Journal of Applied Sciences

ISSN 1812-5654

science alert

ANSInet
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Journal of Applied Sciences 13 (10): 1871-1876, 2013
ISSN 1812-5654 / DOI: 10.3923/jas.2013.1871.1876

Medical Equipment Repair Management System Developed Using Cloud Technology

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Abstract: With advancements in technology, cloud systems not only provide diversified services but are also used in a broad range of applications. This study developed and designed a new medical-equipment repair management system in which cloud and Quick Response (QR) code technologies are employed. This study emphasized the research objectives of cost control and implementation performance and discussed how using a cloud platform reduces cost and the risk of developing information systems. Regarding the cost of information management system development, this study adopted cost allocation and cost reduction approaches and employed the parametric modeling concept to build a mathematical function between costs and the scales of software. This study offers managers the opportunity to assess the overall hospital equipment maintenance process and seek improvements for increased efficiency and effectiveness. The new system built in this study is a novel alternative to existing systems. The existing system enabled this system to be both economical and highly competitive.

Key words: Coud system, mdical-equipment repair management system, QR code

INTRODUCTION

Technological advancements have propelled the widespread use of cloud services and their range of applications. Cloud systems provide diversified, flexible service resources. Rather than running software on a desktop computer or server, Internet users are able to use the "cloud" (a networked collection of servers, storage systems and devices) to combine software, data and computing power scattered in multiple locations across the network (Cavoukian, 2008). The primary objective of businesses adopting cloud systems is to reduce the cost of developing information systems individually. Therefore, cloud computing has been recognized as a crucial development in information technology. The most prominent feature of cloud computing is efficient resource allocation. This technology also provides functionality for managing information data in a distributed and comprehensive manner that supports several platforms, systems and applications (Poonam and Bharat, 2012). Based on individual needs, businesses can use the cloud platform to develop computing resources, storage spaces and network services. Businesses no longer need to be concerned with upgrading and maintaining hardware capacity, obtaining resources to perform software computing and hiring costs of maintenance personnel. These features not only enable businesses to significantly reduce installation costs for information systems but businesses are also spared the costs incurred for maintenance, system upgrades and personnel-hiring. Hawser (2009) argued that companies accessing cloud technology probably received higher quality from this technology than they received from their Internet IT departments. Studies have indicated that effective use of cloud computing solutions enables small firms to increase their competitiveness and allows them to compete with larger firms (Wang, 2012). Therefore, understanding why cloud services are receiving increasing attention and becoming a popular topic in the information field is not difficult. In addition to the development of cloud systems, establishing Quick Response (QR) codes in the information field has also received widespread attention. This is primarily because QR codes provide a rapid, convenient, accurate and automatic data collection method. In addition, QR codes enable efficient and accurate tracking of products. Chu *et al*. (2012) applied QR code technology to medical equipment repair management. The results indicated that this method can significantly improve the efficiency of medical equipment repairs, ensure engineers receive accurate information, shorten website processing time and highlight the significance of solving such problems. To apply the

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benefits this technology to the medical field, this study considered combining cloud computing technology with QR codes in a medical-equipment maintenance management system for hospitals. This study re-developed a repair management system by employing cloud and QR code technologies in this new system. This study focused on cost control and implementation performance to identify an optimal solution by combining modern technology. Integrating cloud computing and QR code technology into the repair management system enabled equipment engineers to arrive at the location of faulty equipment promptly, provided instant access to equipment-related information and error code meanings for rapid repair of the faulty equipment and reduced overall repair time. The technology developed in this study provides a novel and efficient method.

ESTIMATING THE COST MODEL FOR INFORMATION SYSTEM DEVELOPMENT

The reason businesses opt to use cloud platforms is based on the expectation of reducing costs related to developing information systems and to transfer risk at an appropriate time. In other words, when companies do not use cloud computing in system developments, they must develop their own information systems and employ additional human resources to perform system maintenance and maintain smooth system operations. This study derived an information system cost model based on methods used to develop mathematical models. These methods were adopted because they have rarely been examined in previous studies. In general, when developing information systems, businesses must consider hardware and software acquisition costs. Software cost estimates included expert consulting, estimation by analogy and parametric modeling, as referenced according to the main classifications in research studies (Boehm, 1989). The x in the software function scale denotes the number of function points. This study assumed that the IT function scale was a linear function αx+bx. The adjustment factor function g(y) reflects other cost factors affecting software development for the entire system as well as the software factor scale. Because of differing levels of influence from various factors, these values are shown as the sum of their influences. The algorithm model for cost estimation is as follows:

$$C_1 = (ax + bx + k) + \sum_{j=1}^{n} gi(y) \quad (1)$$

Where:

- C_1 = The cost estimation to develop an information system
- a = The software cost estimation
- b = The hardware cost estimation
- x = Measurements according to the function points scale
- I = Nodes required to install an information system, i = 1, 2, 3…n nodes
- y = The vector of the adjustment factor
- k = A constant

In addition to considering the preliminary information system development costs, businesses must also routinely maintain and care for the systems. Once malfunctions occur, immediate repairs must be performed. The costs of IT system maintenance at time t are defined as follows:

$$C_2 = \int_0^t \beta \sum_{i=1}^{n} \sum_{j=0}^{m} dt \quad (2)$$

Where:

- C_2 = The costs of maintaining the information system after development
- β = The unit node for cost estimation (e.g., care and labor costs)
- j = The costs of repairing the information system equipment, j = 0, 1, 2, 3,…., m

In addition to accounting for the generation of these costs, information system development requires consideration of the probability for risks occurring. Because risks are a potential factor that cannot be fully estimated, when they occur, losses (e.g., system crashes, database corruption and loss of critical confidential data) are possible, thereby leading to business downtime losses. This study assumed that risks primarily comprise two variables, namely risk probability and risk loss. Risk probability refers to the probability that risks will occur and risk loss refers to the extent of losses once a risks occurs. IT system risks are represented as follows Eq. 3:

$$C_3 = \int_0^t \sum_{i=1}^{n} (Ri \times Li)\, dt \quad (3)$$

Where:

- C_3 = The potential financial losses caused by associated risks
- Ri = The probability that the ith risk will occur
- Li = The extent of losses caused by the ith risk

By summing Eq. 1-4 is obtained where C_t represents the estimated total investment cost. By entering Eq. 1-3 into 4, objective function (5) is obtained. This study only used these equations for inferences and did not employ numerical values as examples.

Objective functions:

$$C_t = C_1 + C_2 + C_3 \quad (4)$$

$$C_t = (\alpha x + bx + k) + \sum_{i=1}^{n} + \int_0^t \beta \sum_{i=1}^{n} \sum_{j=0}^{m} dt + \int_0^t \beta \sum_{i=1}^{n} (Ri \times Li) dt \quad (5)$$

DESIGN OF NEW PROCESSES

Under a cloud computing framework, information devices and sensitive data storage spaces used by the system are stored in a cloud service provider. Therefore, businesses strongly emphasize security issues concerning "anti-data theft," "encrypted protection of accessed data content," "complete data deletion confirmation after service termination," and "anti-eavesdropping network packets." Cloud platform providers must ensure uninterrupted services and focus on "blocking immediate threats to information security," "providing virtual environment systems and network security," "preventing malicious program attacks," and "developing transparent security management mechanisms." Information security issues occur in both public and private cloud environments. The key to whether cloud computing can be accepted by businesses is the ability of cloud service providers to propose appropriate adaptive strategies for resolving the described information security issues. Although cloud systems offer businesses an opportunity to lower information-system development costs and avoid hidden risks, security mechanisms such as data privacy and data protection remain concerning. Shi *et al.* (2011) stated that cloud computing users were facing new secure data-storage challenges, including data privacy and secured data possession in untrusted servers. Businesses place greater trust in self-developed information systems and adopt stringent protective measures. In other words, realizing the full potential of the next generation of the Internet and cloud computing is impossible without improving the understanding of protecting data security and privacy (Wang, 2012). Hospitals may find that completely accepting cloud systems is extremely difficult because they have an obligation to fully protect patient personal data and privacy. To fully utilize the advantages of cloud systems, this study chose a medical equipment-repair management system as the basis and combined QR codes with cloud features to establish an innovative and multifunctional system. During the experimental test phase of development, the new system was first used in a simulated environment to avoid affecting the operations of the existing system. Virtual data were used in the tests to prevent the potential leakage of actual data. To confirm the prototype application, several QR codes were tested for various medical equipment.

Figure 1 shows the unique characteristics of the QR codes that were adopted; the basic information of the medical equipment, including supplier contact information, was encoded in the QR code; and a distinctive QR code was pasted on each piece of medical equipment. When a particular machine failed, the On-Call Maintenance System (OCMS) immediately notified the equipment engineers to proceed to the designated area, check the malfunctioning medical equipment and determine the cause of equipment failure. On site, the engineers used a mobile hand device (e.g., PDA and tablet PC) and a pre-installed application to scan the QR code of the equipment. After decoding the application program, web browsers were employed to obtain the required information. In addition, the mobile hand device was connected to the cloud servers through internal hospital network systems to enquire regarding equipment operation and the meaning of relevant error messages according to the technical manual and determine means of resolving the problem. With adequate information, engineers were able to identify the cause of equipment failure rapidly and accurately and develop solutions in short timeframes. By using the system search function during the repair process, the engineers were able to verify whether repair parts were in stock for replacement and were able to immediately contact external vendors to order repair parts or outsource the repairs to vendors when encountering situations, such as repair parts that were out of stock or equipment failures beyond the repair abilities of the engineers.

APPLICATIONS OF CLOUD PLATFORMS

Regarding service, cloud computing, in essence, provides three types of services (1) Infrastructure as a service (IaaS), (2) Platform as a service (PaaS) and (3) Software as a service (SaaS). IaaS provides users with basic computer resources such as cloud hardware equipment and cloud networks. Users can use the operating system, storage spaces and their own applications and network functions without managing and controlling the fundamental cloud infrastructure. PaaS provides software platform developers with programming languages and tools for cloud computing, enabling them

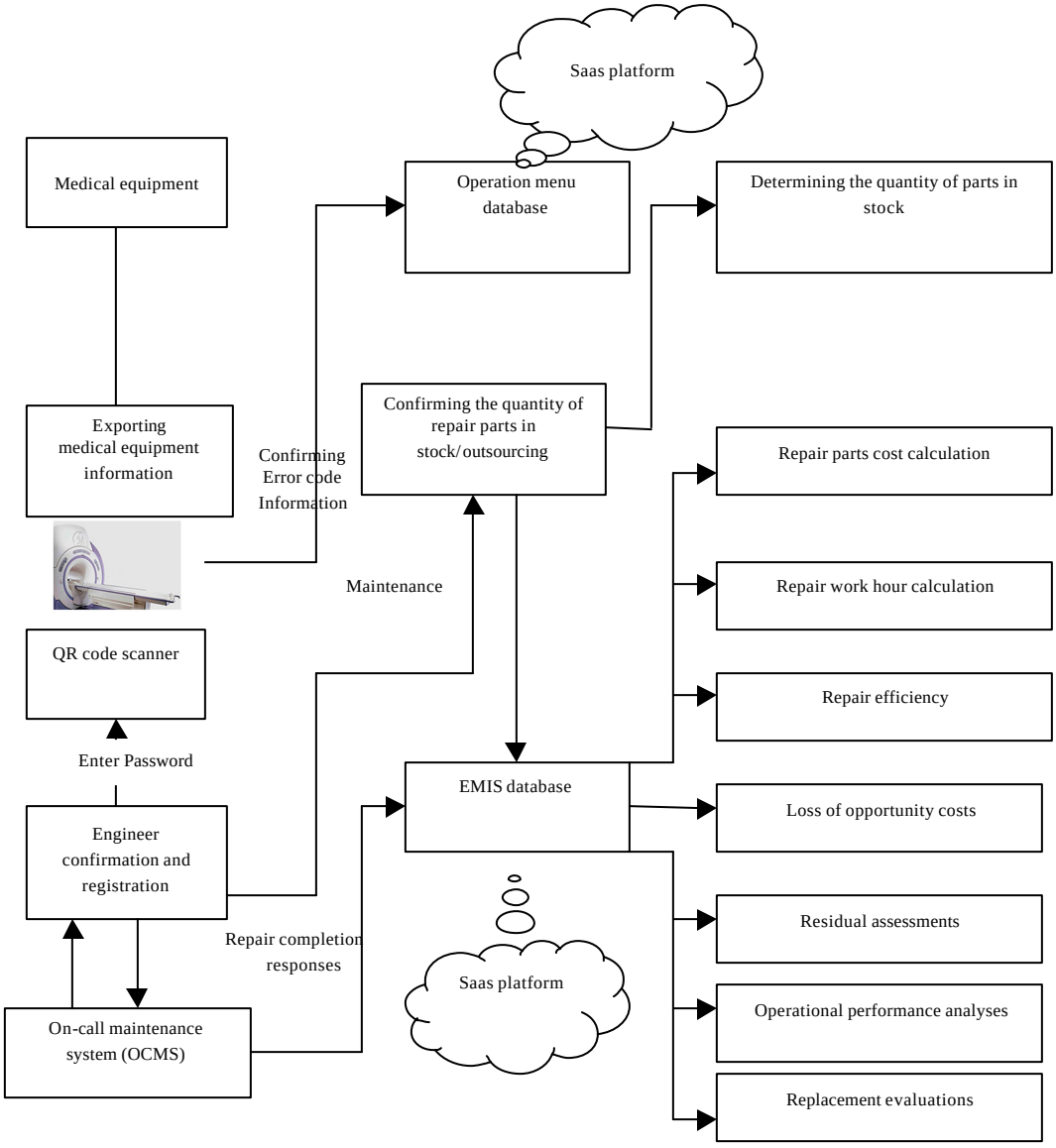

Fig. 1: Novel medical equipment repair process

to develop and design their applications in the cloud infrastructure to establish their own service platforms. SaaS provides users with the application programs that cloud service providers use in the cloud infrastructure. These application programs can be accessed using a variety of client devices and interfaces; thus, users are not required to manage and control the fundamental cloud infrastructure, Internet, hardware server, operating systems, storage spaces, or application programs. This study focused on the development of the SaaS platform primarily because SaaS applications were accessible from various client devices. The equipment engineers could use the mobile hand devices to easily and rapidly access large amounts of required information, particularly when managing study documents for the medical equipment. Hospitals possess numerous medical instruments or machines with varying functions. Each instrument is associated with distinct operating and technical manuals which encompass circuit diagrams, functioning principles, error code instructions and troubleshooting procedures. Thus, the necessity of having to carry these manuals for every equipment failure incident increases the inconvenience of engineers. Therefore, by converting study documents into electronic files and storing them in

the SaaS, engineers can perform searches based on immediate needs by using the SaaS query function during the repair process, thereby considerably enancing repair performance and quality.

EXPERIMENTAL RESULTS

To avoid affecting the operation of existing systems, the development phase and the experimental testing phase of the new system were conducted in a simulated environment and virtual data were used for all test data. Furthermore, the accessibility of data from databases must be limited for a trustworthy system; thus, only the authorized engineers were able to retrieve the required information after passing a validation process. Most stages of this system were directly related to the exchange of data between the mobile device and the server. Furthermore, the results of both tests from the perspective of efficiency and cost savings showed that the system is quick and economical, making it highly competitive with exiting repair management system.

In addition, after each repair, the engineers must implement case-closing procedure by using the OCMS. All costs incurred from the repair (e.g., parts, outsourced repair expenses, repair work hours and repair efficiency) are recorded in the Equipment Management Information System (EMIS) on the SaaS platform. Complete recorded data will provide increasingly diverse statistical analysis in the future. Moreover, in addition to controlling and understanding the total repair costs, users can further analyze these data to determine whether the medical equipment achieved the performance standards. For medical equipment failing to meet set standards, causes can be determined through analysis and feasible improvement strategies can be recommended. These analysis results can then be offered to managers or engineers who are appraising the overall maintenance program and seeking increased efficiency and effective usage of available resources.

THE PURPOSE OF DEVELOPING THE EMIS

Large hospitals have increased management complexity. Therefore, establishing a set of comprehensive systematic management processes can reduce the level of complexity. Moreover, managers can use the various data derived from the operational process as the bases for improvement and correction. To fully manage and control the operations of numerous medical instruments, a comprehensive management system is required for management and control. Mutia *et al.* (2012) argued that facilities management is a strategic function that positively contributes to business growth and organizational success. From a medical-equipment security perspective, when equipment operates continuously, stably and accurately, it directly and indirectly minimizes medical errors and incidents of injury, thereby enhancing patient security. In other words, introducing and implementing a medical equipment repair system improves equipment operation performance, reduces repair downtime, enhances of medical care quality and creates increased opportunity costs. Such systems increase equipment lifetime and provide information essential for equipment management. Regarding medical equipment repair management systems, most hospitals adopt commercial software packages and a few hospitals develop their own software. Evidence has shown that in several cases, such system management software is both expensive and inefficient. This study contends that to properly manage medical equipment, the EMIS functions demonstrated in Fig. 1 should be developed. In addition to understand repair costs and efficiency, management should attach considerable importance to opportunity cost losses attributable to equipment downtime and repairs. Furthermore, evaluations of repair costs, operation efficiency and residual values of the existing equipment should be performed for each machine to facilitate assessments and decisions regarding replacing older equipment.

CONCLUSION

Several contributions are summarized from the results of this study. First, to date, no researcher integrating cloud computing and QR code technology into repair management systems has enabled equipment engineers to reach the location of faulty equipment promptly. In this study, when a repair was necessary, equipment engineers used a handheld mobile device, such as a PDA or a tablet PC, pre-installed with an application that scanned QR codes on the equipment at the repair site. After the application decoded the QR code, the required data were obtained through a web browser. By using the SaaS platform, the error code meaning provided by the equipment was identified. With superior information, the equipment engineers quickly and accurately determined the cause of the equipment failure and effectively resolved the problem in the shortest amount of time possible.

Second, this study attempted to estimate a cost model for information system development. Regarding the information-system cost estimation, the notions of cost allocation and cost reduction were emphasized and basic concepts from algorithmic models were used to construct

the function between the cost and scale of software. The researchers attempted to use the equations to define the risk-reduction leverage value for the basis of this study to support the argument that introducing cloud computing can reduce the costs of developing, maintaining, upgrading systems and employing personnel, as well as preventing risks. Third, the EMIS was constructed on the SaaS platform, where the primary objective was to properly manage all medical equipment, comprehend current operational situations and provide higher management level with information to control repair costs for all equipment and to use the repair efficiency performance of each engineer as the basis of their performance evaluation. In addition, managements must attentively examine the effects of equipment malfunction and repair periods on medical practices, estimate probable losses and determine alternative plans to obtain compensation for losses resulting from service failure occurrences. Furthermore, proper adoption of various data from the EMIS database facilitate the provision of sufficient information regarding new equipment selections, purchases, installations and maintenance for assessments, thereby enabling management to arrive at optimal decisions.From the perspective of efficiency and cost savings, the new system is fast and economical, rendering it highly competitive with existing management systems. This study offers management the opportunity to assess overall equipment-maintenance processes in hospitals and seek improvement for increased efficiency and effectiveness.

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