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RFID-Based Clinical Decision Support System using Simulation Modeling

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Abstract: Clinical Decision Support System (CDSS) is often used by health care providers to test the operational efficiency of new ideas before they are applied in practice. In health care, decisions are related to many variables. Simulation modeling is a way to test changes in the different variables in a computerized environment to decide on ideas for improvements before implementation. Usually simulations encounter assumptions. Simulation results are as accurate as the assumptions. Radio Frequency Identification (RFID) sensors enable real-time, efficient and accurate collection of data. These data are used by professionals to make decision related to sharing of the resources between hospital departments. This paper proposes a simulation model to support health care decision makers in assessing ideas related to resource utilization based on RFID-based collected data. The study demonstrated the usefulness of combining RFID with computer simulation for exploring the trade-offs between resource utilization and clinic performance. Useful software applications can be built on top of new technologies to contribute to optimizing business processes, reducing data errors and improving the overall applications' results.

Key words: Clinical decision support system, simulation, RFID, resource utilization, patient flow

INTRODUCTION

Due to the great demand for quality health care services providers, large amount of financial resources have been allocated to the health care sector. In 2011, the Saudi government has allocated $18.3 billion for healthcare services and social development, representing an increase of 12% compared with last year's allocation, (Saudi Gazette, 16 February 2011). Efficiency used to be considered as the primary indicator of hospital performance (Drucker, 2001). Hospitals are considered a relatively large and dynamic organization with great number of movable resources. Resources include human, equipments and beds. Operation efficiency and resource utilization highly influence the cost and quality of services provided. The cost of medical services in hospitals is controlled by higher operational efficiency (Hollingsworth *et al*., 1999). Health care providers believed that inefficiencies existed in clinics is a result of a number of factors, among these is the inappropriate resource utilization (Merkle, 2002). Therefore, one of the very important efficiency and budgeting decision made by quality managers in the health care sector is related to resource utilization.

Technology in general and information technology in specific have succeeded in improving operation efficiency and reducing cost. Health care providers are making intensive efforts in using information technology to bring down the growing health care cost. Some researchers argue that hospitals use of technology is still lagging behind the current technology. This could be referred to the ignorance of people in the ranks of hospital management of computer science or operations research (Carter, 2002).

This study combines two technologies for managing resource utilizations; RFID and simulation modeling. RFID is used as a tracking system to collect real-time data about the movable resources and simulation provides an environment for the quality managers to assess the potential benefits of resource utilization and optimization decisions they would like to make prior to implementation. This would increase the accuracy of data used by simulation and consequently the simulation results and reduce the series of trails and errors, effort and overhead expenses. In addition, Decision Trees were combined with the above technologies to provide recommendations based on the simulation results. The study focuses on describing the patient's flow in clinics and the data, formulas and equations needed to simulate this flow.

RADIO FREQUENCY IDENTIFICATION (RDIF) IN HEALTH CARE

Radio Frequency Identification (RFID) is a Dedicated Short Range Communication (DSRC) technology. RFID is a technology that provides a sophisticated solution to

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wide range of business needs (Shepard, 2005) including health care sector. Traditionally, health care providers use manual methods to capture resources utilization. Although, the staff spent large amount of time on updating the paperwork, most of the time it encounter some mistakes. This is because in larger organizations it is more difficult to track objects with manual methods. RFID tracking enables real-time resource visibility.

Health care investments in RFID technology is growing among health care providers. This is due to the great benefits it brought to the sector. RFID technology in health care reduces human errors, improves patient flow efficiency, optimizes resource utilization and enhances the quality of care services (Cangialosi *et al*., 2007). In addition, it can improve patients' safety, eliminates paper-based document, saves cost, increases efficiency and productivity and reduces patient waiting time.

Although RFID technology has been available for a while, actual software applications built on top of this technology have been few. Wicks *et al.* (2006), Miller *et al.* (2006), Isken *et al.* (2005), Al-Nahas and Deogun (2007), Taneva and Law (2007) discussed the potential uses and benefits of this technology in health care. Miller *et al.* (2006) discussed how RFID technologies were used on tracking patients in the Emergency Department. Amini *et al.* (2007) explored the potential value of RFID data for tactical and strategic purposes and the redesign of processes within supply chain through the deployment of simulation modeling and analysis. This study applies the RFID technology to collect real-time data related to patients and staff movement and utilization in a hospital as actual data used for clinical decision support system.

CLINICAL DECISION SUPPORT SYSTEM (CDSS)

A Clinical Decision Support System (CDSS) is an interactive Decision Support System (DSS), used by health care providers to assist them with decision making tasks. It uses and analysis clinical-related data to generate case-specific advice. CDSS do not make decisions for health care professionals. The main key to CDSS is constructing strategies or making sound decisions in light of a number of assumptions. Simulation results are as accurate as the assumptions. The CDSS would make suggestions of outputs for the professionals to look through. Utilization of simulation techniques in the health care has increased dramatically within the past 10 years. Jun *et al.* (1999) addresses many works performed in this area. Bhuvaneswari *et al.* (2007) proposes a distributed knowledge management based decision support in health care that merge knowledge from different actors into a decision support specific.

PROPOSED RFID-BASED DATA COLLECTION SOLUTION

RFID is an automated data-capture technology. In the proposed model, each patient, staff and hospital equipment is issued an RFID tag/wristband. Each RFID tag/wristband is identified by a Unique Identification Number (UIN) used to identify objects and their flow within the hospital by wirelessly transmitting their locations to the receiver and storing the data to be used by the CDSS and other information systems in the hospital.

Patient waiting time gives indication related to clinical performance efficiency and resource utilization. Hospital need to go through a long process of identifying and collecting data about resources utilization, analyze the data and accordingly produce a number of decisions. Usually a number of variables influence the performance efficiency, such as number of nurses, preparation and examination rooms, beds, physicians, availability of medical records and others. A decision on which resource to share among units need to be tested for assessing its feasibility before implementation. Simulating this basic strategy for a clinic would show which changes would lead to performance improvements. The real-time objects identification and tracking are achieved using RFID tracking systems instead of manual. Zhang *et al.* (2011) focus on proposes an RFID-driven supply chain management system that incorporates real-time data with simulation to enable the creation of accurate scenarios.

PROPOSED CLINICAL PERFORMANCE SIMULATION MODEL

Simulation model has been widely used by many industries to assist in the decision support Guariso *et al.* (1996), Belz and Mertens (1996), Akpolat and Eristurk, (2007), Yang (2008) and Mahdavi and Shirazi (2010). In this study, simulation modeling is used for developing CDSS. To simulate some process, the process must be very well understood and required data need to be selected. Benneyan (1997) and Najmuddin *et al.* (2010) have addressed the patient flow process in hospitals. Oviatt and Hollingsworth (2005), Samaha *et al.* (2003) and Ruohonen *et al.* (2006) focused on simulating patient flow in Emergency rooms. This study proposes a comprehensive simulation flow that focuses on simulating the patients' flow in clinics. Implementation details are provided and simulation model is integrated with tracking technologies to improve the accuracy of the results.

The proposed CDSS simulates a hospital with several departments that have independent check-in counters. It simulates the patient flow and waiting time in the clinics within the different departments. Waiting time in radiology department, laboratories and other hospital areas are not taken into consideration. Patients' flow is simulated from the moment they enter the department until departing and illustrated in Fig. 1.

When a patient arrives to the department, (s)he first goes to the check-in counter and gives his/her appointment card to the receptionist. This helps the receptionist obtain the patient's information or data of the last visit and order his/her medical record. Then patient will be transferred to the waiting room near the examination and preparation room and wait until called by the nurse. When the patient's medical record is brought to preparation room, the nurse calls the patient to the preparation room and prepares him/her for examination. There will be an independent preparation room in the department. Once finished, the nurse will bring the medical record to the exam room of the specified physician and the patient will be waiting in the waiting room again until called by the physician. After the patient is seen by the physician (s)he will leave. The patients' arrangement to enter the preparation and the exam rooms is based on first in first out (FIFO).

Next, is a description of the data automatically collected by the RFID sensors. This data is required by the simulation model to assess the feasibility of different decisions. In compliance with Barry (2002), equations and formulas were developed and used in the proposed simulator.

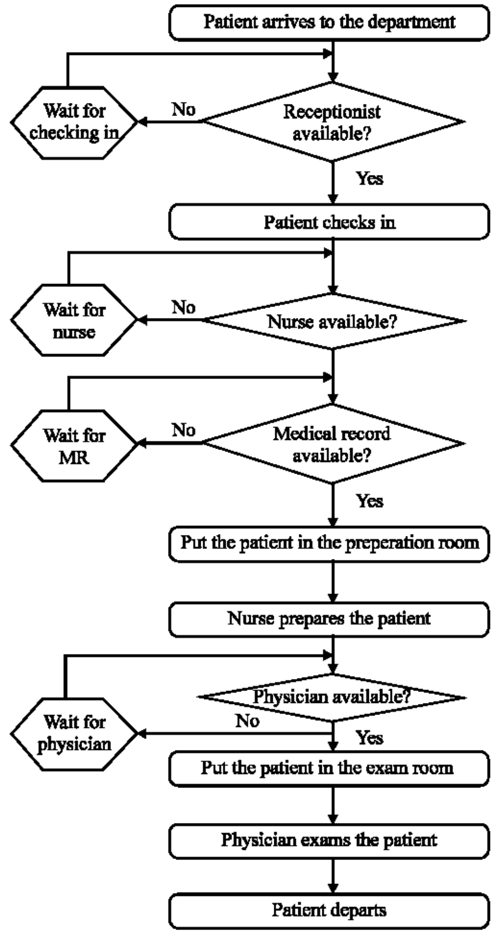

Fig. 1: Clinical patient flow diagram

Simulation data: A number of data required for running the simulation model. These data were collected via RFID sensors placed in the different departments around the hospital. The data required for simulation are as follows:

- Number of working hours
- Number of receptionists
- Number of physicians
- Number of clinic nurses
- Number of appointments per physician
- Distribution of Inter-arrival time between patients
- Distribution of time for patient to check-in
- Distribution of time to bring the medical records
- Distribution of time for patient preparation
- Distribution of time for patient examination

Simulation formulas: The following formulas used in developing the simulation:

- Arrival time is the time when the patient enters to the clinic department
- Inter-arrival time = the arrival time of the second patient - the arrival time of the first patient
- Patient check-in time = time patient enters the waiting room - patient arrival time to the department
- Waiting time for receptionist = patient's starting time of the check-in process - patient's arrival time to the department
- Waiting time for medical record = time the medical record is brought to the preparation room-time patient entered the waiting room (If there is a nurse available)

If the medical record has been brought while the nurses were busy with preparing the preceding patients, waiting time for medical record will be 0:

- Waiting time for nurse = time the patient enters to the preparation room-time the patient enters to the waiting room
- Patient preparation time = time the patient leaves the preparation room-time the patient enters to the preparation room

- Patient examining time = time the patient leaves the exam room-time the patient enters the exam room
- Waiting time for physician = time the patient leaves the preparation room- time the patient enters to the exam room
- Total Patient waiting time = patient waiting time for receptionist+patient waiting time for medical record+patient waiting time for nurse+patient waiting time for physician.

Simulation results: The simulation uses the simulation data and formulas to calculate the following results:

- Average of patients' total waiting time = Total Patient waiting time / the number of total patients
- Average of patients' total waiting time in the waiting room = the sum of (Waiting time for medical record+Waiting time for nurse+Waiting time for physician) for all patients/The number of total patients
- Percentage of patients waited for check in = (number of patients waited for check in/number of total patients)×100
- Average waiting time for check in = the sum of the waiting time for check in for all patients/the number of total patients
- Percentage of patients waited for medical record = (Number of patients wait for medical record/Total number of patients)×100
- Average waiting time for medical record = the sum of patients' wait time for medical record/Total number of patients
- Percentage of patients waited for nurse = (Number of patients waited for nurse/Total number of patients)×100
- Average waiting time for nurse = the sum of patients' waiting time for nurse/Total number of patients
- Percentage of patients waited for physician = (Number of patients waited for physician/Total number of patients)×100
- Average waiting time for physician = the sum of patients' waiting time for physician/Total number of patients
- Receptionists utilization = (the sum of check-in time for all patients/the number of hours of work)×100)/the number of Receptionists
- Nurses utilization = ((the sum of preparation time for all patients/the number of hours of work)×100)/the number of nurses
- Physicians utilization = ((the sum of examination time for all patients/the number of hours of work)×100)/the number of physicians
- Average number of patients remained after the working hours per physician = Number of patients remained after the working hours/Number of physicians
- Average overtime for physicians = The sum of working time after the working hours for physicians/the number of physicians

EXPERIMENT RESULTS

Ten experiments were carried out in light of the following inputs and clinical quality criteria. Input assumptions can be entered by the users. In addition, the values of these parameters can be automatically inserted based on the actual data collected by the RFID sensors. Clinical quality criteria are set by the quality manager based on clinical performance best practices. Due to the limited space, only a summary of two experiments are presented below.

The experiments present the results of the simulation based on changes in input variables. A decision tree in a "if-then" model is adopted to generate recommendations. The decision tree uses simulation results and quality criteria in generating these recommendations.

Input variable:

- Working hours: 7 h
- Average inter-arrival time between patients: 5 min
- Average time for patient to check-In: 8 min
- Average time to bring the medical record: 5 min
- Average time for patient preparation: 7 min
- Average time for patient examination: 20 min

Clinical quality criteria:

- Percentage of patients wait for check in = 60%
- Average wait time for check in = 8 min
- Receptionists utilization = 80%
- Percentage of patients wait for medical record = 60%
- Average wait time for medical record = 10 min
- Percentage of patients wait for nurse = 60%
- Average wait time for nurse = 16 min
- Nurse utilization = 80%
- Percentage of patients wait for doctor = 60%
- Average wait time for doctor = 20 min
- Doctor utilization = 90%
- Average number of patients remained after the working h =2
- Average overtime for doctors = 10 min
- Minimum accepted doctors utilization = 60%
- Minimum accepted nurses utilization = 50%
- Minimum accepted receptionists utilization = 40%

Experiment No. 1: Impact of the changes in the number of receptionist: The first experiment shows the impact of the number of receptionists on resource utilization and clinical performance. Simulation parameter were set to number of doctors = 2, number of appointments per doctor = 20 and number of nurses = 2. The proposed experimentation model is executed with five scenarios for a comparison between the impacts of the different assumptions. The simulation results are presented in both a table form and graph. Figure 2 shows the simulation results in graphical format.

Figure 2 shows that the receptionists' utilization decreases dramatically as the number of receptionists increase while the nurses' and doctors' utilization remain the same with the change in the number of receptionists.

Figure 3 shows that the number of receptionists has little impact on the total waiting time of the patients. The first simulation shows that with 1 receptionist, the average wait time of patients at the check-in counter was around 60 min, this causes the patients' flow to the waiting room to slow, as a consequences it reduced the waiting time for nurses and doctors. On the other hand, the overtime for the doctors appears to increase due to the patients' delays in the check-in counter.

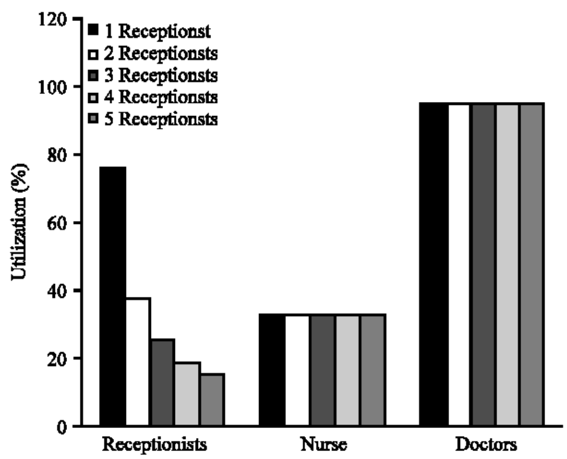

Fig. 2: Impact of the number receptionists on the receptionists' utilization

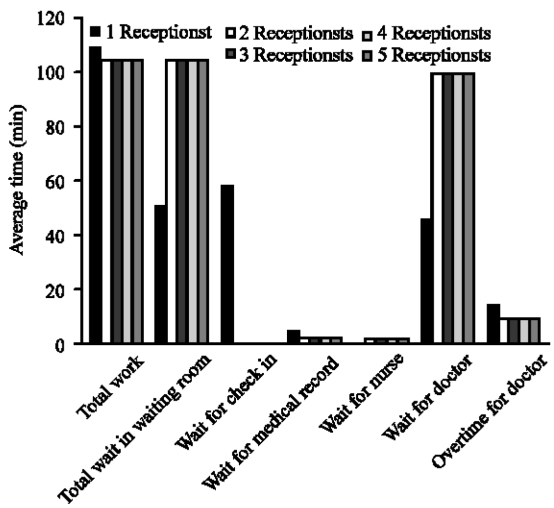

Fig. 3: Impact of the number of receptionists on the average wait time

With the increase in the number of receptionists to 2 in the second simulation, the waiting time for the check-in is eliminated and the waiting time in the waiting room for nurse and doctor has increased. This is due to the quick flow of patients to the waiting room. In addition, the overtime for doctors appears to decrease since most of the patients will be ready in the waiting room to see the doctor upon the doctor's availability.

A number of recommendations were presented to professionals accordingly. These recommendations represent the proposed improvement needed to meet the quality standards. Follows are the recommendations related to the above described scenarios.

Simulation No. 1 : (1 Receptionist):

- Receptionists work needs to be enhanced
- Decrease the number of nurses
- Increase the number of doctors

Simulation No. 2: (2 Receptionists):

- Decrease the number of receptionists
- Decrease the number of nurses
- Increase the number of doctors

Experiment No. 2: Impact of the number of doctors and nurses on resource utilization: The second experiment shows the impact of the number of both doctors and nurses on resource utilization and clinical performance. Simulation parameter were set to number of receptionists = 2 and number of appointments per doctor = 20. The proposed experimentation model is executed with eight scenarios of different combinations. The simulation results are presented both in table form and graph. Figure 4 shows the simulation results in graphical format.

Figure 4 shows that the ratio of number of nurses to the number of doctors has no effect on the receptionists' utilization. The nurses' utilization decreases as the ratio of number of nurses to the number of doctors increases. Nurses' utilization is not enough to determine which ratio is the best, patients' waiting time for nurse related to that ratio should be taken into consideration. On the other hand, the doctors' utilization remains the same and not affected by this ratio.

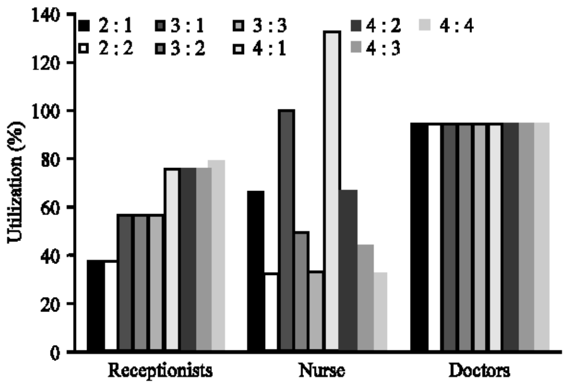

Fig. 4: Impact of the ratio of the number of doctors to the number of nurses on the resource utilization

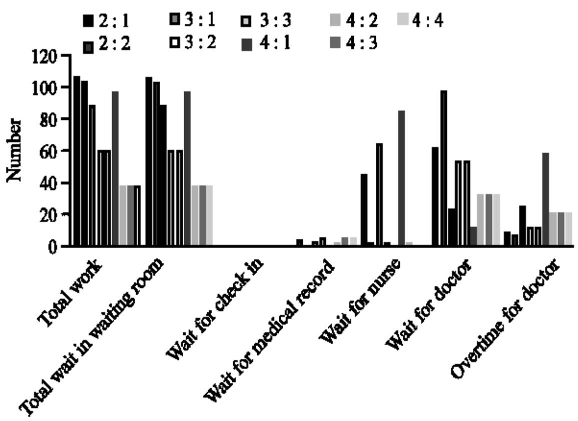

Fig. 5: Impact of the ratio of the number doctors and the number nurses on the average wait time

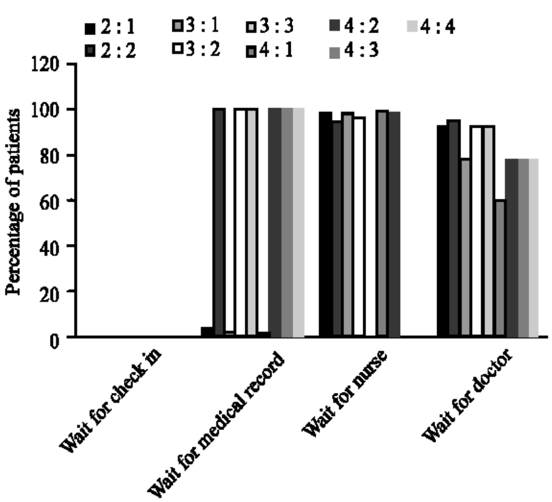

Fig. 6: Impact of the ratio of the number of doctors to the number nurses on the number of patients waiting for the different services

Figure 5 shows that the total waiting time of the patients' decreases as the ratio of the number of nurses to the number of doctors' increases .When this ratio increases, the total waiting time remains the same.

Figure 6 shows that the percentage of patients waiting for the medical record increases as the ratio of the number of nurses to the number of doctors' increases. This is because if there is enough number of nurses the patients may finish from the preparation process before bringing the medical record and the waiting time for medical record will be short.

The percentage of patients waiting for nurse decreases as the ratio of number of nurses to the number of doctors increases.

The percentage of patients waiting for the doctor increases as the ratio of the number nurses to the number of doctors increases and remains the same when number of nurses become 2 or more since when there are enough number of nurses the patients will finish quickly from the preparation process and will be waiting for doctors that are busy with examining the preceding patients.

A number of recommendations were presented to professionals accordingly. These recommendations represent the proposed improvement needed to meet the quality standards. Follows are the recommendations related to the above described scenarios.

Simulation 1. (2 doctors :1 nurse):

- Decrease the number of receptionists
- Enhance the work of nurses
- Increase the number of doctors

Simulation 2. (2 doctors :2 nurses):

- Decrease the number of receptionists
- Decrease the number of nurses
- Increase the number of doctors

DISCUSSION

A dynamic RFID data-driven CDSS would be useful for health care providers. Incorporating real-time data into simulation improves existing static input simulation tools by enabling the creation of more accurate scenarios. The above experiments and results show that the proposed CDSS model can provide one with highly predictive outcomes that reduces risk and increase confidence in decisions to be made. This can help in better managing resources among departments which will impact the overall clinic quality of performance. This indicates that health care providers should give more emphasis and effort in using information technology in improving operation efficiency, bring down the growing health care cost and ensure the high quality of service.

The work focused on the design and implementation of the proposed model. Evaluating and validating the model is a total different work. Another point to consider is the cost-effective study of the proposed model. Applying the proposed system will cost health care providers millions. It is well understood that the improvement in the quality and the performance in decision making well worth the time, cost and effort. Yet, a clear cost-benefit analysis of the proposed solution is needed.

CONCLUSION AND FUTURE WORK

In this study, a RFID-based clinical decision support system using simulation modeling was introduced. Using RFID, health care providers have a chance to track fast and accurate patient, staff and medical records in real-time, improve patient's safety and confidentiality, prevent/reduce medical errors, increases efficiency and productivity and cost savings through wireless communication. The simulation model supports health care decision makers in testing the results related to simulating resource utilization based on the RFID-based collected data. The next step in this research project is to develop a flexible model where patient flow can be rule-based stored and customized to users' specific environment and can be applied into different types of health care institutes.

Decision trees were used to provide recommendations to users based on the simulation results. Future work may involve quantifying the presented recommendations and providing experiments to measure how much did the RFID technology helped in producing more accurate results.

This proposed idea can be applied to other areas such appointment scheduling, resource management, infants safety and others.

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