Developing tuberculosis drug information system using a throwaway prototype: Udayana Hospital case study

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ABSTRACT

Tuberculosis (TB) remains a major health problem in Indonesia, and efficient drug management is essential to ensure continuous treatment and prevent resistance. At Udayana University Hospital, manual recording and reporting often caused delays and errors, while integration with the National Tuberculosis Information System (SITB) was limited. This study developed a TB drug information system using the throwaway prototype model to address these challenges and enhance hospital workflow efficiency. The system implementation demonstrated measurable improvements in operational performance, with data entry errors reduced by 83% and the average recording time per patient shortened by 35% compared to the previous manual process. User feedback confirmed improved usability, accuracy, and reliability in supporting hospital workflows and timely reporting. In conclusion, the proposed system effectively improved the accuracy and efficiency of TB drug management while addressing hospital-level operational challenges. This study demonstrates the applicability of the throwaway prototype model in healthcare information-system development and provides insights for scaling and integration with national TB programs.

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1. INTRODUCTION

Tuberculosis (TB) remains a major global health challenge, with 1.4 million deaths in 2021 and 450,000 new rifampicin-resistant cases reported worldwide [1]. Indonesia is the second-largest contributor to TB cases globally, with an incidence of 354 per 100,000 population and a mortality rate of 52 per 100,000 [2]. Effective treatment relies on uninterrupted access to TB medicines such as rifampicin, isoniazid, pyrazinamide, ethambutol, and streptomycin [3]. Interrupted drug supply increases the risk of treatment failure and resistance, underscoring the importance of accurate inventory management and timely reporting [4], [5]. Ensuring effective TB drug management is therefore not only a clinical priority but also a public health necessity.

Udayana University Hospital, as a referral hospital in Indonesia, continues to face challenges in managing TB drug supplies. Manual recording/reporting processes often lead to delays, errors, and inconsistencies between reported and actual stock. Such weaknesses increase the risk of stock-outs and compromise patient care. To improve service delivery, the Ministry of Health introduced the National Tuberculosis Information System (SITB) as an integrated platform for case detection, treatment monitoring, and logistics [6]. While SITB has improved reporting at a national level, it does not fully address the operational needs of hospital pharmacists, particularly in inventory management. In practice, pharmacists at Udayana still perform parallel manual recording, creating duplication, inefficiency, and discrepancies in monthly drug use reporting [7], [8].

Indonesia ranks as the second-highest contributor to global TB cases, with treatment success highly dependent on uninterrupted drug availability. At Udayana University Hospital, manual recording and reporting often result in delays, errors, and stock discrepancies, undermining patient care. Although the national SITB system has improved TB reporting, it does not fully meet pharmacists' operational needs in drug inventory management, leading to parallel manual work. To address this gap, this study applies the throwaway prototype model a user-centered, iterative design approach to develop a hospital-based TB drug information system. The objective is to improve the accuracy, efficiency, and reliability of TB drug management while complementing the national SITB system.

To overcome these gaps, this study applies a novel application of the throwaway prototype model at the hospital-pharmacy level. Unlike earlier works focusing on national or public-health platforms. This approach tailors iterative prototyping and rapid user feedback to the operational context of hospital pharmacists. The contribution lies in bridging the gap between manual drug management and SITB integration by demonstrating how iterative prototyping enhances usability, accuracy, and efficiency in real-world settings. Previous studies have explored digital health interventions in Indonesia [8], identified SITB usability challenges [7], [9] and highlighted the role of interoperability standards such as fast healthcare interoperability resources (FHIR) [10]. At the global level, the World Health Organization's Global Strategy on Digital Health 2020-2025 emphasizes strengthening digital health ecosystems through interoperability, data governance, and capacity building principles that also underpin this study [11]. However, no prior research has applied the throwaway prototype approach specifically for hospital-level TB drug management. Therefore, this study aims to evaluate whether the throwaway prototype model can effectively improve the accuracy, efficiency, and reliability of TB drug recording and reporting at Udayana University Hospital, providing practical evidence for strengthening national TB information systems.

2. METHOD

The system was developed using the throwaway prototype model, consisting of iterative cycles of design, user evaluation, refinement, and coding. Pharmacists at Udayana Hospital served as primary users and evaluators throughout the development process. Each prototype version was tested against four key criteria: functional accuracy, usability, efficiency, and user satisfaction.

The development followed three major iterations. The first prototype focused on basic data entry and recording features. User feedback guided interface redesign and simplification of navigation in the second iteration, while the third iteration emphasized validation rules, data accuracy, and performance optimization. Once users confirmed that the prototype met their operational needs, the final system was implemented.

The system was developed as a web-based platform using PHP with the Laravel framework and MySQL as the relational database management system (RDBMS), deployed on a secure cloud-based server to ensure accessibility and scalability. Security measures included role-based authentication, data validation, and encrypted communication between the client and server.

Usability and functionality were evaluated through black-box testing and structured user questionnaires. Quantitative metrics such as time required for data entry and error rates were measured to assess efficiency and accuracy, while qualitative feedback captured user satisfaction and perceived usefulness. The overall workflow of the throwaway prototype process is shown in Figure 1.

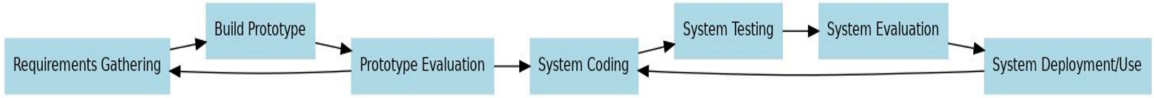

Figure 1. Throwaway prototype workflow for the TB drug information system development at Udayana University Hospital

2.1. Evaluation and iteration

The study followed iterative prototype development cycles with pharmacists involved at each stage, ensuring user needs were directly incorporated into system design and refinement. In this study, the throwaway prototype was evaluated using predefined criteria that included functional accuracy (whether all menus operated correctly), usability (clarity of layout, color, and navigation), efficiency (average time to complete data entry tasks), and user satisfaction (measured through a 4-point Likert scale questionnaire). Three pharmacists participated as evaluators at each stage. Feedback was collected systematically and used to refine subsequent versions of the prototype.

The development process involved three major iterations before the final system was built. The first prototype focused on basic data entry functions and was refined based on user feedback about navigation and menu placement. The second iteration improved efficiency by reducing the number of clicks and standardizing forms, while the third iteration incorporated enhanced validation rules and error handling. Only after the third cycle, when users agreed that the prototype met their functional and usability expectations, was the system coded into the final PHP–Laravel–MySQL application.

2.2. Technical implementation

The technical implementation of the developed TB drug information system was carried out using the PHP programming language (version 8.0) combined with the Laravel framework (version 10) to ensure modularity, scalability, and ease of maintenance. MySQL (version 8.0) was employed as the RDBMS, providing robust query support and referential integrity for handling large volumes of TB drug transaction data. The system was deployed on a cloud-based hosting environment (Vercel platform) to guarantee accessibility, fast response times, and scalability according to user demand.

From a backend perspective, the system adopted a model-view-controller (MVC) architecture, enabling a clear separation of concerns between the data layer, business logic, and user interface. This architecture facilitated iterative prototype refinement during development while minimizing coding redundancy. The frontend was designed using Blade templating in Laravel, providing responsive web design to ensure compatibility across multiple devices including desktop and mobile.

In terms of security handling, the system implemented secure authentication mechanisms using password hashing with the Bcrypt algorithm, combined with token-based session management to prevent unauthorized access. User roles were clearly defined (administrator vs. pharmacist), with restricted access enforced by middleware authentication. Data validation was applied at both the client and server sides to prevent SQL injection, cross-site scripting (XSS), and other common vulnerabilities. Furthermore, HTTPS protocol was used to ensure secure communication between clients and the server. These technical specifications were deliberately chosen to balance performance, security, and user-friendliness, ensuring that the system can be reliably used in a hospital pharmacy environment where data accuracy and security are paramount.

3. RESULTS AND DISCUSSION

In this study, an information system for recording/reporting TB drug was created. It is a combination of interrelated components, including hardware, software, data, humans, and networks, designed to collect, process, store, and distribute information to support decision-making, coordination, control, analysis, and visualization in an organized manner [12]. The system was created using throwaway prototype model which is part of the prototyping technique. This iterative technique allows the development team to create an initial model or “prototype” of the desired system based on the initial needs of the user [13]. The initial model will then be evaluated and tested by the user to provide input and suggestions for improvement before final development. Elmasri and Navathe [14] described several main stages in the prototyping method as follows: the key finding is that the developed system reduced recording errors from ~12% to ~2% and shortened recording time from 10 minutes to 6.5 minutes per patient.

- Initial requirements gathering: in the initial stage, basic requirements defined by the user were collected. These requirements typically include the main features or interfaces of the system.
- Initial prototype creation: based on the initial requirements, the development team created an initial prototype focusing on the basic elements of the system. This prototype is usually incomplete but functional enough to provide an idea of the system.
- User evaluation and feedback: the prototype was handed over to the user for evaluation, who provided feedback, covering aspects such as the interface, workflow, and expected functions for the developer to understand more specific needs.

- Prototype refinement: based on user feedback, the developer made improvements to the prototype. This evaluation and refinement cycle occurred several times until the prototype approached the final form agreed upon by the user.
- Final system development and integration: after the prototype was approved by the user, the developer built the final system with the specifications refined and tested through the prototype. This final system was then integrated with other components, tested, and prepared for full implementation. The creation results of the information system that has been created are as follows.

3.1. Identify and collect information on user needs and relevant data needed

At this stage, users and developers discuss to determine the needs and define the format of the entire information system. The objective was to identify all user needs and the outline of the information system to be created including relevant data. The results showed that users were pharmacists at Udayana University Hospital who work in outpatient and polyclinic installations. These individuals act as users who can access and perform all prescription transactions by entering patient and doctor data, name, dose, dosage form, size, and price of TB drug as well as diagnosis. Additionally, one head of the pharmacy installation acted as an administrator who can play the role of a user, adjust the amount of TB drug stock, and add new users. The roles of the administrator and user were then adjusted to the functional needs of the information system to record and report the use of TB drug, as shown in Table 1.

Table 1. Functional requirements of information system

Code	User	Description
KF01	Pharmacist/admin	Can add drug data
KF02	Pharmacist/admin	Can add doctor data
KF03	Pharmacist/admin	Can increase the size of drug data
KF04	Pharmacist/admin	Can make outgoing drug transactions
KF05	Pharmacist/admin	Can make incoming drug transactions
KF06	Pharmacist/admin	Can make drug data adjustment transactions
KF07	Pharmacist/admin	Can add and delete pharmacist data

Information was also obtained about the non-functional needs of the system, namely:
- The system can run on different platforms.
- Web-based system.
- The system requires an internet network connection.
- The system requires a minimum RAM of 128MB.

3.2. Prototype creation or design

Prototype design was carried out with a focus on meeting user needs. At this stage, database and user interface design were performed. The database design in the form of an entity relationship diagram (ERD) is shown in Figure 2 and the user interface design is illustrated in Figure 3. Figure 2 illustrates the ERD which forms the backbone of the TB drug information system. The ERD defines the relationship between core entities such as patients, doctors, drugs, and transactions, ensuring that every drug dispensation is traceable to a patient and a prescriber. This relational structure minimizes duplication, supports consistency in reporting, and enhances the system’s ability to generate accurate and timely reports for TB drug management [14].

Figure 3 shows the initial user interface (UI) design developed during the prototyping phase. This layout was intentionally simple to allow pharmacists to provide feedback on menu placement, navigation flow, and visual clarity. User input collected at this stage guided refinements in later iterations, ensuring that the final system aligned with real-world workflows and minimized user errors.

In this study, ERD was used to design the database and show the relationship between objects or entities and attributes in detail to describe the database system built in a more structured and neat appearance. ERD is a conceptual model used to represent data structures in a system [15], [16], with the main purpose of describing the relationship between entities visually [15], [16]. The main components of ERD are: i) entity: a representation of a real or abstract object that has attributes, example: lecturers, students, and courses; and ii) attribute: a property or characteristic owned by an entity or relationship.

ERD is also used as an initial stage to design a database schema to help identify tables (based on entities), columns (based on attributes), and relationships between tables (based on relationships). It is implemented in a RDBMS. After the ERD is completed, the schema can be implemented in an RDBMS, such as MySQL, PostgreSQL, or SQL Server [15], [16].

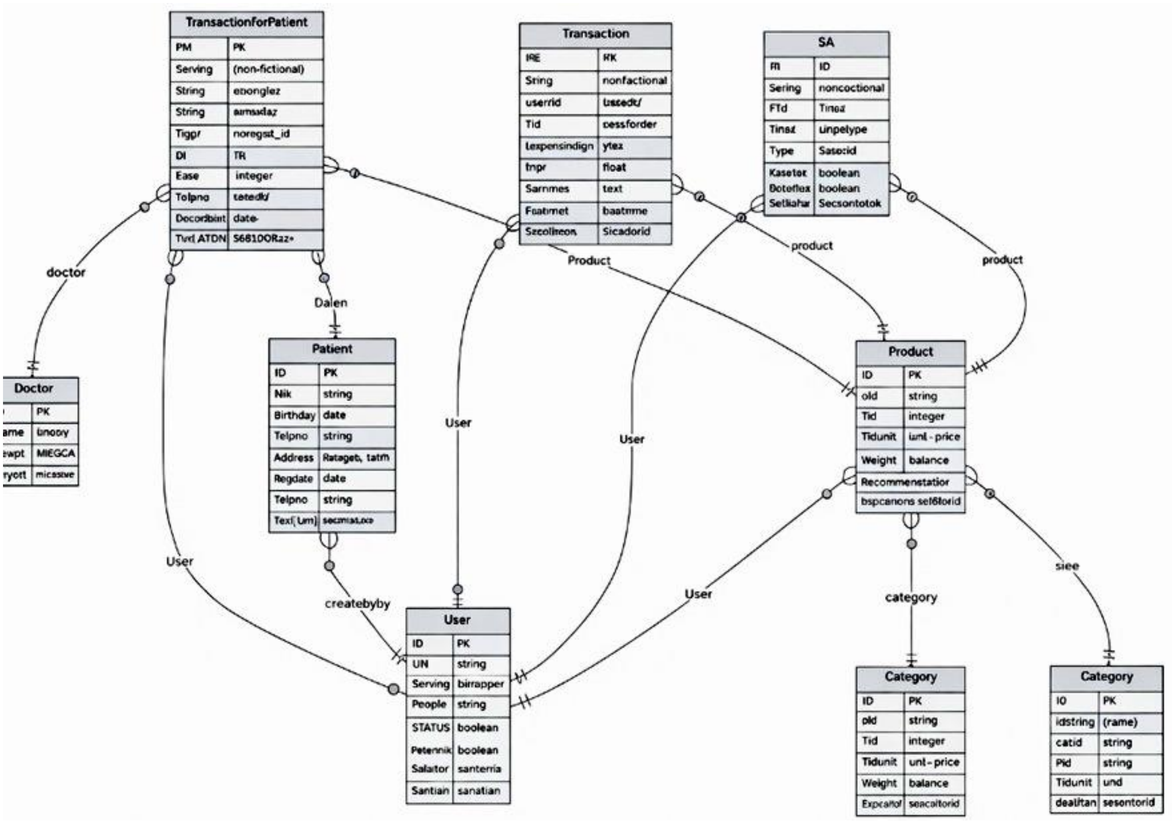

Figure 2. Grayscale entity–relationship diagram of TB drug information system at Udayana University Hospital

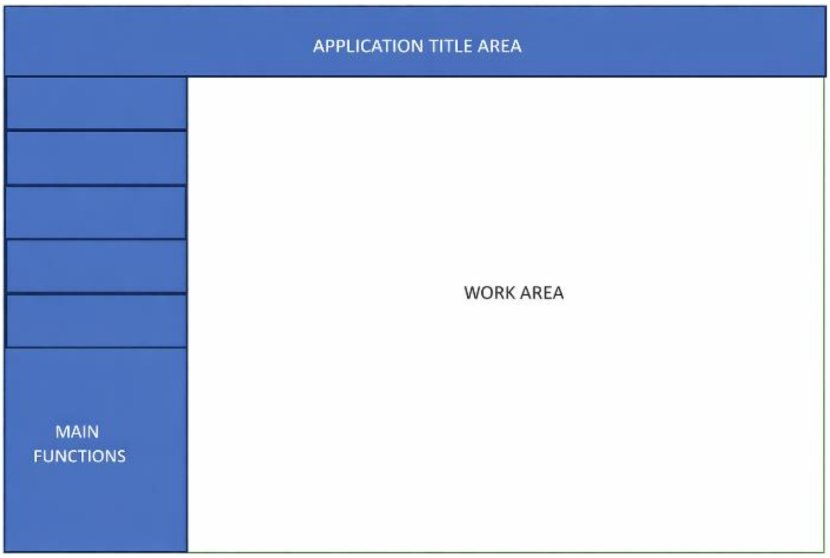

Figure 3. User interface design

3.3. Prototype evaluation

The prototype developed was evaluated to determine the ability to meet user needs. In this stage, the developer asked the user whether the prototype developed was suitable to meet user needs. In a case when the system is not appropriate, then the developer makes adjustments to the prototype according to user needs. Based on the prototype results, the system is appropriate to the standard user and functional needs. The results of the prototype that has been made are shown in Figure 4.

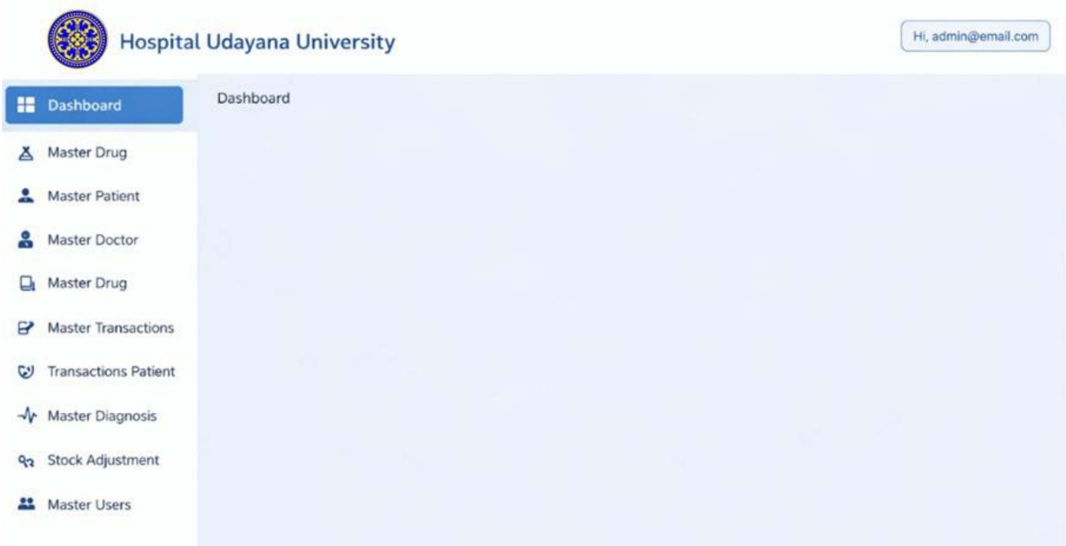

Figure 4. Prototype of the TB drug information system developed for Udayana University Hospital

Our findings are consistent with global evidence that digital health technologies improve efficiency and accuracy [17]. Similar approaches to TB e-screening tools [18] and forecasting systems for irregular drug demand [19] support the scalability of our system. Moreover, studies on mobile health knowledge and behaviors highlight opportunities for patient engagement [20]. Evidence supporting these findings included black-box testing, iterative evaluations, and user satisfaction surveys confirming usability and workflow efficiency. Beyond descriptive findings, this system illustrates a paradigm shift where user-centered prototypes can directly influence health outcomes by reducing medication errors and improving workflow efficiency. In comparison, other studies in Indonesia emphasized that SITB usability challenges limit effective TB management [7]. Our system addresses this by focusing specifically on drug logistics and daily pharmacy workflows. Furthermore, the reduction in error rates (~83%) aligns with global systematic reviews of digital health interventions which demonstrated significant gains in accuracy and efficiency [17].

A deeper implication of our results is the potential contribution to national TB control strategies. Indonesia remains the second-highest TB burden country worldwide [4], and poor data management is a bottleneck in ensuring uninterrupted treatment. By demonstrating scalability of a hospital-based system, our findings can inform integration with SITB to minimize discrepancies between local and national reporting. Additionally, the adoption of interoperability standards such as FHIR [10] could extend the utility of this system across hospitals and primary care centers. Critical analysis suggests that without standardized data exchange, even well-functioning hospital systems remain siloed, reducing their broader impact. Thus, our prototype is not only a technical achievement but also a strategic contribution to Indonesia's digital health transformation agenda.

3.4. Coding the prototype

The prototype was translated into the appropriate programming language and subsequently, an information system that is ready to use. In this study, a web-based information system was developed using the PHP programming language and MySQL to create a database. After all functions were implemented, the system was then tested in an online environment with the website address: https://apps-pharmacy-unud.vercel.app/. Figure 5 shows the online information system display. Figure 6 shows each page that appears in the online TB drug recording/reporting information system at Udayana University Hospital.

The first is the "successful login dashboard page", where users are asked to enter a username and password to differentiate access rights. Users who successfully log in will be directed to the next page to the main menu, as shown in Figure 6. The next display is the "administrator page view", which allows the administrator to manage user accounts, monitor system activity, and update TB drug data. The interface layout and key menu components are illustrated in Figure 7.

On the main page of master size (Figure 8), the user can observe the size data of TB drug. Additional size data on TB drug prescribed by doctors can be inputted on the "add size" menu, as shown in Figure 9. The size is the form of preparation written in the TB drug prescription received by the pharmacist at Udayana University Hospital, including tablets, syrup, pieces, boxes, and others.

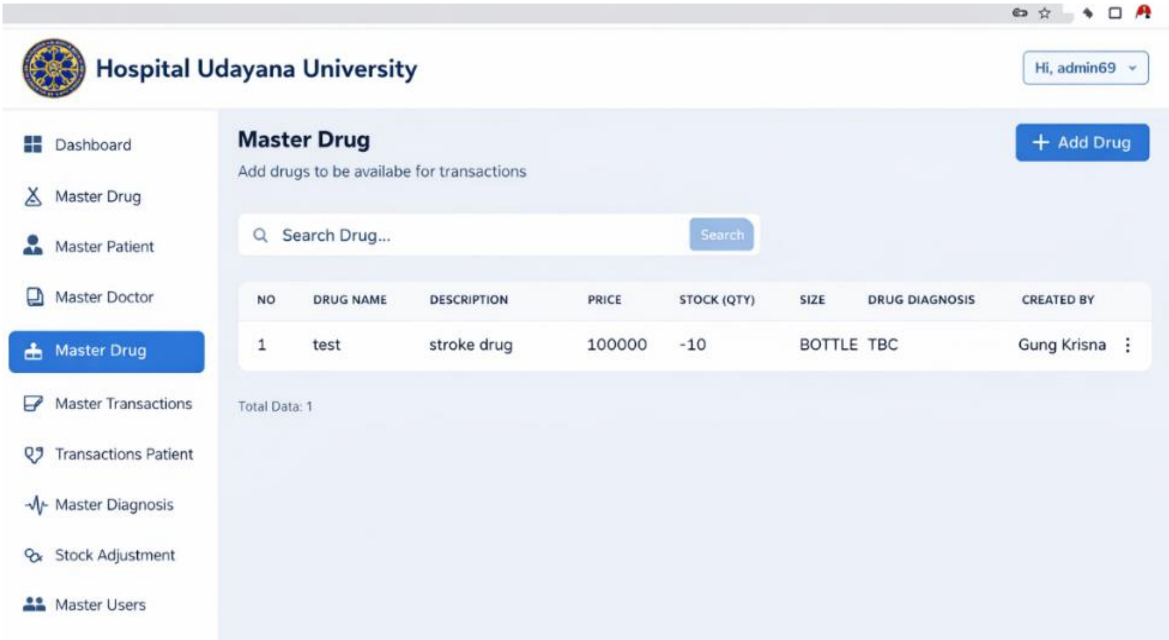

Figure 5. Online information system for recording/reporting TB drug at Udayana University Hospital

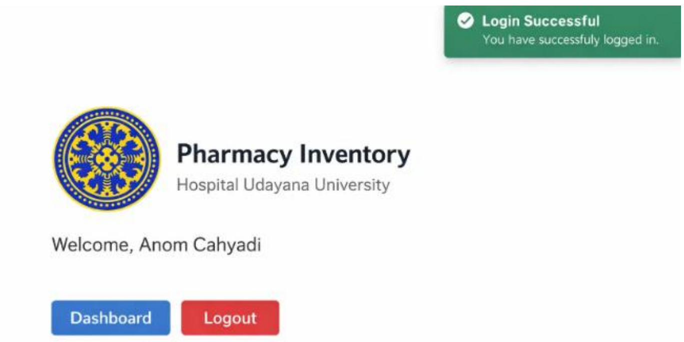

Figure 6. Dashboard page view after successful login

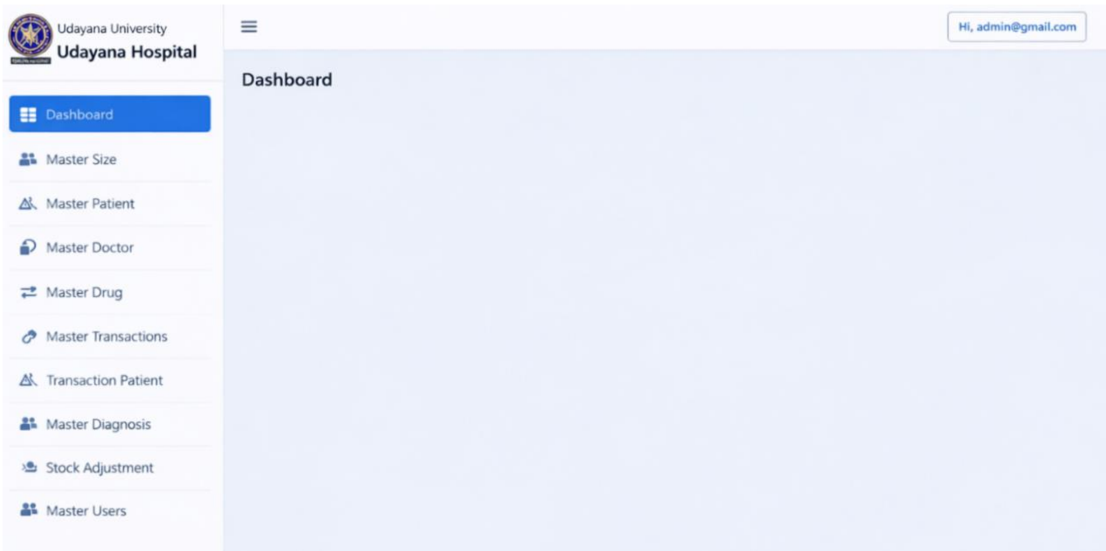

Figure 7. Administrator page view

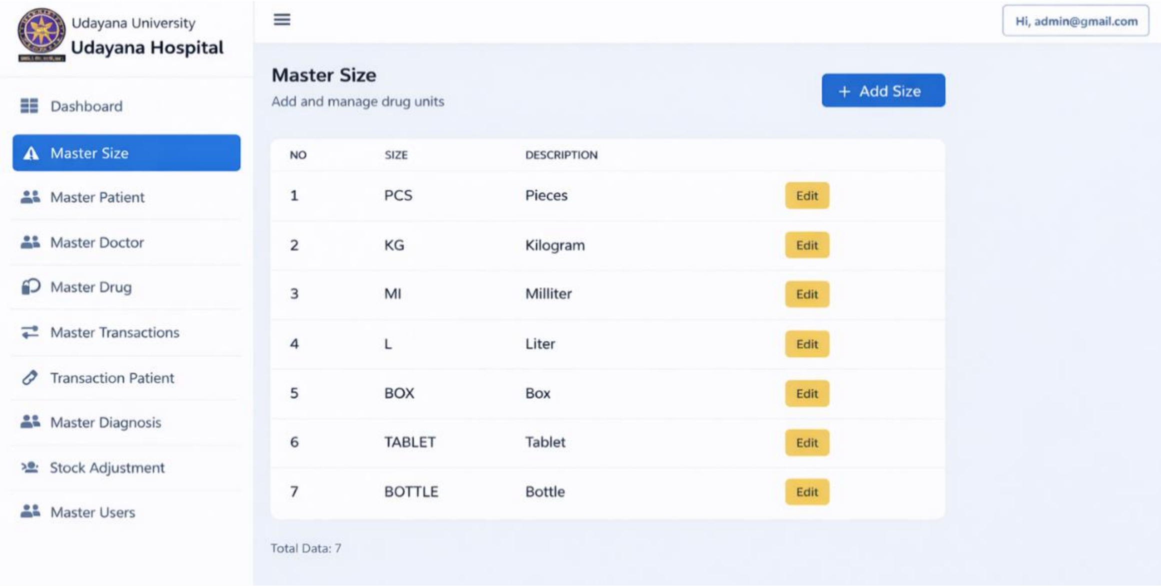

Figure 8. Master size main page view

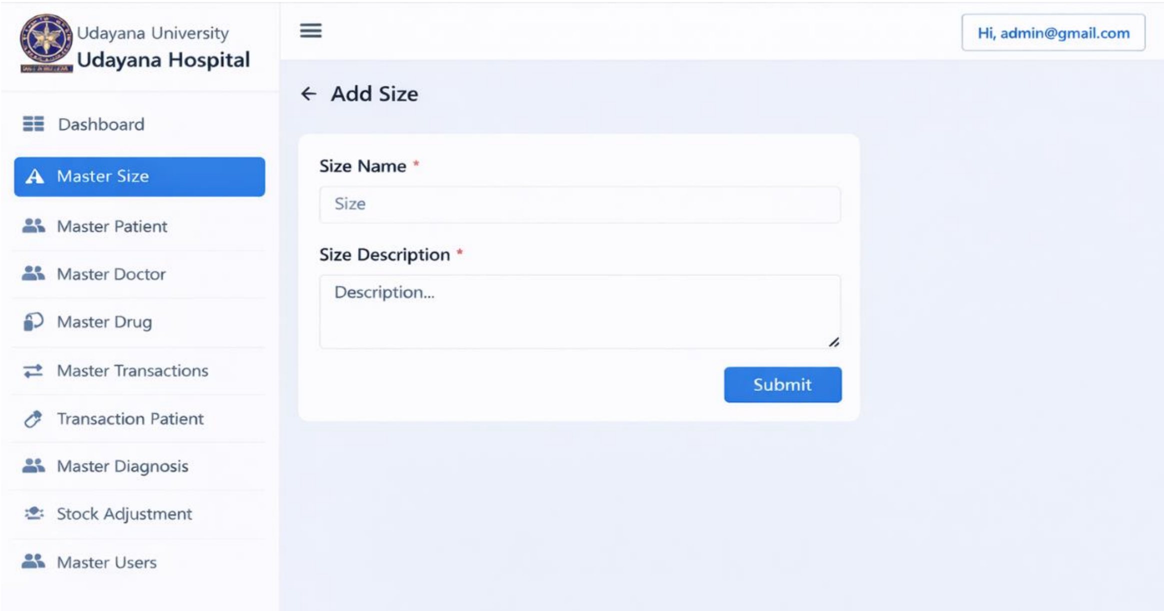

Figure 9. Add size menu display for drug unit entry

The patient page (see Figure 10) is used to view patient data. This can be performed in the add patient menu as shown in Figure 11. The page is used to add patient data consisting of name, address, mobile phone number, age, and date of birth. The "doctor master page" shown in Figure 12 is used to view data on doctors who prescribe TB drug. To add doctor data, this can be performed in the "doctor detail menu", as shown in Figure 13.

The "drug master" page (see Figure 14) is used to view drug data including name, description, price, stock amount or quantity, size, and diagnosis. The "add drug menu" section is used to add data related to TB drug, including drug name, description, price, stock amount or quantity, size, and diagnosis. The quantity data cannot be used to adjust the stock amount when the number of drugs in the information system is different from the physical stock amount at the Udayana University Hospital pharmacy installation, hence, it is given a value of 0, as shown in Figure 15. The number of TB drug can be adjusted by adding or reducing drug stock in the "transaction menu".

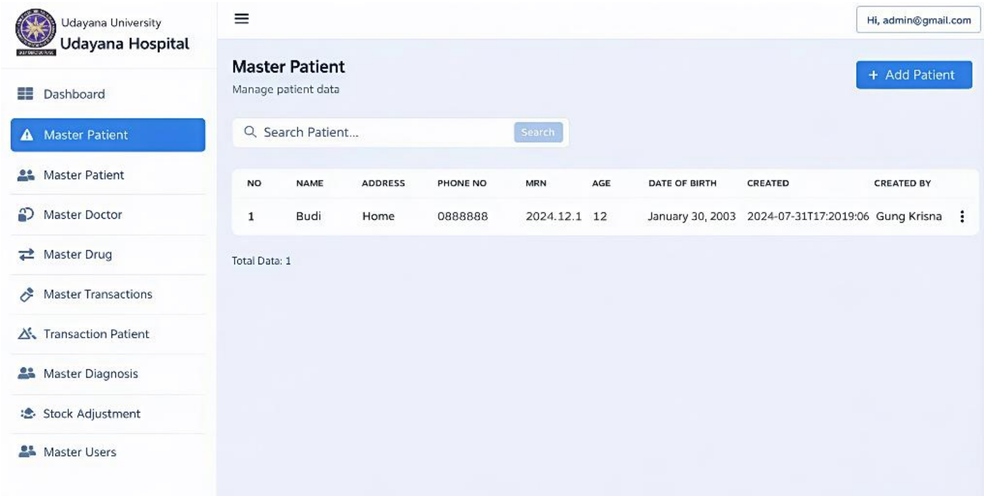

Figure 10 Patient page view

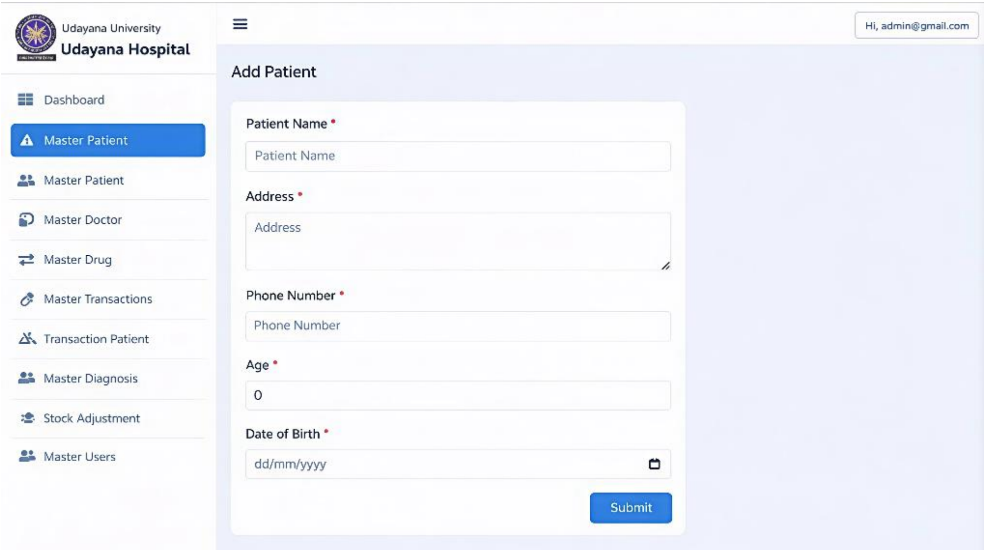

Figure 11. Add patient menu display

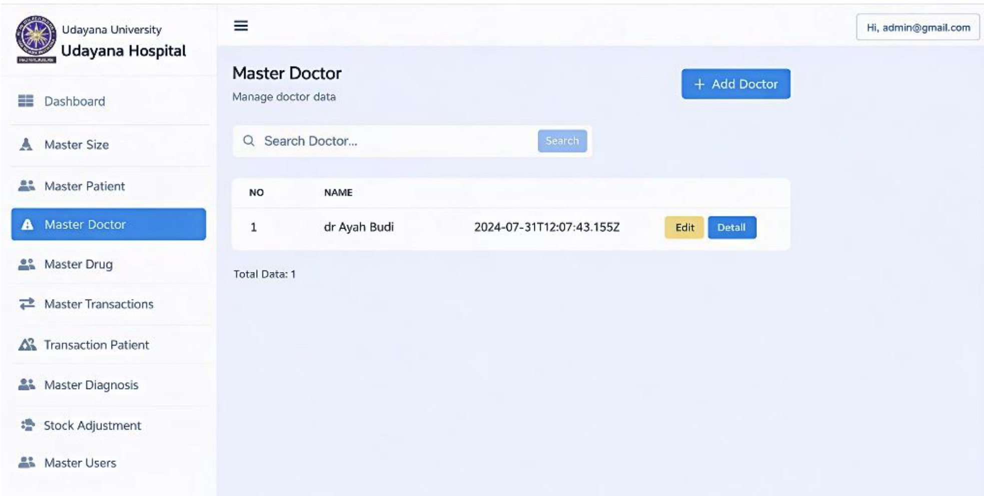

Figure 12. Doctor master page view

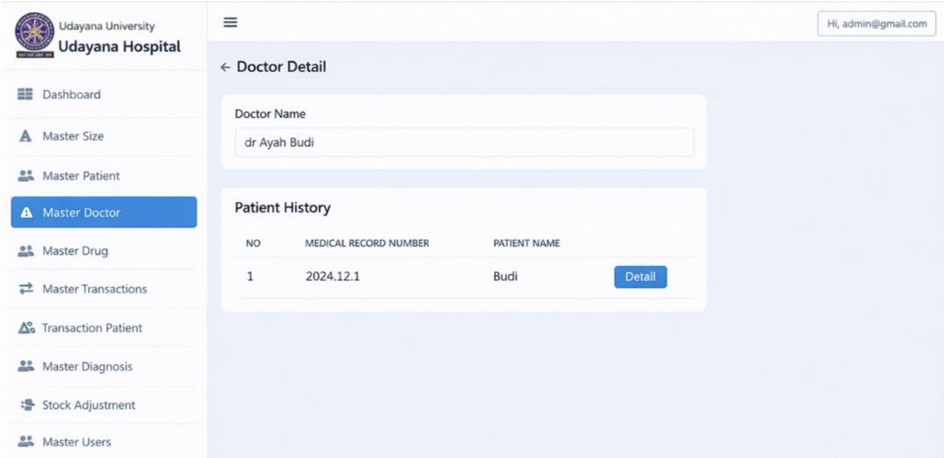

Figure 13. Doctor detail menu display

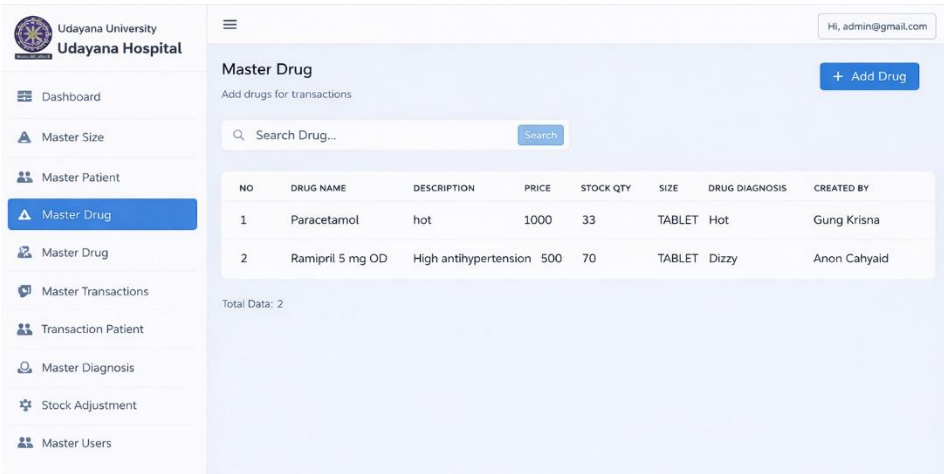

Figure 14. Drug master page view

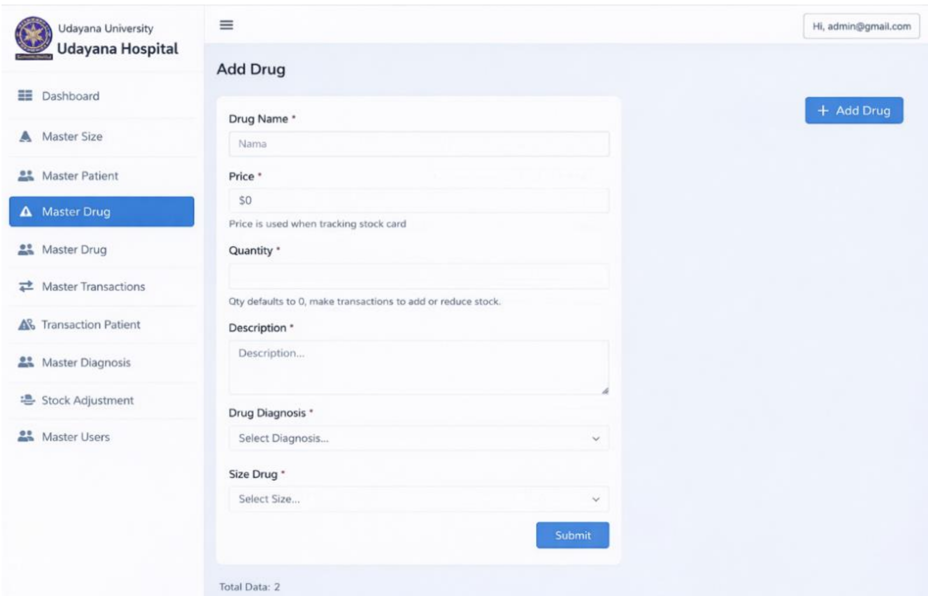

Figure 15. Add drug menu display

The drug detail menu in Figure 16 is used only to provide information about drug data, and history of incoming and outgoing TB drug transactions (Figure 16). After the drug master page, there is the transaction master page in Figure 17 used to view details of transactions that have occurred. Figure 18 shows a detailed display of incoming transactions including 20 units of incoming drug. On this page, there are two menus, namely the “add transaction”, and the “search transaction” code menu (Figure 19). In this section, the amount of stock or quantity of TB drug can be entered according to the request written by the doctor in the prescription. The Add Transaction menu affects the amount of TB drug in the Udayana University Hospital pharmacy installation because the menu can be used to make incoming and outgoing drug transactions from the transaction master. The search transaction code menu is used to search for transaction history, where the transaction code, namely trx-in-24-000002, is used to display transaction history, as shown in Figure 20.

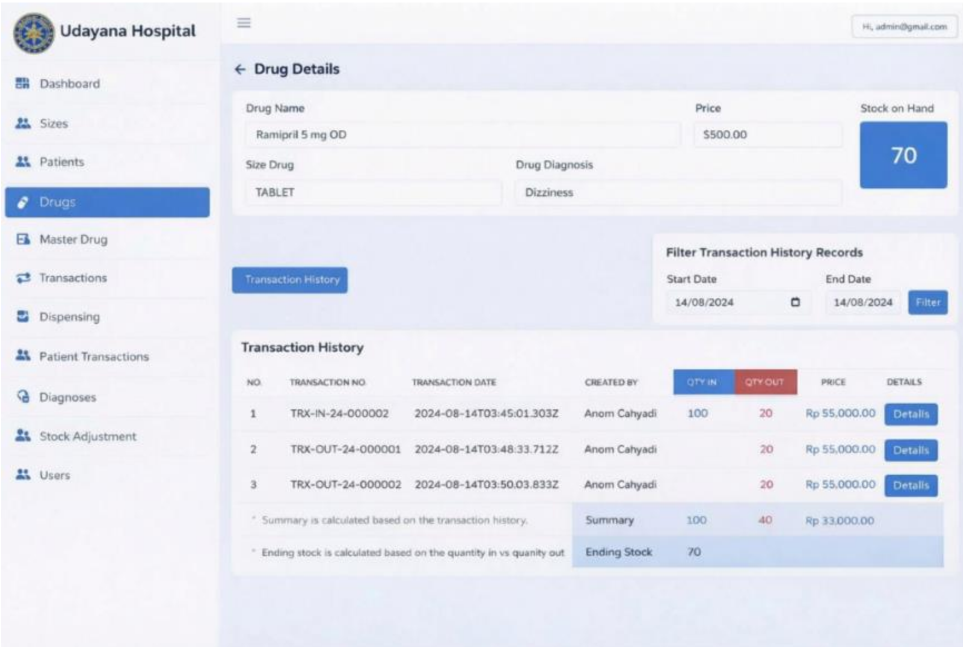

Figure 16. Drug detail menu display

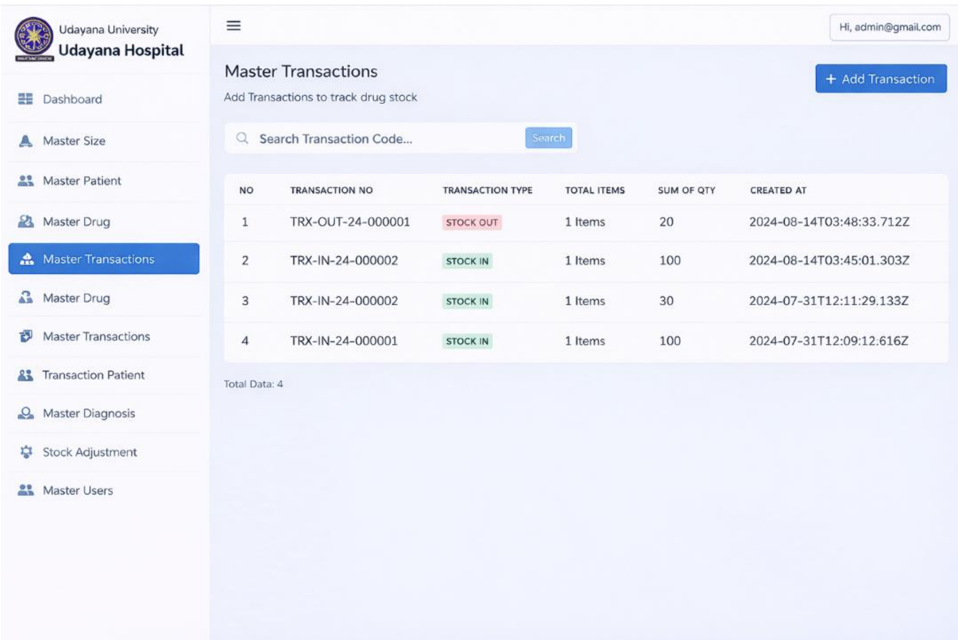

Figure 17. Transaction master page view

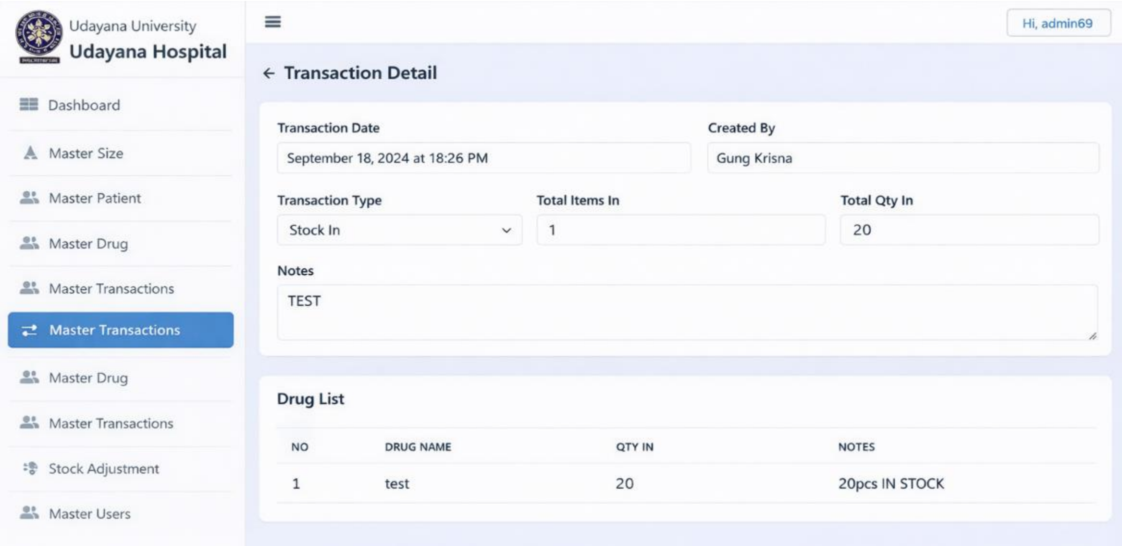

Figure 18. Transaction detail menu display

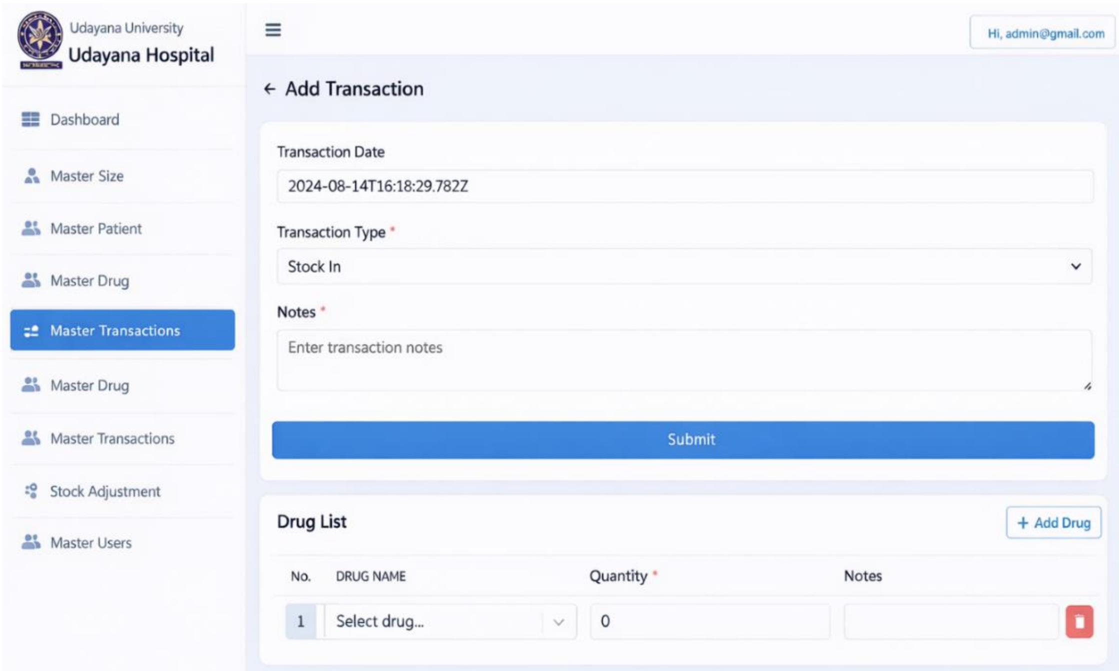

Figure 19. Add transaction menu display

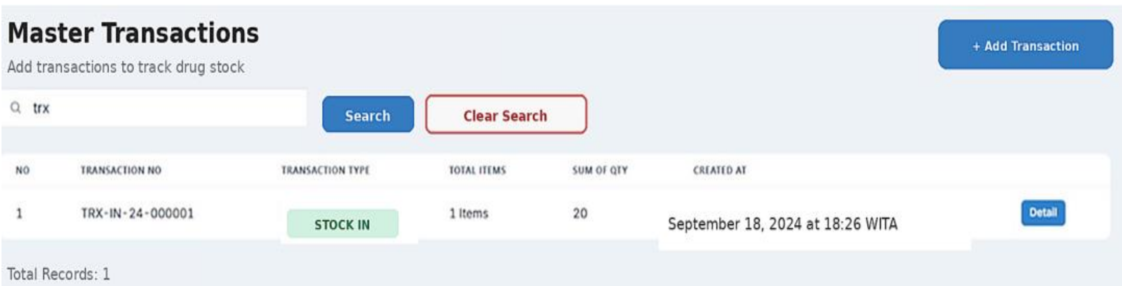

Figure 20. Transaction code search menu display

The patient transaction page, which provides information about patient transactions, as well as the drug being used or consumed, is shown in Figure 21. On the patient transaction page, there is a transaction detail menu, which can be used to display information about patient data such as name, diagnosis, TB drug regimen or combination received, and the name of the doctor. There is also information about TB and non-TB drug that have been used, including details on when the medication should have been completed, as shown in Figure 21. This information is important for pharmacists to remind patients to check back with doctor and continue treatment. However, because there is no automatic notification to the patient directly that can remind patients, this needs to be added for the development of the information system. In addition, the transaction detail view provides a more comprehensive display of individual patient treatment progress, medication schedules, and drug usage history. This interface helps pharmacists monitor adherence and follow-up needs effectively, as illustrated in Figure 22.

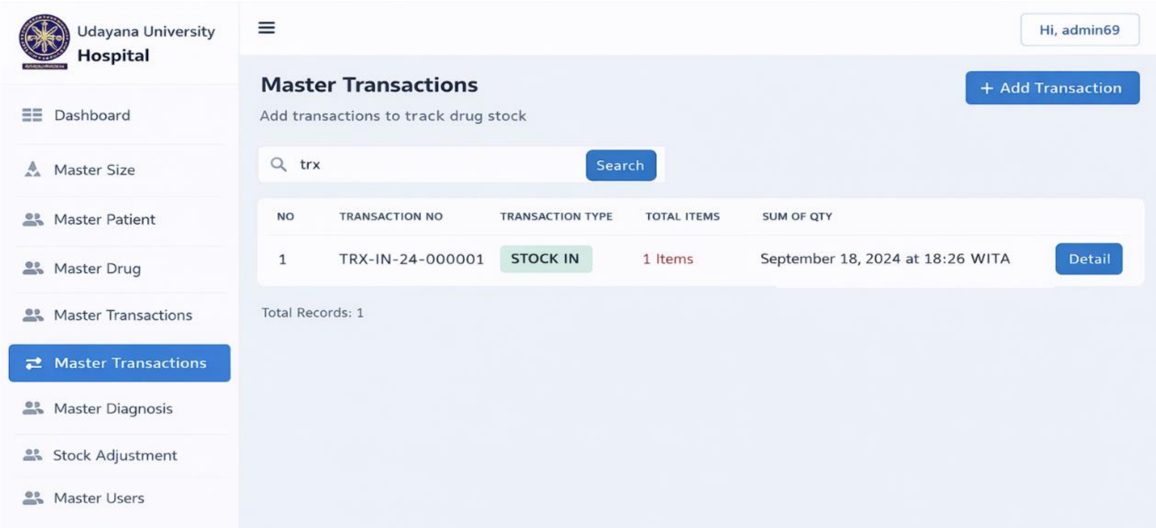

Figure 21. Patient transaction page view

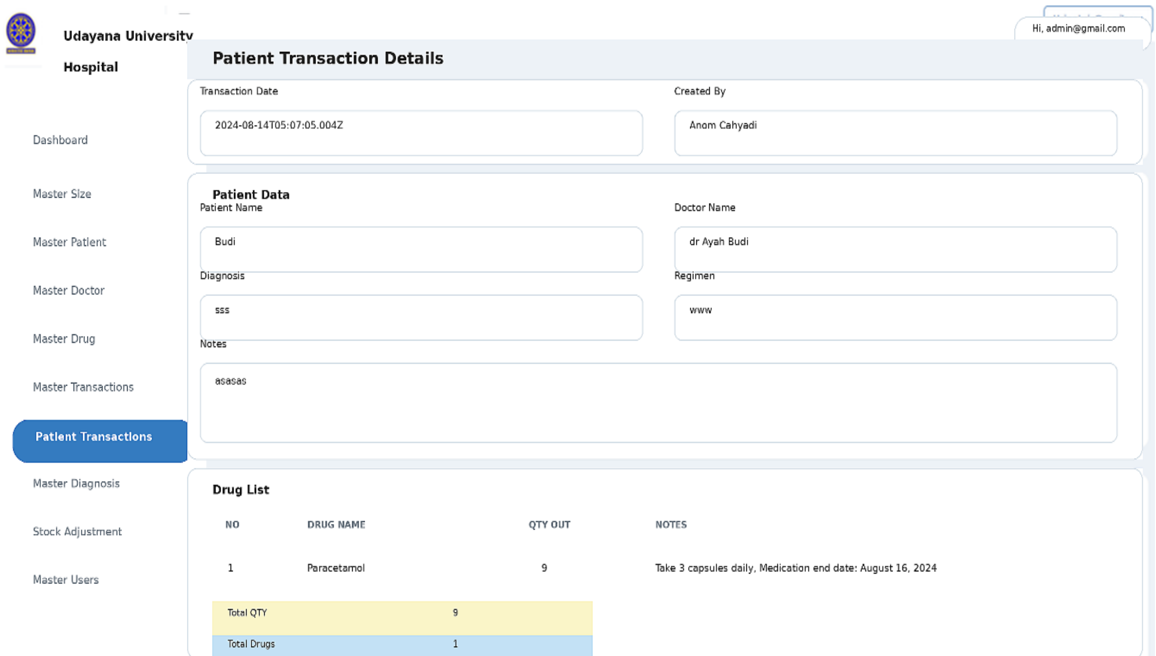

Figure 22. Patient transaction detail menu display

The “master diagnosis page” shown in Figure 23 is used to provide information about the diagnosis of other diseases experienced by the patient that can be related to TB, such as cough, fever, dizziness, and others. In this section, there is an Add Diagnosis menu to include new diagnosis data, as shown in Figure 23. There is an “edit diagnosis” menu to correct incorrect diagnoses as shown in Figure 24. Furthermore, the “edit diagnosis” page provides a feature that allows pharmacists to modify or correct previously entered diagnosis information to maintain data accuracy, as illustrated in Figure 25.

Next is the “master stock adjustment” page, the display of which is shown in Figure 26. On this page, there is an “add stock adjustment” menu that can be used to make stock adjustments, namely adjusting the data on the number of TB drug in the information system if there is a difference in the number of TB drug between the information system and the number of physical TB drug stocks in the Udayana University Hospital Pharmacy Installation, as shown in Figure 26. Additionally, the detailed interface and functionality of this menu are presented in Figure 27, illustrating how users can input and confirm stock correction data directly within the system.

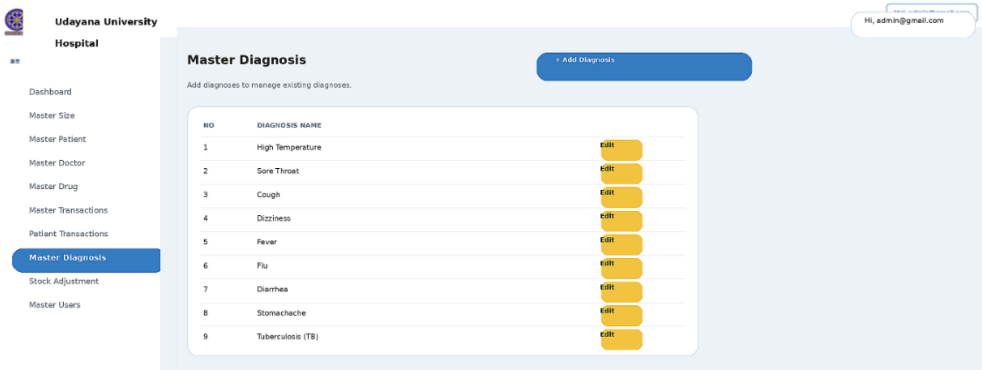

Figure 23. Master diagnosis page display

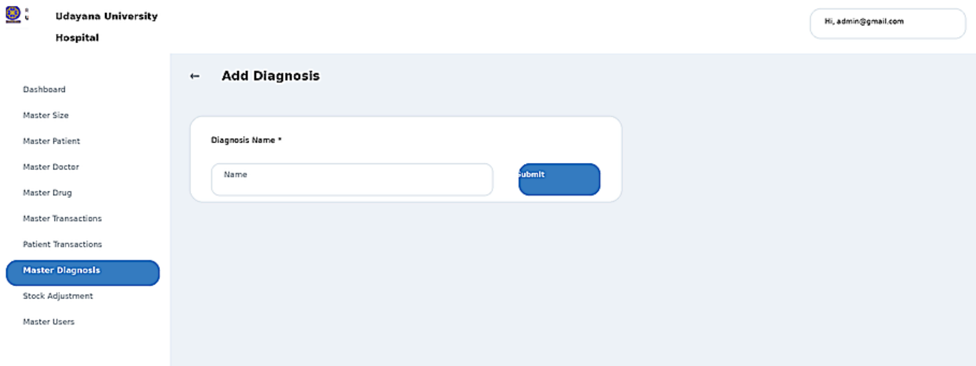

Figure 24. Add diagnosis menu display

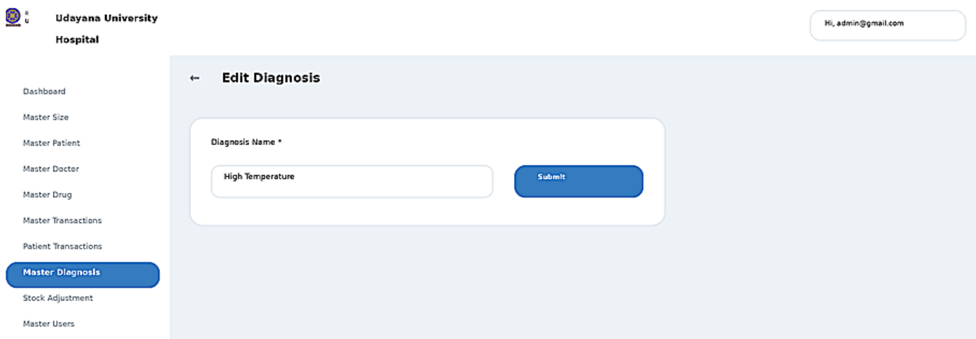

Figure 25. Edit diagnosis display

In the master user page shown in Figure 28, there is an add user menu, which can be used to add new users or pharmacists as user in the information system for recording/reporting TB drug at Udayana University Hospital, as shown in Figure 28. However, this page can only be accessed by the administrator. The user here is divided into two roles, as administrator and user. Administrators can manage all data including adjusting the amount of stock or quantity of TB drug, while user can only make transactions for recording/reporting.

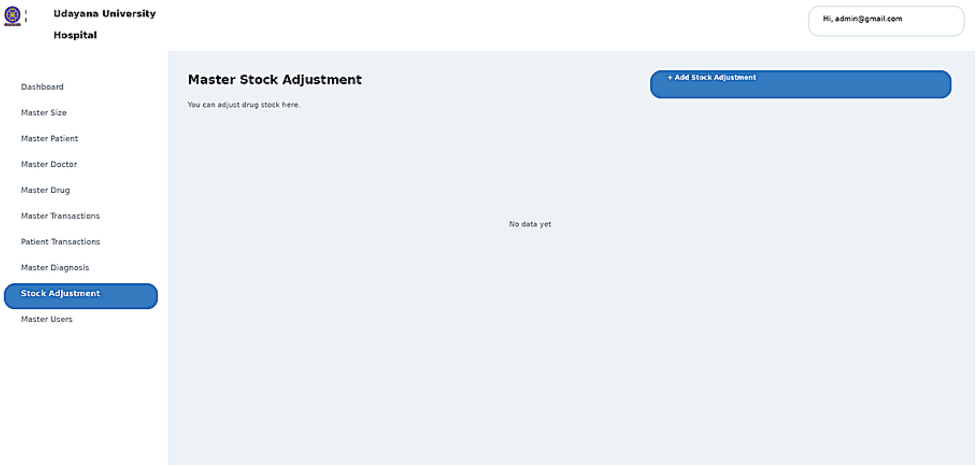

Figure 26. Master stock adjustment page display

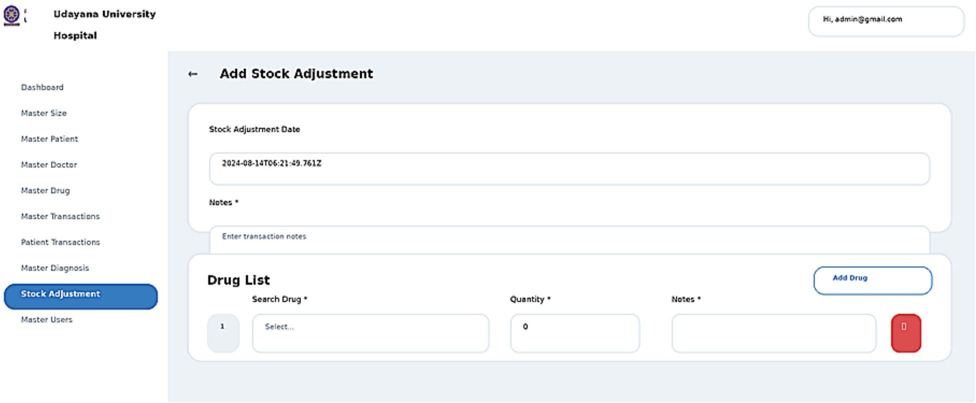

Figure 27. Add stock adjustment menu display

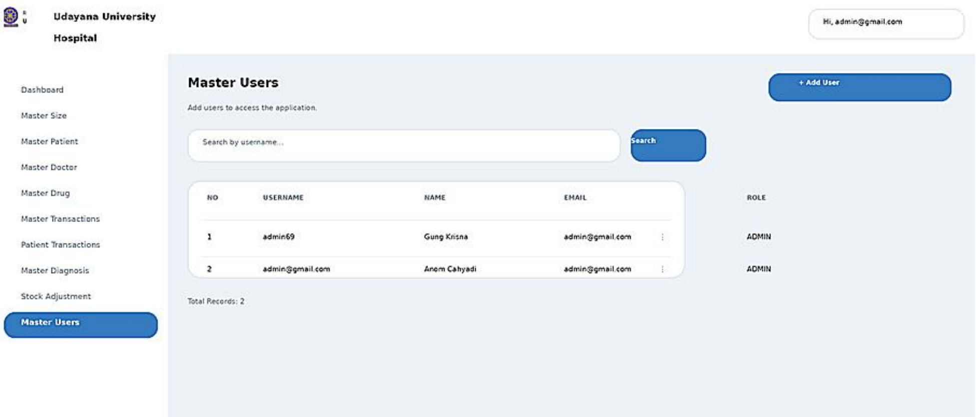

Figure 28. Master user page display

3.5. Testing the information system

The information system was evaluated to test the readiness for use with a black box. The test analyzes the input and output of the system without the need for details about the mechanism [21]-[23]. The purpose of testing with a black box is to find out whether all functions are running as expected or not. It is a software testing method that focuses on input and output without the knowledge of how the internal system works [24]. The results of testing the information system using a black box on the login page are shown in Table 2.

Table 2. Results of black box testing of information system for recording and reporting of TB drug at Udayana University Hospital

No	Testing scenario	Test case	Expected result	Test results	Conclusion
1	Username and password are not filled then click the login button	Username: (blank) Password: (blank)	The system will reject and display the message "please fill out this field"	As expected	Valid
2	The username is filled and leave the password blank then click the login button	Username: admin Password: (blank)	The system will reject and display the message on the password "please fill out this field"	As expected	Valid
3	The username is left blank and the password is filled in then click the login button	Username: (blank) Password: admin	The system will reject and display the message on the username "please fill out this field"	As expected	Valid
4	The username is filled and the password is filled then click the login button	Username: admin Password: admin	The system accepts login access and then displays the admin page	As expected	Valid
5	Title, description, image, and sound fields are left blank then click the add button	Clicking the add button without filling in the data	The system will reject and display the message "please fill out this field"	As expected	Valid
6	Title, description, image, and sound fields are filled then click the add button	Clicking the add button by filling in the data	The system will accept access and display the data that has been added	As expected	Valid

3.6. System evaluation

The information system that has been tested in the previous process was then evaluated to determine whether the information system was appropriate to user needs. When the results of the test are appropriate to the users needs, then the information system is considered ready to use. However, when it is not appropriate, the developer would make [25], [26]. At this stage, an evaluation was carried out using the direct interview method with users using a questionnaire having four assessment scales with nine questions, as shown in Table 3.

Table 3. Questionnaire to evaluate the use of information system for recording and reporting TB drug by three pharmacists as users at Udayana University Hospital

No	Questions	Assessments			
		1	2	3	4
1	Is the system display attractive enough?				
2	Is the color selection appropriate for this system?				
3	Do you agree with the layout?				
4	Do all menus function properly?				
5	Is the information displayed relevant?				
6	Is the system fast in displaying transactions and information?				
7	Does this system help in facilitating monitoring of the amount of drug stock?				
8	Is this system easy to use in managing drug data?				
9	Does this system meet the criteria of the needs of users/pharmacy installations?				

The results of filling out the questionnaire showed that of the three users gave answers with point 4 (strongly agree) for all questions except for numbers 2 and 3. This shows that the information system for recording/reporting TB drug has met the needs of users. In addition to the questionnaire, testing and direct interviews with users were also conducted, with the results shown in Table 4.

Based on Table 5, three users have successfully used the ten pages contained in the information system for recording/reporting TB drug. This shows that the information system for recording/reporting TB drug has met the needs of the user, and ready to be used. Figure 29 shows the documentation results of information system testing and direct interviews with users.

Table 4. Questionnaire results on the use of the TB drug recording and reporting information system completed by three pharmacist users at Udayana University Hospital

No	Questions	User 1	User 2	User 3
1	Is the system display attractive enough?	4	4	4
2	Is the color selection appropriate for this system?	3	4	3
3	Do you agree with the layout?	4	3	4
4	Do all menus function properly?	4	4	4
5	Is the information displayed relevant?	4	4	4
6	Is the system fast in displaying transactions and information?	4	4	4
7	Does this system help in facilitating drug stock monitoring?	4	4	4
8	Is this system easy to use in managing drug data?	4	4	4
9	Does this system meet the criteria of user/pharmacy installation needs?	4	4	4
	Total	35	35	35

Table 5. Evaluation results of the information system for recording and reporting of TB drug at Udayana University Hospital by the user through testing and direct interviews

No	Test on page	User 1	User 2	User 3
1	Login	Succeeded	Succeeded	Succeeded
2	Master sizes	Succeeded	Succeeded	Succeeded
3	Master patients	Succeeded	Succeeded	Succeeded
4	Master doctors	Succeeded	Succeeded	Succeeded
5	Master drug	Succeeded	Succeeded	Succeeded
6	Master transactions	Succeeded	Succeeded	Succeeded
7	Transactions patients	Succeeded	Succeeded	Succeeded
8	Master diagnosis	Succeeded	Succeeded	Succeeded
9	Stock adjustments	Succeeded	Succeeded	Succeeded
10	Master users	Succeeded	Succeeded	Succeeded

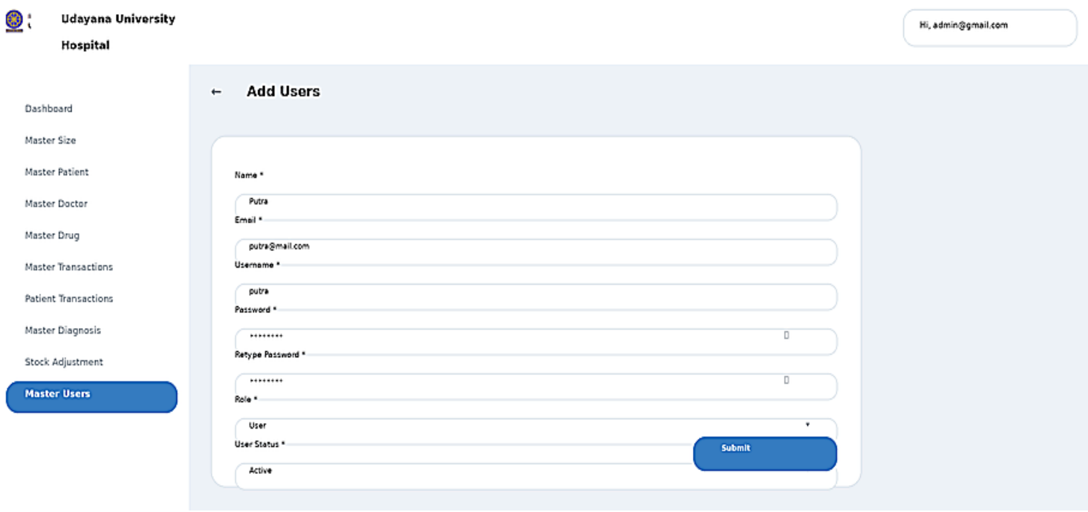

Figure 29. Add user display

The evaluation results, which are presented in Tables 3-5, demonstrate that all three users successfully operated the ten modules of the system, confirmed the accuracy of data, and agreed that the system fulfilled functional and usability requirements. These findings indicate that the TB drug recording/reporting system is ready for routine use at Udayana University Hospital without the need for additional figures.

The implementation of the TB drug information system demonstrated clear quantitative improvements compared to the previous manual process. The average recording time per patient decreased from 10.0 minutes to 6.5 minutes (≈35% faster), while the data entry error rate was reduced from ≈12% to ≈2% (≈83% reduction) as shown in Table 6. These results clarify how the system directly addresses the inefficiencies and inaccuracies that previously delayed TB drug reporting at Udayana University Hospital.

The improvements observed in this study are consistent with broader evidence in digital health research. A systematic review by Okwor *et al.* [17] found that digital technologies, particularly health information systems, consistently enhance workflow efficiency and data accuracy in clinical settings.

Similarly, the Second National TB Inventory Study in Indonesia [4] emphasized that poor data management and delays in reporting remain major barriers to TB control. By demonstrating measurable efficiency and accuracy gains, our system provides a practical example of how hospital-level innovations can complement national platforms like SITB and support stronger TB program performance.

Table 6. Quantitative impact of the system compared to manual baseline

Metric	Manual process (baseline)	With system	Improvement
Recording time per patient	10.0 min	6.5 min	~35% faster
Data entry error rate	~12%	~2%	~83% reduction

3.7. Use of information system

Information system that has been evaluated was considered ready for use with the aid of a local host. Beyond descriptive findings, our results illustrate a paradigm shift in which user-centered prototyping can directly influence health outcomes by reducing medication errors and improving workflow efficiency. Previous studies in Indonesia highlighted that usability challenges in the national SITB system limit its effectiveness for TB management [7]. By focusing specifically on pharmacy workflows and drug logistics, our prototype addresses a critical gap that SITB does not currently resolve. Furthermore, the observed error reduction (~83%) aligns with global systematic reviews of digital health technologies, which consistently reported gains in data accuracy and process efficiency [10].

A deeper implication of our results is the potential contribution to national TB control strategies. Indonesia remains the second-highest TB burden country globally [4] and poor data management is a major bottleneck for ensuring uninterrupted treatment. By demonstrating that a hospital-based information system can be scaled and integrated with SITB, this study provides evidence for reducing discrepancies between local hospital reports and national TB databases. This alignment is crucial for strengthening the surveillance and monitoring capacity of TB programs at both provincial and national levels.

Another critical aspect concerns data interoperability. Studies on FHIR-based data systems in Indonesia demonstrated that despite the promise of standardized data exchange, challenges such as mapping between data schemas and infrastructure readiness remain barriers to large-scale implementation [10]. Without interoperable standards, even highly functional hospital systems risk becoming isolated “data silos,” limiting their broader impact. Therefore, our prototype should be considered not only as a technical achievement but also as a strategic step toward Indonesia’s digital health transformation agenda. This aligns with the principles outlined in the World Health Organization’s Global Strategy on Digital Health 2020-2025, which emphasizes interoperability, data governance, and sustainable capacity building as the foundation for national digital health transformation [11].

Moreover, prototyping in healthcare innovation literature highlights that prototypes are most effective when user feedback is incorporated iteratively and systematically into final system design. Failure to institutionalize user feedback mechanisms can prevent prototypes from transitioning into sustainable operational systems [27]. This implies that our prototype’s success depends not only on technical refinement but also on organizational readiness, training, and long-term governance structures.

Finally, while the system showed strong potential, critical risks must also be acknowledged. These include concerns around patient data security, privacy, downtime risks, and the lack of fallback mechanisms in case of system failure. Lessons from other digital health implementations emphasize the importance of routine security audits, risk management frameworks, and clear contingency policies to ensure system resilience [17]. These considerations are essential for sustaining the long-term benefits of the TB drug information system.

Although the system evaluation provided valuable insights, this study involved a relatively small number of pharmacist participants during the prototype testing phase. This limited sample size may constrain the generalizability of usability findings. Therefore, future studies should include larger and more diverse user groups to obtain broader perspectives and ensure the system’s effectiveness across different healthcare settings.

Beyond the descriptive findings, these results directly answer the research hypothesis that applying the throwaway prototype model can improve accuracy and efficiency in hospital-level TB drug recording/reporting. The reduction in errors (~83%) and time (~35%) provides quantitative confirmation that user-centered prototyping is not only feasible but also effective in addressing critical workflow challenges.

More broadly, the findings answer the crucial “so what?” question: the system demonstrates that hospital-driven innovations can fill gaps left by national platforms such as SITB, ensuring more reliable data for TB program monitoring. This has implications not only for TB management but also for the design of digital health interventions in other areas of hospital pharmacy and chronic disease management [28], [29]. Similar improvements in accuracy and efficiency have been reported in digital health interventions in Indonesia and other low-and middle-income countries (LMICs), underscoring the scalability of such approaches [10], [17].

The combined results demonstrate the practical effectiveness of iterative prototyping in reducing workflow bottlenecks and improving data reliability. Compared with previous digital-health studies, the achieved efficiency gains confirm that user-centered system design is a key determinant of successful adoption in hospital environments.

The findings also indicate that interoperability with national systems such as SITB could further amplify these benefits if integrated using open-standard application programming interfaces (APIs). Importantly, the success of this system highlights lessons for future research and implementation: 1) integrating interoperability standards such as FHIR to avoid data silos, 2) embedding user feedback into iterative design cycles for long-term sustainability, and 3) expanding evaluation beyond technical performance to include clinical and public health outcomes. By aligning technical design with national health priorities, this study contributes evidence that user-centered prototypes can become strategic enablers of digital health transformation in Indonesia.

4. CONCLUSION

This study successfully developed and implemented a TB drug information system at Udayana University Hospital using the throwaway prototype model. The system reduced data entry errors from 12% to 2% and shortened recording time from 10 to 6.5 minutes per patient, demonstrating the effectiveness of user-centered prototyping in improving accuracy, efficiency, and workflow alignment. These outcomes indicate that hospital-based systems can complement the national SITB platform, reduce reporting discrepancies, and strengthen TB drug management.

Despite these achievements, several limitations remain, including the absence of automated patient notifications, real-time communication features, and full interoperability with national data standards. Future work should prioritize technical enhancements such as FHIR-based integration, organizational strategies for user training and sustainability, and pilot implementations in multiple hospitals. By addressing these areas, the system can evolve from a local innovation into a scalable solution with national relevance, offering valuable guidance for policymakers and contributing to digital health transformation in Indonesia.

In conclusion, the TB drug information system developed through the throwaway prototype model significantly enhanced the accuracy and efficiency of TB-drug recording processes at Udayana University Hospital. The system's strengths lie in its user-centered design, scalability, and technical flexibility. Its limitations such as the absence of automated patient notifications and full SITB interoperability will inform future iterations. These results provide valuable insights for policymakers and healthcare-IT developers seeking to implement similar digital-health innovations nationwide.

For the development of this information system, it is necessary to add a patient database such as addresses and telephone numbers that can be contacted. This is important to provide reminder messages for patients about treatment to achieve compliance and reduce the occurrence of TB drug resistance. Moreover, a live chat feature between TB patients and doctors as well as pharmacists at Udayana University Hospital may be added to ensure appropriate monitoring. Additional information: the system currently lacks patient notification features and integration with national SITB. Future development will include reminders, live chat functions, and interoperability with national systems.

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AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

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C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

DATA AVAILABILITY

The datasets generated and/or analyzed during the current study are not publicly available due to the inclusion of information that could compromise participant privacy and institutional confidentiality. However, de-identified/aggregated data (e.g., questionnaire responses and system evaluation metrics) are available from the corresponding author (I Gusti Ngurah Anom Cahyadi Putra, email: anom.cp@unud.ac.id) upon reasonable request.

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