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RFID-based information visibility for hospital operations: exploring its positive effects using discrete event simulation

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Abstract Long queues and wait times often occur at hospitals and affect smooth delivery of health services. To improve hospital operations, prior studies have developed scheduling techniques to minimize patient wait times. However, these studies lack in demonstrating how such techniques respond to real-time information needs of hospitals and efficiently manage wait times. This article presents a multi-method study on the positive impact of providing real-time scheduling information to patients using the RFID technology. Using a simulation methodology, we present a generic scenario, which can be mapped to real-life situations, where patients can select the order of laboratory services. The study shows that information visibility offered by RFID technology results in decreased wait times and improves resource utilization. We also discuss the applicability of the results based on field interviews granted by hospital clinicians and administrators on the perceived barriers and benefits of an RFID system.

Keywords RFID · Information visibility · Discrete event simulation · Scheduling · Health care · Field interview

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1 Introduction

Recent studies anticipate an increasing demand for health services, especially given the regulatory changes triggered by the Healthcare Affordability Act (Obamacare) in hospitals [1]. Meeting this demand requires the provisioning of more resources in the form of laboratories, technicians, doctors and nurses, equipment, and supplies. To offer an alternative to increasing expenses as a means of increasing capacity, researchers are increasingly searching for ways to improve the *efficiency* or *utilization* of existing resources through patient flow optimization, resource utilization and wait time analysis. Over time, researchers and practitioners have attempted using different decision rules to decrease patient wait times even with limited available resources.

Queue length has a significant impact on patient wait times at various points in the hospital [2], which ultimately affects the quality of health care delivery. Some studies such as Su and Shih [3] have used queueing theories to understand how patients can be scheduled to visit physicians. The basis of such queuing theories is the concept of first-in-first-out (FIFO), which is easier to implement when each queue has a single source and a single sink. This is commonly the case when patients are scheduled to visit physicians after first entering the hospital. However, in reality, during the phase after the physician visit, also known as the post-consultation phase, patient queues would consist of individuals from different physician's visits seeking to complete different labs. A queueing theory that processes patients from multiple sources to multiple sinks quickly becomes intractable to study analytically. Instead, we are interested in exploring the use of simulations to address the challenge posed by the post-consultation phase bottleneck. Our particular focus is on managing the queues created at the various medical laboratories (for post-consultation activities), where patients from different physician's visits complete laboratory tests, and how those queues affect resource utilization and average wait times.

Minimizing the average wait time of patients requires an efficient schedule for post-consultation activities. For example, although medical laboratories are an integral part of the health care delivery system (over 70 % of all medical decisions are based on results from medical laboratory tests [4]), their ineffective utilization leads to disproportionate lengthy queue build-ups. Even though the services that laboratories offer are increasingly becoming distributed, they are tightly related by the cascading effects of the long patient queues they promote [5]. Hence, to achieve overall efficiency in wait times and optimal resource utilization, high resource utilization at supporting departments (such as the medical laboratory departments) should be ensured as well. The medical laboratory division, as a resource component of the hospital, should be operated in a way that it does not negatively affect overall plans of improving resource utilization and patient satisfaction. For instance, all flow times, beginning from the receptionist, to the specialty department, and onward to the laboratory departments need to be considered when trying to improve the quality of health services in the hospital.

Oftentimes, long wait times may be stressful for patients and encourage them to balk or renege from a queue [6]. In most hospitals, the patient's perception of service times is based only on the length and wait time of the queue they are currently in. However, *in a scenario where wait times across the stations of a hospital a patient must visit is visible, the patient is empowered to choose a station with minimal wait time, thereby decreasing the total service time and increasing the utilization of all hospital stations.* This paper takes a simulation-based study of an approach for managing patient queues through the information visibility capability of a Real-time Location System (RTLS), namely RFID technology [7].

We believe this study will be of interest to administrators at hospitals for a number of reasons. First, the study proposes the uncommon idea of tagging patients with RFID technology, rather than tagging equipment or supplies. RFID tagging is already a proven strategy to improve inventory management, and administrators are confident in the technology [8]. Tagging patients empowers them to make their own informed decisions in a hospital (granting some control in their care) while offering a plethora of real-time data that may be used to understand and characterize patient behaviors and wait times across a hospital. Moreover, integrating RFID tags for patients does not require a reorganization of existing services and operations; all that is necessary are monitors to show wait times through the hospital and an information technology infrastructure that can collect real-time data from the tags (infrastructure that is already in place if the hospital uses RFID tags for equipment and other inventory). While cost may be a concern, it can be minimized by giving RFID tags only to visitors seeking outpatient services and by provisioning the tags through a contract with a trusted RFID vendor a hospital may already be doing business with. In addition, to control cost, the RFID tags can be re-used through multiple approaches. Two examples of such approaches are:

1. As part of most hospitals' existing IT infrastructure and patient management system, patients may have permanent identification cards that help them access services whenever they visit the hospital. Such a card can be embedded with an RFID tag. The tag can then be activated and updated with the necessary visit information whenever the patient visits the hospital for health services.
2. Patients are given RFID temporary cards upon entry to the hospital. The card is then submitted back to the front desk when it is time to exit.

The presented study takes a simulation approach to explore the impact of RFID technologies that provide patients with accurate information about their expected wait time to receive services at different lab facilities in a hospital. Simulation, as a methodology, has been used in previous studies to examine various health organization systems, including training and competence building [9]. Concerning the scheduling problem discussed in this paper, it is intuitive to say that, if a patient requires services from multiple facilities in any order, and has accurate data about the wait and service times at each facility, he or she will tend to gravitate towards services with shortest wait times. We use a discrete event simulation to investigate the benefits to wait times and hospital resource utilization when patients are aware of wait times at different functional facilities. We surveyed previous studies and utilized well-accepted parameters for hospital queuing methods to design a simulated health facility that, theoretically, mimics the dynamics and distributions of patient flow patterns. The design of the simulation model is generic, making the observed benefits applicable to any practical setting where patients are given at least one choice about the order in which they visit hospital facilities.

We organize the rest of the paper as follows. First, we present a literature on the concepts of patient flow and wait times in hospitals. We also discuss the role of RFID in managing patient flows based on information visibility. Next, we present our methodology, where we discuss the parameters used to build the two models. Furthermore, discuss the performance measures and statistical tests utilized. In the subsequent section, we present and discuss our results and potential benefits of RFID for managing patient queues and resource utilization. We access the applicability of our RFID proposal by performing field interviews of hospital clinicians and administrators about the perceived benefits, perceived implementation barriers and the need for real-time patient information visibility for hospital operations. Finally, we conclude by discussing the limitations of this study and opportunities for future extensions.

2 Literature review

Efficient patient scheduling to reduce their wait times is necessary to improve operational and financial performance in a hospital. As part of procedures to improve these performances, one aim of most health institutions is to decrease patient wait times [10]. As a result, optimization of workflow processes, with the aim of increasing resource (e.g. staff, equipment and facilities) utilization and decreasing wait times has been a popular subject in previous research. For instance, in their study, Xiao et al. [11] investigated how workflow in the emergency department could be improved and optimized using a discrete event simulation approach.

The flow of patients in a hospital can take many forms and paths. Previous research proposes that workflow, rather than lack of resources, is a major bottleneck in eliminating delays in hospital scheduling operations [12]. Patients who visit health institutions are commonly required to perform multiple lab tests and wait for results after the physician consultation. Queues with different lengths and wait times occur because of these lab test requirements.

Previous research has utilized different techniques to study queues and improve scheduling in health facilities. For instance, a pioneer in hospital appointment scheduling, Bailey [13] implemented an individual-block appointment system with fixed intervals equal to average consultation times and with two initial patients. This was designed as an improvement over one of the existing appointment systems which was based on a single-block system where all patients are assigned to arrive at the same time [14]. By use of discrete event simulation, Lailomthong and Prichanont [2] studied patient wait times with various appointment strategies with a focus on reducing the number of patients who visit the hospital for treatment at the same time. Brahimi & Worthington [15] developed a time-dependent queuing method to study outpatient appointment systems and thereby improve patient wait times. They formulated their proposed queuing system as an inhomogeneous Markov chain in discrete time, and extended the method to systems with continuous time distributions.

Rather than focusing on patient schedules as a way of improving patient wait times, Yeh & Lin [16] studied how to minimize patient queue times by optimizing the scheduling of nurses. They applied a genetic algorithm to nurses' hospital schedules to produce near-real time schedules. Using this approach, they found that average queue times at the hospital they studied could be reduced by up to 43.47 %.

Technology-enabled tracking techniques such as RFID technology, are common in many applications such as supply chain and security [17]. For instance, in the case of security, RFID technology is used as a mechanism to control access to buildings. In healthcare, RFID has been implemented to support or enable different operations. For instance, Chowdhury & Khosla [18] developed a model for a hospital patient management system using RFID. Among other things, their model helped improve patient safety, avoid adverse drug events and reduce cost. Also, a previous study by Amini, Otondo, Janz, & Pitts [19] described how RFID could be used as a unique approach to collect data on trauma patient flow in a hospital using a discrete simulation approach. In their research, they leveraged high value data produced by RFID to simulate the movement of patients from the critical care assessment area in a trauma center to the X-ray and CT/MRI labs. Patients, in no scheduled order, underwent a random number of labs.

Fisher and Monahan [20] performed a qualitative study in which they conducted 80 semi-structured interviews at 23 U.S hospitals over a three-year period to assess the use of real-time location systems in different contexts. In their study, they found that RFID technology helps in asset, personnel and patient tracking. However, their study also identified that for RFID implementation to be successful, hospitals must understand and consider their unique environments for using the technology. Particularly for patient tracking, which is uncommon in most hospital implementations, there needs to be a clear rationale, set of goals and specific scenarios to guide the implementations. Hence, RFID human-tracking implementations in different hospitals could potentially yield different results based on specific scenarios and goals for implementation.

In this study, we present the use of a simulation model as a way to understand the impact and performance that an RFID-based scheduling approach will have on improving patient scheduling in a hospital environment. As is suggested by previous studies [20], we perform our analysis in a specific context, and with a specific goal to schedule patients for multiple clinical lab tests after an initial physician consultation. The result of the simulation study can then support decision-making about the implementation of an information visibility technology such as RFID in a hospital. We develop and present a simulation case study based on hospital industry-specific parameters to show how health institutions can understand and identify the benefits of an RFID implementation in their business operations.

3 Methodology

In this section, we present a brief overview of the RFID technology and explain how the technology is well suited for providing information visibility in a hospital. We also present the problem scenario in which RFID technology could be beneficial to patient scheduling. We then present a baseline model, an RIFD-based model and the parameters used to build them.

3.1 RFID technology

For real-time information visibility, RTLS have been one of the most widely used platforms [8]. RTLS technologies such as RuBee is a two-way wireless protocol that uses Long Wave magnetic signals to help provide visibility for high-security assets [21]. However, for information visibility, most of these new systems have not reached a matured developmental stage. Particularly for applications that focus on equipment, supply, and device tracking, RFID has been the technology of choice in health care as a result of its relative operational maturity [22]. Thus, we propose the use of a proven RTLS technology to track not only equipment and supplies, but also patients within the hospital. RFID is a semiconductor-based technology that operates through wireless means to track or identify objects [23]. At the basic level, it works with two components; a tag and reader. The tag contains a transponder that transmits wireless messages such as an ID stored in a database. The reader's role is to receive and authenticate the messages it receives from the RFID tag. RFID tags come in two forms; either a passive tag or an active tag [17]. Active tags have their own power source, are more powerful and expensive. Passive tags are less powerful than their active tag counterparts and less expensive. The use of technology (e.g. RFID) in health care has a positive influence on operational efficiency and financial performance of health institutions [24]. That is, instant business decision can be made based on real-time data produced by an RFID system without necessarily making substantial changes to the business processes [25]. The RFID system can generate real-time data about wait times at different lab facilities, and offers the needed information visibility to help achieve this purpose.

3.2 Problem scenarios

We developed simulation models for two scenarios (Fig. 1) with the SIMIO simulation software (Enterprise Edition Version 7.124) [26]. The first model is a 'Baseline Model' depicting an existing patient flow model in a hypothetical hospital with mid-sized capacity.

This hospital has a basic Electronic Health Records (EHR) management system but does not use any RFID technology to handle patient scheduling. The second 'Information visibility-enabled' scenario models the same hospital setup but with an RFID component, where patients are tagged with RFID tags, and data on their queue activities at the various lab facilities are recorded. This is for efficient scheduling of patients who are advised to perform a set of multiple laboratory tests by their physician. The patients would not actively engage with the RFID technology. Rather, information would be passively transmitted by RFID tags to the RFID receivers for processing. Hence, the level of a patient's expertise with the RFID system or technology, in general, would not be a prohibitive factor in the implementation of the RFID system. Our aim was to study the impact of the RFID technology on patient scheduling as compared to a traditional non-RFID method of scheduling.

3.3 Post-consultation phase

The two models only consider a scenario where patients have to perform labs tests. Whereas not all physician-patient encounters result in a request for lab tests, studies have shown that physicians rely heavily on lab results for decision making [4], and order an average of 3 lab tests per patient per day [27]. In our model, we, therefore, schedule patients for 3 lab tests per physician visit per day. Furthermore, although patients may need to visit just a subset of the available labs or need to visit labs in a particular order in practice, we do not impose such an order or precedence requirement. The reason for this is two-fold. First, requiring patients to visit labs in a specific order negates the benefits of the information visibility RFID offers. For example, if every patient was required to visit each lab in a specific order, patients will never be able to select what laboratories to visit, and hence cannot leverage the knowledge about the labs' wait time data to minimize their total time in

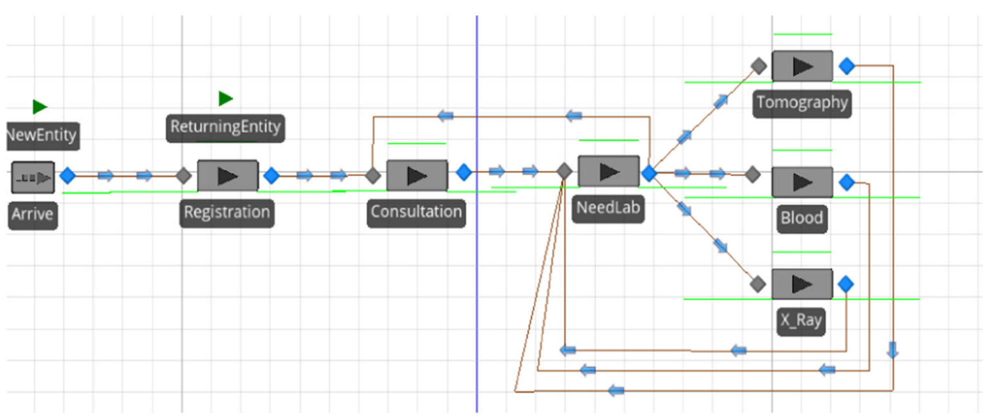


Fig. 1 SIMIO Discrete Event Simulation Model

the hospital. Second, simulating the general case where any lab can be visited in any order yields insights that are generalizable to any concrete hospital scenario where patients can choose the order of their lab service. For example, in a real-life 'mixed' scenario where some labs must be visited in a specific order but other labs can be visited in any order, the former 'chained together' labs can be collapsed into a single unit and thought of as a single laboratory in the simulation model with its own queue and service time.

In the baseline model, patients choose with uniform probability the order in which they visit the labs. Scheduling does not take into account the current workload of a particular lab department. Hence, a patient may choose to visit the closest lab right after visiting the physician without having cognition of the queue lengths at other needed labs. The problem with this approach is that if the queue at the patient's first choice of lab is too long, while the subsequent required labs have shorter queues, the patient's overall wait time at the hospital could increase unnecessarily. If a patient knew which lab had the shortest queue at any point in time, it would be to his or her advantage to visit that lab first.

3.4 Hospital layout

Hospitals of different sizes operate based on different patient workflows. However, there are many similarities in terms of key procedures used to reduce bottlenecks in patient flow. The procedures patients go through, as described in this paper are based on an ambulatory care type of health care delivery, where there are a lot of paper-based and face-to-face interactions [28]. The simulation models a standard Outpatient Department (OPD) where there is a registration point, waiting rooms, specialty departments and medical laboratories. It has the capacity to carry out various medical laboratory tests at different stations within the hospital premises. Specifically, we model medical labs for Blood Test, Computer Tomography and X-ray.

3.5 Baseline model

We built the baseline model (shown in Fig. 2) to reflect a scenario where no RFID or any other Real Time Location System (RTLS) is in use. In the baseline model, patients do not have prior knowledge of the queue lengths at various labs and thus, randomly choose which lab to visit. Both new and returning patients visit the registration desk for patient registration. The receptionist questions the patient regarding the purpose of his or her visit so he or she can be referred to the requisite specialty department.

After registration, the patient waits in the reception area until a nurse from the specialty department comes to call him or her. Meanwhile, the specialty department is provided with documentation of the patient's visit and information. Once the patient reaches their destination, a nurse records the patient's vital signs and documents this information in a

Fig. 2 Baseline Patient Flow Model

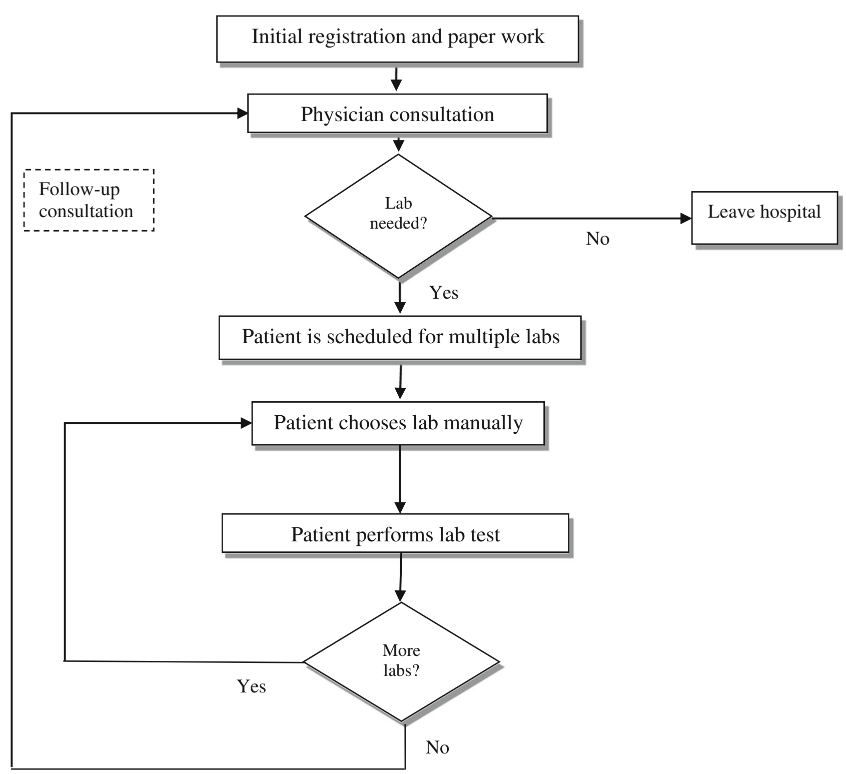


chart. Next, the physician receives the patient when it is his or her turn for consultation.

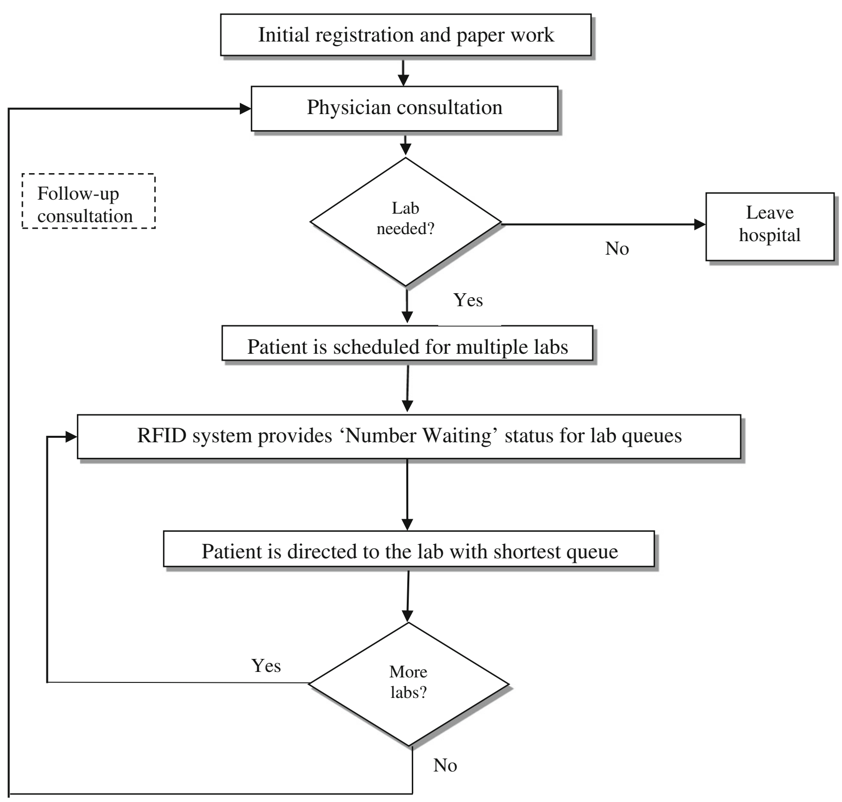
After consultation, the critical phase of our models begins. If the patient needs further lab tests, the physician directs him or her to complete those labs. The patients proceeds to schedule those labs at random. Otherwise, the patient may leave the hospital. Once the tests are completed, the patient returns to the physician for a follow-up, and then leaves the hospital.

3.6 RFID-based model

The information visibility-enabled (RFID-based) scenario, shown in Fig. 3, demonstrates the scheduling of patients with knowledge of real-time information from the RFID system. This scenario considers the use of RFID for patient tagging and subsequent collection of patient flow data. The information is to help schedule patients to the shortest queued labs, and hence eliminate bottlenecks. This, in turn, would help reduce cost as well as help speed up the health care delivery process. In this scenario, the patient begins his visit at the registration desk for registration procedures. The receptionist asks the patient's purpose of visit to determine what department he or she should be referred to. In case of a new patient, he or she is given an RFID smart card that contains all his personal information as well as information about the purpose of his visit. This information is automatically entered into a real-time monitoring system that contain information regarding personal identification, along with information on the department and the specialty room the patient has been referred to.

A unique part of the information, identifiable by only the patient (e.g. patient ID) is also shown on a TV monitor stationed at the waiting area and at various lab departments. Both returning and new patients need to register their RFID-enabled ID cards at an RFID kiosk. When it is the patient's turn to see the physician, he or she goes to the indicated room number shown on a monitor. At the physician station, the nurse first takes the patient's vital signs after which the patient goes to see the physician. This information is added to the patient's RFID record (consisting of activities tracked by his RIFD tag). After consultation, if lab works are required, the patient is informed of the appropriate labs to perform. The physician enters the information into the electronic health record system to which all relevant lab departments have access. Since all labs have different service and wait times, the RFID system can use the current number of patients at each of the locations to establish queue lengths and help direct patients to the lab with the shortest queue. The RFID system provides information on queue lengths at the various labs via TV monitors stationed at the waiting areas and at the lab departments. Based on this information, the patient may choose the shortest queue. After each lab, the patient is able to access real-time updates of the queue length for each remaining lab as provided on the TV monitor. Based on that, information, he or she determines the order in which to visit the labs.

Fig. 3 Patient Flow Model Based on Information Visibility (RFID-Based)



After each test is conducted, the result is entered into the electronic health record so that the relevant lab departments and physicians can have access. Based on lab results, the physician reviews his earlier therapy and may make changes to the initial treatment plan. The patient may then exit the hospital after this step. The RFID readers located at the hospital exits record when patients leave and deactivate them from the system.

3.7 Model parameters

The simulation parameters were derived from previous research on patient scheduling and OPD workflow optimization. Different studies have suggested specific time periods for different processes and specialty areas at the OPD [29]. For instance, the typical outpatient appointment time for a private practice is about 10 min [30]. Typically, patients do not make it for their medical appointment at the exact time. They are either late or too early, which leads to increase in physician idle time or patient wait time respectively. Based on Bailey's rule, which proposes an appointment system where the inter-arrival time of patients is based on the average of the consultation times of patients, [13] we chose an average inter-arrival time of 8.96 min [31]. In order to assess the performance of our output measures (discussed in next section), we performed a sensitivity analysis where we varied patient inter-arrival times between a range of 6.96 min and 10.96 min with a median value of 8.96 min.

Two different types of patients visit to the hospital were modeled: new patients and returning patients. Patients who did not need medical lab tests were not of primary concern in our study. Both new and returning patients pass through the same process except that first-time visitors need to register separately for an RFID smart card. We modeled the distribution of patients' visit to the hospital according to the results of the National Hospital Ambulatory Medical Care Survey of 2007. The survey states that 82.9 % of patients who visited the OPD were established patients while 17.1 % were new patients [32]. In addition, 69.7 % of patients who visited the clinic were asked to return for a follow-up consultation.

Multiple variables could affect patient wait times and physician idle times at the hospital. Some of these are patient appointment interval, service time at laboratories, patients' arrival pattern, frequency of no-shows and walk-ins, physicians' arrival pattern, and interruptions in patient services [10]. In our study, we used parameters related to service, wait and patient inter–arrival times to build the simulation models. The models simulate labs for X-ray, Computer Tomography, and Blood Test departments. Based on an average of 2000 patient visits per week, the distribution of patient flow at various points in the hospital is shown in Table 1. Each lab station has two lab technicians except the Blood Test lab, which has only one technician.

Table 1 Parameter Values for Main Processes used in Simulation Models

Process	Distribution (minutes)
Inter-arrival times	8.96 [31]
Registration	
New patients	Exponential (5) [33]
Returning patients	Exponential (1) [33]
Physician examination time	TRIA(10,15,30)
Laboratory work	
Blood Test (Lab 1)	Uniform (1,2) [29]
X-ray (Lab 2)	Uniform (5,10) [29]
Computer Tomography (Lab 3)	Uniform (5,10) [29]
Follow-up appointment	Uniform (15,30) [29]

3.8 Performance measures

In our paper, the performance measures are based on resource utilization and the influence of average queue length on the average time patients spend to finish their lab procedures. Improving utilization of resources not only helps to decrease lengthy queues at the medical labs but also, subsequently improves quality of care [34]. By decreasing the patient average wait time such that the idle times at the consultation room and lab are decreased [33], more capacity is generated. The hospital is, therefore, able to take care of more patients per day and increase efficiency. Moreover, higher utilization also reduces the amount of time during which staff and expensive medical equipment are sitting idle.

As we modeled and measured the performance of the two patient flow scenarios (RFID and baseline), we determined whether the use of information visibility-based scheduling could lead to an improvement in resource utilization, average queue length and patient wait times. We determined the statistical significance of the differences between the parameter values in the two models at all the labs. We performed paired-samples t-tests for the average wait time, average queue length and utilization for all inter-arrival times.

4 Results

In this section, we present results of the simulation study, statistical analysis, and discuss the related findings. We also discuss a post-hoc qualitative study in which we performed field interviews of a group of hospital clinicians and administrators to determine the benefits of our proposed RFID system and barriers to its implementation.

4.1 Simulation and statistical analysis

We ran 40 replications of the simulation models. Each replication lasted 240 days with a warm up period of 7 days. Table 2 shows measurement values for 'Average Wait Time' (in minutes), 'Average Queue Length' and 'Lab Utilization' for both the baseline and RFID-Based models.

We also performed a paired-samples t-test to determine, whether for the same patient flow environment in a hospital, performance values generated by the RFID-based technology was significantly better than values generated by the baseline scenario for our variables of interest (Table 3). All tests were performed at a significance level of 0.05. The 'Average Wait Time' for the RFID model was significantly lower than for the baseline model at all the three labs (i.e. Blood test lab, $t(4) = 2.83$, $p = 0.047$; X-ray lab, $t(4) = 3.141$, $p = 0.0348$; CT lab, $t(4) = 2.878$, $p = 0.045$). Also, the 'Average Queue Length' at the labs was significantly higher in the baseline model as compared to the RFID-based model except at the Blood test lab (i.e. Blood test lab, $t(4) = -0.836$, $p = 0.450$; X-ray lab, $t(4) = 3.359$, $p = 0.028$; CT lab, $t(4) = 2.301$, $p = 0.083$). There was no significant difference in 'Lab Utilization' for both the RFID-based and baseline models at all the labs (i.e. Blood test lab, $t(4) = -0.248$, $p = 0.816$; X-ray lab, $t(4) = -0.901$, $p = 0.418$; CT lab, $t(4) = 0.696$, $p = 0.525$).

4.2 Field interviews

To assess the applicability of our RFID system proposal, we performed field interviews of a group of both physicians and hospital administrators about the implementation of our proposed system in a hospital. We adopted a survey instrument by Yazici [8] in which the author studied the benefits of auto identification and data capture technologies for real-time equipment and people management. We interviewed three hospital administrators and three physicians who work at both mid-sized and large hospitals in the east coast, southern and mid-western regions of the United States respectively. The hospital environment is unique, given that physicians have a considerably higher degree of freedom in how they dispense their duties in comparable to other support and administrative staff. However, the administrators generally possess a better practical understanding of the operational needs of different sub-systems within the hospital and how they should interact to achieve a more efficient system. We, therefore, wanted to understand the practical reactions of both groups of employees at the hospital regarding the use of the RFID technology for patient scheduling. Each field interview lasted an average of 40 min. We grouped a set of semi-structured interview questions into three categories to address the following: (i) perceived benefits of our proposed RFID system; (ii) perceived barriers to the implementation of our proposed system; and (iii) the existence of the need for real-time information visibility for patient scheduling in the hospital. The questions in these categories only served as probing questions and often led to detailed discussions on some topics.

4.2.1 General interview findings

Perceived benefits of RFID for patient scheduling From the study, both the clinical staff and the administrators perceived that the proposed RFID system would help improve the efficiency of patient scheduling, particularly in large hospitals. The respondents noted that the system would help increase patient satisfaction. As one respondent observed, "Patients will be extremely happy if they can finish up their labs early and spend less time at the hospital." Another respondent noted, "Besides scheduling, the location

Table 2 Simulation Results for Baseline and RFID-based Models

Inter-Arrival Time	Average Wait Time			Average Queue Length			Lab Utilization		
Baseline Model									
	Blood	X-ray	CT	Blood	X-ray	CT	Blood	X-ray	CT
6.960	0.180	1.18	1.140	0.027	0.160	0.160	21.530	53.850	53.890
7.960	0.156	0.780	0.780	0.010	0.100	0.098	18.720	46.970	46.900
8.960	0.156	0.714	0.640	0.010	0.070	0.070	16.650	41.720	41.800
9.960	0.120	0.480	0.468	0.010	0.050	0.047	15.050	37.730	37.680
10.960	0.108	0.380	0.380	0.010	0.035	0.030	13.690	34.130	34.070
RFID-Based Model									
	Blood	X-ray	CT	Blood	X-ray	CT	Blood	X-ray	CT
6.96	0.168	0.950	0.840	0.023	0.137	0.120	21.50	53.870	53.760
7.96	0.138	0.660	0.600	0.017	0.084	0.079	18.830	46.948	47.010
8.96	0.132	0.550	0.498	0.014	0.060	0.050	16.60	41.740	41.490
9.96	0.120	0.432	0.414	0.012	0.043	0.040	15.070	37.710	37.549
10.96	0.102	0.354	0.354	0.009	0.032	0.033	13.675	34.239	34.230

Table 3 Results of Statistical Tests

Variables (Baseline-RFID)		Mean	Std Deviation	Std Error	t	df	Sig. (2-tailed)
Average Wait Time	Blood	0.0120	0.0095	0.0042	2.8280	4	0.0470
	X-ray	0.1176	0.0837	0.0374	3.1410	4	0.0348
	CT	0.1404	0.1091	0.0496	2.8780	4	0.0450
Average Queue Length	Blood	-0.0016	0.0043	0.0019	-0.8360	4	0.4500
	X-ray	0.0118	0.0079	0.0035	3.3590	4	0.0280
	CT	0.0166	0.0161	0.0072	2.3010	4	0.0830
Utilization	Blood	-0.0070	0.0630	0.0282	-0.2480	4	0.8160
	X-ray	-0.0214	0.05309	0.02374	-0.901	4	0.418
	CT	0.0602	0.19348	0.08653	0.696	4	0.525

visibility capability of such a system would help track some types of patients such as geriatric and psychiatric patients who may tend to wander off."

Perceived barriers to the implementation of proposed RFID system The respondents noted that the cost and complexity of the RFID implementation could hinder its adoption. Interestingly, while clinicians agreed that such a system would have a high level of priority in terms of technological needs in the hospital, administrators perceived otherwise. The administrators generally oversaw the prioritization, acquisition, and development of different projects at the hospital and from a sea level perceived other projects could be more strategically important than an RFID implementation. Also, the administrators noted that the adoption of RFID could be hindered if it requires a significant level of workflow and process re-design. Such changes may necessitate added employee training and active participation that would introduce a level of task to their existing busy schedule. Requiring such commitment from employees, may result in considerable push back if not planned well, especially from physicians who carry out their duties in a relatively semi-autonomous manner, as required by their profession.

Another barrier that both the clinicians and administrators noted is the ability of the RFID system to integrate with existing IT infrastructure at the hospital such as an Electronic Medical Record (EMR) system. Furthermore, a key concern was the ability of the system to be compliant with the Health Insurance Portability and Accountability (HIPAA) Act. One respondent noted, "Only non-identifiable information should be displayed on the TV monitor, else it would not be acceptable!"

The existence of the need for real-time information visibility for patient scheduling All the respondents expressed the need to facilitate patient inflow and outflow at the hospital. The respondents expressed that if patients could finish their lab works early due to their ability to choose which lab to go first, lab results can get to physicians on time for further review. This would help improve the quality of care provided to patients. The administrators generally supported the view that an optimal use of such a system would be in large hospitals spread over a relatively larger geographic area. They agreed that besides information visibility, the geo-location identification capability of an RFID system would help satisfy key return in investment (ROI) requirements by higher-level managers.

5 Discussion and implications

Benefits of the use of RFID as a real-time location system option in health care environments have been well explored in the previous studies. However, most studies on the implementation of RFID have focused more on tagging of equipment, and less on tagging of humans. Part of the reason is attributed to lack of justification for the operational feasibility of how human tagging with RFID technology could help improve business processes. This study contributes to the existing literature on RFID implementation on health care by showing, via discrete simulation, that health institutions could indeed improve their operational efficiency by tagging patients and gaining information visibility. Besides enabling the effective use of laboratory resources as shown in this study, RFID patient tagging can also support efficient billing and streamline the patient discharge process [35]. During emergency periods such as flu outbreak, tornado or other disasters, the surge in the volume of patients may make previously determined distribution models used to forecast service demands at the lab unreliable. An RFID system, when used, could schedule patients such that lab queues do not backup while other labs are near empty.

Furthermore, an RFID system can offer real-time information about the human resource needs of each lab such that there could be the possibility of re-assigning non-essential personnel, whose skills can be leveraged at any lab irrespective of the type of clinical lab (e.g. data entry clerks). For instance, when the patient-to-staff ratio exceeds the acceptable limit at a particular lab facility, staff from other facilities can be re-assigned temporarily to ease up the congestion created by an increased queue length.

The simulation and statistical analysis shows that generally, RFID technology can significantly improve patient scheduling in a hospital. It was noted that since the ‘Average Wait Time’ in the baseline model is relatively higher than in the RFID-based model, it results in a higher average number of patients waiting in queues to perform their lab tests as compared to patients in the RFID-based model. Hence, for the same lab procedure, the RFID-based model creates a relatively shorter queue than the baseline model. Compared to the baseline model, the RFID-based model approximately maintained the resource ‘Lab Utilization’ at all three labs, while decreasing the ‘Average Wait Time’ and ‘Average Queue Length’ parameters. It is worth noting that the variability of the ‘Average Wait Time’ and ‘Average Queue Length’ parameters decreased by approximately 60 % when the RFID-based model was implemented. Also, as the ‘Inter-Arrival Time’ increased, the ‘Average Wait Time’ and ‘Average Queue Length’ parameters decreased across all 3 labs.

In general, information visibility provided by the RFID-based model can help improve customer experience at the hospital in terms of length of outpatient visit at the hospital. In addition, by maintaining a balanced workload across all labs, even for different inter-arrival times, staff allocation can be well planned for different labs. This would help decrease employee ‘burn-out’ as well as lab underutilization.

Whereas both clinicians and administrators perceived the use of the RFID technology as beneficial to patient scheduling in the hospital, the administrators mostly perceived that the implementation, if not carefully considered and planned may be hindered by a couple of unintended consequences. Such factors include an added layer of task for both clinicians and support staff as they are required to support patients with directions on the use of the technology. The implementation may also require an additional need for more staff to serve as coaches. This added cost could only be justified if a well-articulated ROI is developed as part of the project proposal.

6 Limitations and research opportunities

It is important to note the key limitations as well as potential opportunities for our study. First, the simulations we ran could be considered as a synthesis of a number of empirical studies on hospital patient dynamics, in the sense that the distribution of simulation inputs use well-established parameters from the literature. While this approach is consistent with a simulation methodology in similar projects, when not applied carefully, it could yield a level of abstractness in the results and make it deficient of a real-world experience. Hence, while our approach of using well-established statistical distributions for our parameters may be adequate to generate results amenable to statistically compare RFID and non-RFID settings, fitting simulation inputs to real data from a real hospital would be ideal.

Secondly, the model assumes all patients would respond to the RFID-based information in a manner that would lead them to choose the lab with the smaller wait time. However, in reality, patients may actually disregard the information provided by the RFID monitors, thus yielding a detriment to the overall optimization of the workflow in the hospital. Finally, the simulation model could have benefitted from a more extensive sensitivity analysis with respect to different changes in the distribution of patient inter-arrival and laboratory service times. There is no question that an extensive sensitivity analysis would be useful to exercise whether our key insight, namely that RFID-based information improves utilization, decreases patient wait times and queue length, still holds under a wider variety of operating conditions. However, it is important to recognize that, for the sake of determining if the RFID-based information has a benefit in a generalizable setting, fixed parameter settings taken from previous studies is still reasonable.

Beyond addressing the limitations, we present several directions for potentially extending this research. First, further studies would have to explore actual patients’ reaction in an implementation and the need for employee participation in coaching patients on the appropriate use of the information provided to them. This study should explore how patients actually react to the ability to choose their own lab sequence based on information provided by the RFID system.

Also in an implementation of our recommendations, extensive sensitivity analyses should utilize actual statistics of patient flow in both pre- and post-RFID scenarios to determine the real benefits of an RFID-based system. The study should be conducted in a large hospital since, as identified through the field interviews, large hospitals can better optimize the information visibility and location identification capabilities of an RFID system than small hospitals.

Finally, the study could be extended to include other aspects of a hospital’s operations besides laboratory tests. For instance, we intend to study triage operations in emergencies such as earthquake and hurricane occurrences where the inflow of patients can reach exponentially high values within a short period.

7 Conclusion

In this multi-method study, we conducted a simulation study on the scheduling of patients for medical laboratory tests in a hospital environment using the RFID technology. We explored the role of RFID systems in supporting information visibility in the health care environment, and how that leads to improved patient laboratory scheduling. Simulation models were developed and compared for two scenarios. The first scenario was a baseline model where patients visited medical labs for tests with no cognizance of existing queue lengths at the lab facilities. For the same hospital environment, we modeled the second scenario (RFID-based scenario) such that patients had prior knowledge of the current queue length at the various labs, and using this information, could go to the lab with the shortest queue. In a post-hoc study, we performed field interviews of a group of physicians to determine the applicability of our proposed RFID-based system in a hospital. This study shows that RFID-based information visibility scheduling could help reduce the total number of patients in a queue at the various labs. This further helps decrease the total wait time of patients at the hospital, subsequently leading to greater quality of care and patient satisfaction.

Interviews with a group of hospital clinicians and administrators from different hospitals indicate that there is a need for the use of RFID for patient scheduling. However, such an implementation would require careful planning such that it fits into existing IT infrastructure in the hospital. This would present a two-fold benefit; first, it will help decrease the cost of the implementation of such a solution. Next, it will help in the seamless integration and running of the RFID technology with existing critical IT infrastructure in the hospital such that there is no lapse in operational and regulatory processes. Although this study focused on scheduling for patients for lab work, it can be extended to include other functional areas of a hospital's operation.

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