Design and Evaluation of Web-Based Information Systems for the Medical Laboratory

https://doi.org/10.3991/ijoe.v19i03.36505

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Abstract—The handling of information about periodic quality inspections, the maintenance of test equipment, and other instrument monitoring tasks are acknowledged as being among the high-priority tasks concerning equipment and material management in the medical laboratory. Lack of management and neglect of equipment can result in malfunctions that end up costing more time and resources. This paper proposes a design for a web-based information system that addresses the issues of managing expensive medical equipment (ME) and consumable medical materials (CMM) in laboratories. Looking to improve data administration in medical laboratories' day-to-day operations, this study aims to create a design for an information system with complete functionality and evaluate that system based on the user specifications. Initially, a list of more than 200 materials and 50 medical equipment records were collected and transferred into the system. Three independent laboratories utilized the ME/CMM information system we developed to evaluate its performance compared to their traditional systems. The t-test statistical analysis was used to assess feedback surveys. The findings show that the system provides users convenience and effectiveness in handling ME and CMM; thus, our system significantly reduces the workload of staff and inefficient costs.

Keywords—medical laboratory, web-based application, web-based information system

1 Introduction

Medical laboratory administration is one of the critical tasks that keeps a laboratory maintained as efficiently as possible and ensures the most accurate results from the instruments in the test center [1]. To allow the lab equipment to function properly, a laboratory information system is required to manage the large number of instruments and materials in the laboratory. However, the significant financial costs of such systems have been a crucial limiting factor and barrier to uptake for several laboratories, particularly in developing countries [2, 3]. A previous report disclosed that several laboratories in minor hospitals still required an efficient material and supply management system [4]. Due to the high cost of commercial software and limited resources, numerous administrative work is done manually often with paper-based management [5]. Consequently, these operational tasks are time-consuming. Unorganized information,

data redundancy, and information that is inconvenient to access are the important factors which cause a lack of information for decision-making and management of the laboratory.

A computerized laboratory information system is intended to collect, record, organize, display, store, and manage laboratory resources in an appropriate manner. An effective system will relieve the laboratory staff of the time-consuming task of tracking all equipment details. However, several studies also reported that some differences between laboratories appeared in several aspects such as lack of supplies and equipment, poorly trained staff in several laboratories, and lack of skilled laboratory professionals [2, 6]. Electronic information systems are thus set up in various ways to handle the corresponding functions which seek to solve these personnel issues. The last century was marked by the rise of information and communication technology. Network services and web-based applications are becoming more involved in providing different ways to work together such as using instant messaging and email to communicate with others. Furthermore, web-based applications can be used in a variety of settings in our daily lives, including educational institutions [7, 8], media organizations [9], government services [10], and healthcare facilities [11].

Generally, designing web-based applications requires knowledge of either client-side or server-side programming. A client-side script is a program that runs on a device owned by the end user, such as a personal computer, tablet, or smartphone. The goal of the client-side "front-end" is to develop a website with which the user can engage. Meanwhile, server-side development entails scripts that are executed on the web server whenever a user's web browser requests relevant data. Such programs are known as "back-end" development because they only run on a web server. Server-side developers often use object-oriented programming languages such as Java, Python, or structured query language (SQL) to interact with and manipulate information stored in databases. The scripting languages of hypertext preprocessor (PHP) are mostly used to create websites and web applications [12].

Most studies about web-based medical and health information systems are concerned with theoretical research, however, there are only a limited number of studies for comprehensive applications of new cooperative medical laboratory systems [13–15]. Fakhouri Amr et al. [16] proposed an architecture framework for quick routing of emergency ambulance services for an interconnected hospital information system, yet further application of the system to real-world situations is still required. Several studies have also discussed a number of barriers and challenges that have arisen in the adoption of these technologies [17]. Additional research has shown that a common information system cannot be the best solution for all the requirements of a laboratory [13]. Therefore, a system requires a thorough study of the laboratory processes and an understanding of the operational feasibility of experiments conducted there. Particularly, in the real-world setting, a requirement has emerged for health professionals and laboratory staff to keep up with these advancements [11, 18].

Recently in Thailand, one of the strategic targets for implementing the Information Technology Development Policy of Thailand 4.0 has been concerned with Public Health, Health, and Technology [19]. Therefore, several applications were designed to support reducing workloads in medical laboratories. Recently, several studies have attempted to employ innovative information systems in healthcare units. To improve the time reporting results in clinical chemistry laboratories, an auto-verification system

was proposed for cancer institute facilities [20]. A research laboratory proposed software to improve the online analysis report system by changing the delivery process report from paper-based to a database management system that can be accessed via the internet [21]. Furthermore, a recent report, regarding initial accreditation for the laboratories of small facilities, discussed that the most common cause of failure to meet the accreditation requirements was the management of laboratory equipment, reagents and consumable materials [22]. The lack of monitoring systems for medical equipment and consumable materials is leading to insufficient capacity to maintain a quality laboratory system. Although several commercial information systems have been proposed, small-scale institutions with limited financial plans are facing major challenges due to the high price of software [23]. Therefore, there remains a considerable gap between transforming the traditional paper-based system into a computerized laboratory information system in numerous medical laboratories in the country.

Therefore, the purpose of this study is to design and develop a web-based information system for medical laboratories which allows convenient access from a personal computer or other smart device, and efficient management of equipment and materials in the laboratory. The systematic approach to the overall design of the system and its features is described in Section 2. In Section 3, we describe the implementation of our designed system and the complete method for evaluating the performance of the information system. Lastly, results and discussions for future studies are stated in Section 4.

2 Design of system

2.1 Overall schematic of the system

The system was designed to monitor and manage the medical equipment and materials in a medical laboratory, and to allow access to information such as equipment information, availability of materials, appointments for maintenance or expiration data, via personal computers and via smartphones and other smart technology devices. The overall system schematic diagram is presented in Figure 1 which demonstrates that the users can reach and manage the information system through the web-based application.

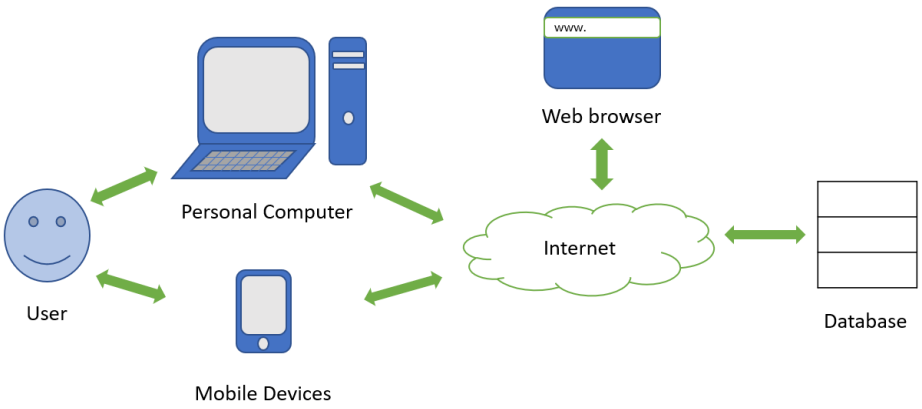

Fig. 1. Overall system schematic diagram of information system application

3 User and function design

The design of the ME/CMM information system is illustrated in the utilization case diagram in Figure 2. There are two main components, namely the type of users describing the authority to manage the data and the use cases defining the functionality of the system. The definitions of the different types of users in the ME/CMM information system are as follows:

1. Admins are people who have responsibility for allocating the permissions to perform data operations on the system. Admins have the highest authority to input and manage data by editing, deleting, and tracking log data in the web content management system.
2. Users are the people who have been granted permissions to access and manage data in the system. Users can input data, and view and track information within the system. However, users are not permitted to edit or delete the data in the system.
3. Guests are the people who have been granted access solely to view the data or information in the system.

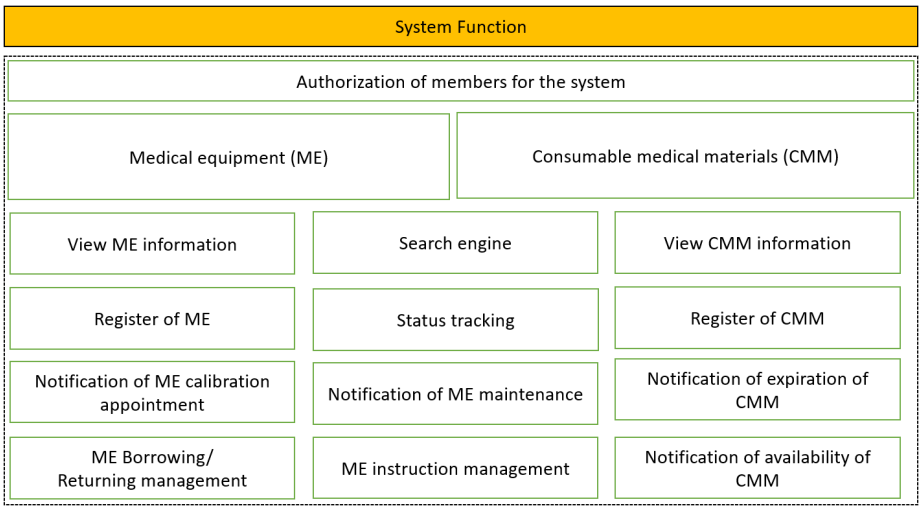

Fig. 2. Example of the design structure of the ME/CMM information system

The nine key features of the system's functionality were based on the survey and are as follows:

1. Registration/authorization feature for groups/members

   This feature shows the authorizations for each type of user allowing access to monitor and manage the data based on the username and authorization level granted during registration. Figure 3 illustrates the design structure for the authorization feature in the ME/CMM information system.

System					
sys_member	sys_group	sys_systemName	sys_authenGroup	sys_authenMem	sys_docControl
memberID	**groupdID**	**systemID**	**authenID**	**authenMemID**	**docControlID**
member_fullname	group_name	systemName	groupID	groupID	docContolCode
member_username	group_des	systemRead [1 = yes, 2 =no]	systemID	memberID	docControlTDes
member_password		systemAdd [1 = yes, 2 =no]			
member_tel		systemEdit [1 = yes, 2 =no]			
member_email		systemDelete [1 = yes, 2 =no]			
		systemReport [1 = yes, 2 =no]			
		systemDescription			

Fig. 3. The design structure of the authorization feature in the ME/CMM information system

2. Accessing information on medical equipment and materials
   Information on medical equipment and materials can be inserted, managed, viewed, or deleted using this feature. Key information such as type of equipment, name, brand, or lot number are also stored in the system.
3. User manual/instructions feature
   The user manual or instructions for each type of equipment and materials are included in the system. Users can insert user manuals, view them, and search for each type of equipment.
4. Feature for tracking the use of consumable materials
   This feature is designed to manage and monitor the numerous types of equipment and consumable materials in the medical laboratory. Key information such as type and name of materials, expiration date, number in stock, and availability are included in this feature of the system.
5. The search engine feature
   This feature is designed so that users can search by location, name, code number, model, or company to assist with tracking and monitoring the data system.
6. Feature for borrowing/returning equipment
   This feature allows tracking of the borrowing and return of equipment and is designed to visualize the status of each piece of equipment, so that the effective usage of medical equipment can be tracked and managed.
7. Notifications for calibration and maintenance of medical equipment
   Automatic notifications from the system allow the user to identify and adjust equipment in need of calibration or maintenance.
8. Notifications for expiration of consumable medical materials
   This feature offers a default notification setting in the system to remind the user and staff in the medical laboratories of expiration of materials. The system is designed to collect and save data about the expiration date and notice period so that the notification is triggered correctly.

9. Instrument repair tracking system

   It is necessary to track equipment in the repair cycle to prevent the loss or misplacement of instruments. This feature is designed to keep track of repair dates and the person(s) or company responsible for each piece of equipment.

4 Implementation and evaluation of system

4.1 System implementation

The initial data used in the ME/CMM information system were collected from three different medical laboratories, namely the Medical Technologists Laboratory of Thammasat University, the Medical Technologists Laboratory of Pathum Thani Hospital, and the Medical Technologists Laboratory of Bhumibol Hospital. The information of more than 50 equipment lists with various types of data, such as ID number, name in Thai and English, brand, model, borrowing and return history, order, and repair history etc. were included. Furthermore, a list of over 200 of purchase orders of consumable medical materials were transferred from a Microsoft Excel file into the information system being developed. Figure 4 demonstrates the examples of the main key features of the ME/CMM information system.

Master			
m_location	m_equipment	m_supplier	m_maintenance
locationID	equipID	supplierID	maID
location_roomNo	equip_eng	supplier_company	ma_company
location_name	equip_thai	supplier_address	ma_address
location_building	equip_brand	supplier_staff	ma_staff
	equip_model	supplier_tel	ma_tel
	equip_codeNo		
	equip_codeNew		
	equip_type [1 = ครุภัณฑ์, 2 = วัสดุสิ้นเปลือง, 3 = ไม่มีสต็อค]		

ซื้อเข้า - NewRegister	
th_equipNew	td_equipNew
docNewID	docNewSubID
supplierID	equipID
memberID	equip_serialNo
systemDateNew [Now()]	docNewID
docDate	locationID
supplierName	seqNew
supplierAddress	qtyEquipNew [Default : 1]
supplierContact	
supplierRefNo	

โอนระหว่างคลัง - transfer	
th_equipTransfer	td_equipTransfer
docTransferID	docTransferSubID
memberID	equipID
locationFromID	equip_serialNo
systemDateTransfer [Now()]	locationToID
docDate	docTransferID
	seqTranasfer
	qtyEquipTransfer [Default : 1]

รับ เบิก เพื่อซ่อม - maintainence	
th_equipMa	td_equipMa
docMaID	docMaSubID
memberID	equipID
locationFromID	equip_serialNo
maID	locationToID
systemDateMa [Now()]	docMaID
docDate	seqMa
ma_company	qtyEquipMa [Default : 1]
ma_address	defectRemark
ma_staff	maPrice
ma_tel	

Fig. 4. Examples of the designed features of the ME/CMM information system

4.2 System evaluation

The ME/CMM information system was applied in three independent laboratories and evaluated by staff in terms of their user satisfaction after using the system for one entire month. Three staff members from each laboratory were asked to use the ME/CMM information system and compare its usage with the traditional system focusing on operational functionality, effectiveness, and overall satisfaction. The scores ranged from 0–10 (low to high respectively). The feedback and the satisfaction scores from the nine laboratory staff were collected and evaluated, comparing the traditional system and the ME/CMM information system after their experience of using it. The statistical t-test was calculated to compare which of the two options had significantly better outcomes.

5 Results and discussions

The web-based ME/CMM information system was written in PHP and SQL to process and handle data management. The system was implemented on a data center with the Tier III architecture standard with a tier for the user interface, an application tier where data is processed, and a data tier, where the data associated with the application is stored and managed. Figure 5 demonstrates the main page of our ME/CMM information system, and a page for registering a CMM. The web page has been written in Thai and has symbols for users' convenience and simply to understand.

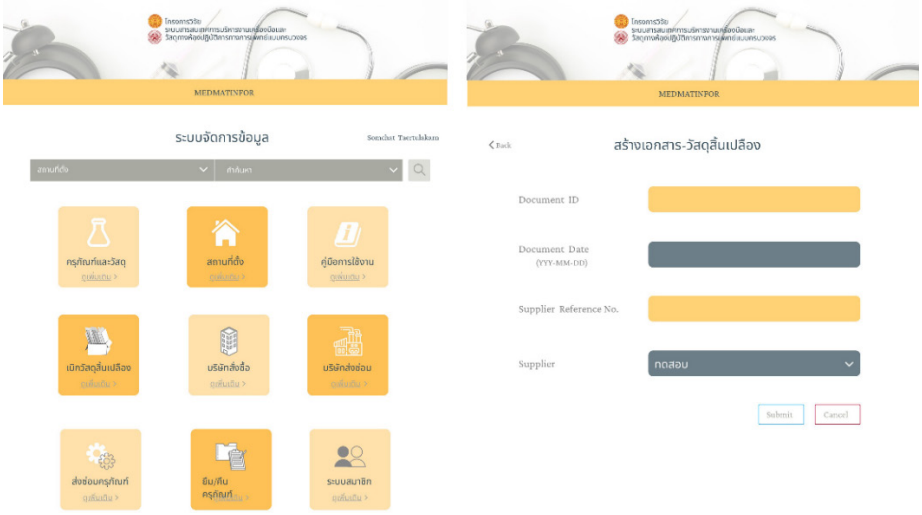

Fig. 5. Pages from the ME/CMM information system

Figure 6 shows examples of an overview of the listed medical equipment and the further details of each device in the system.

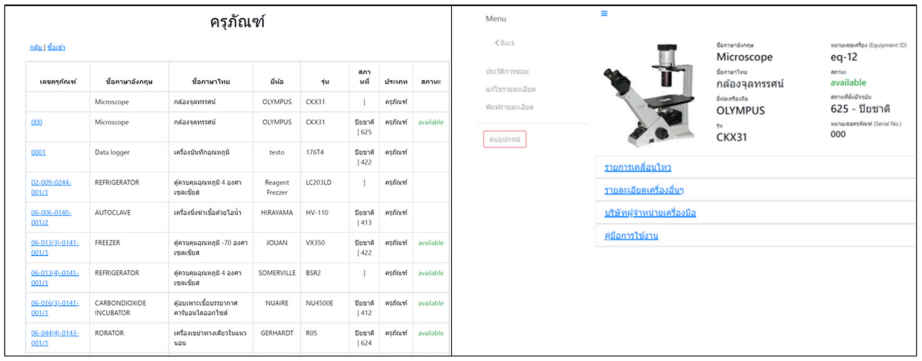

Fig. 6. Example of a summary of the ME list and details of each ME

As demonstrated in Table 1, there were significant statistical differences in the average of functionality scores, effectiveness scores, and satisfaction scores. Regarding testing the null hypothesis that the variances between the traditional system and the ME/CMM information system were equal, an f-test was conducted. The hypothesis is that the two variances are equal. The results revealed a statistically significant difference for the functionality ($F(9) = 0.499$, $p = 0.018$). The F-values in Table 2 indicate that there is not enough evidence to reject the null hypothesis that the variances between the two groups are equal at the 0.05 significance level for functionality and satisfaction.

Table 1. Evaluation results of the ME/CMM information system compared to the traditional system

Evaluation	System	Mean	Std. Deviation	Std. Error Mean
Functionality score	Traditional System	3.6667	2.34521	0.78174
	ME/CMM Information System	8.2222	1.20185	0.40062
Effectiveness score	Traditional System	3.6667	2.34521	0.78174
	ME/CMM Information System	8.444	1.01379	0.33793
Satisfaction score	Traditional System	4.7778	2.04803	0.68268
	ME/CMM Information System	8.5556	1.13039	0.37680

As displayed in Table 2, t-test values were calculated to determine if the means of two sets of data were significantly different from each other. The t-test results show that there is a meaningful statistical difference between the two groups before and after using the ME/CMM information system with scaled averages, $t_{(Functionality)} = -5.326$, $t_{(Effectiveness)} = -5.186$, and $t_{(Satisfaction)} = -4.845$, all with p-values <0.001.

Table 2. Results of the t-test comparing the mean-variance

Evaluation	F-Value	P-Value	T-Test
Functionality score	0.499	0.490	–5.326*
Effectiveness score	6.907	0.018	–5.186*
Satisfaction score	1.155	0.298	–4.845*

Note: *$p < 0.001$.

The evaluation from laboratory staff indicates that the ME/CMM information system is superior to the traditional one. Therefore, we can conclude that the application of the ME/CMM information system is more convenient, effective, and satisfying than the traditional system with significant confidence level of 95% ($\alpha = 0.05$).

Furthermore, based on the application of our system, the survey results discovered that each laboratory was able to reduce the cost of the consumables, reagents, and materials compared to the traditional system. Moreover, after applying the system in the laboratory, staff and board members were able to plan the maintenance budget more efficiently because of the clear data overview available in the tracking system. The findings from the investigation show that the time spent on searching for various data in the laboratory decreased significantly using the system we developed compared to the traditional system. Table 3 demonstrates the average satisfaction score based on the time spent searching and retrieving data comparing the traditional system and the ME/CMM information system. The score ranges from 0 to 5, representing very slow to very fast respectively.

Table 3. The average satisfaction score based on the time spent searching and retrieving data using the traditional system and the ME/CMM information system

Searching Data By	Traditional System	ME/CMM Information System
Name of ME/CMM	2.33	4.78
Serial no.	1.67	4.67
Brand	2.33	4.78
Supplied Company	2.33	4.78
Expired/Maintenance date	2.11	4.78

Based on our investigation, our results revealed that this system provided users convenience and effectiveness in handling ME and CMM. The decrease in inefficient costs and the workload of personnel are the significant reasons for the improvement to the efficiency of a laboratory's capacity. The overview of the ME and CMM lists supports the board staff in choosing and managing stock and maintaining their equipment at the right time. However, in several small hospitals, a management system for managing the stock of material supplies might be of limited use due to the expensive and inconvenient software. Therefore, the web-based information system we designed can serve as an appropriate and worthwhile alternative implementation. The system can be controlled using both personal computers and mobile devices such as smartphones

or tablets. As one of the key functions, the notification feature, e.g., the appointment of maintenance, expiration date, and availability of CMM, offers the users a useful reminder of the state of the system. For additional improvements, this system could be further expanded by integrating the advanced technology of artificial intelligence and image processing to assist in the detecting and monitoring of equipment and stock done by the ME/CMM information system.

6 Conclusion

Computer systems and the internet have revolutionized access to data, and techniques for managing data have evolved. The development of integrated technology can support organizations such as governmental departments or health institutions. This paper introduced the current status of, and existing issues with, medical laboratories management of equipment and stock, and proposed a web-based information system designed to enhance medical laboratories' actual routines for managing data. The web-based application was designed to provide the necessary features and was employed by three independent laboratories to assess the performance of the system. The system could process the collection and management of ME and CMM data, tracking and monitoring of equipment and stock, and provided a more convenient and effective way of working. To assess the functionality of, effectiveness of, and overall satisfaction with the application, feedback surveys were collected and evaluated using the statistical t-test. The outcome revealed that the system provided users convenience and effectiveness in handling CMM, therefore, our system significantly reduced the workload of staff and personnel. Regarding improving the quality of laboratory reporting and the stock usage monitoring of ME and CMM, the workload of staff was supported by the efficient notifications, tracking features, and borrowing/return functionality included in the system. In conclusion, this system could be implemented at other medical laboratories to further support data management in other institutions.

7 Acknowledgment

The authors gratefully acknowledge the financial support provided by Thailand Science Research and Innovation Fundamental Fund Contract number TUFF09/2564.

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Article submitted 2022-10-31. Resubmitted 2022-12-27. Final acceptance 2022-12-29. Final version published as submitted by the authors.