technical expertise of staff members. A thorough needs assessment should be conducted to identify specific training requirements for different roles within the hospital. Training content should be customized based on current proficiency levels with technology and IoT systems. The programs should introduce basic IoT concepts, demonstrate how the IoT bed management system integrates with daily hospital operations, and provide in-depth training on the system's components, functionalities, and benefits. Role-specific training modules should also be developed to focus on the particular interfaces and tasks relevant to each user's responsibilities.

Finally, improving the patient experience is a key area of focus. The development of a mobile application that provides real-time updates on bed status and wait times will greatly enhance communication, reduce patient anxiety, and improve overall satisfaction. The app should have an intuitive and user-friendly interface, making it easy for patients and their families to navigate. By integrating the app with the IoT bed management system, it can offer real-time updates on bed occupancy, expected discharge times, and bed availability. Personalized notifications can also be included, allowing users to receive updates relevant to their situation, such as when a bed becomes available or if there are changes to their waiting status.

These enhancements will ensure that the IoT system is not only efficient but also scalable, user-friendly, and capable of significantly improving both hospital operations and patient satisfaction.

Acknowledgement
This work is supported by Universiti Teknikal Malaysia Melaka (UTeM).

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