Portable Equipment Management in Hospitals

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Abstract

This study presents an analysis of portable equipment management in hospital environments. Considering the significant amount of personnel time for equipment search, this research investigates management models, tracking activities, and technology involvement in equipment management. A simulation-based decision support tool is developed to analyze the different processes and the impact of RFID technology on the widely-adopted organizational systems: centralized, semi-centralized and decentralized. The three organizational systems are analyzed with equipment management supported by either RFID or no technological framework. Using the search time for an item as a performance measure, the better systems as well as the improvable ones are identified.

Keywords
Hospital, tracking, management, equipment, simulation

1. Introduction

Asset management is a critical part of a hospital's logistical operations. Large quantities of equipment are being used to serve a great number of patients in environments that are highly sensitive to time and pressure. According to a study performed by Dr. John Halamka, CIO of CareGroup and Harvard Business School, doctors and nurses spend "an average of 20 minutes a day looking for misplaced equipment, at a cost of up to $100 an hour" [1]. That is why the availability and utilization of equipment as well as the time needed to acquire them are keys to an efficient logistical system.

To help hospitals improve their operations, uses of RFID technology in the healthcare industry are evaluated and classified into five major categories: asset management, inventory management, authenticity management, identity management and process management [2]. The scope of this study falls into asset management, which involves tracking and managing medical equipment (such as IV pumps, wheelchairs, and air purification equipment) inside healthcare organizations to improve asset visibility and utilization.

To simplify the analysis of such organizations and their associated management systems, a hospital is viewed as a set of departments called *units*. Based on the structure of units, asset management and logistical systems in hospitals can be categorized into the following groups:

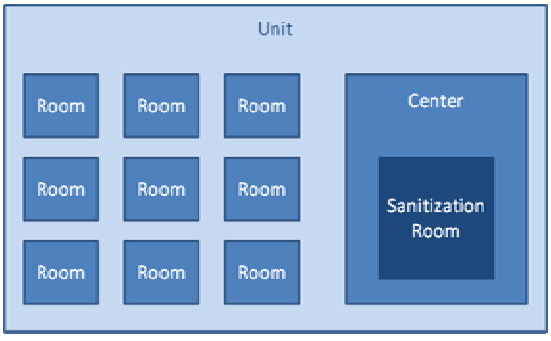

Figure 1: Layout of a hospital's unit

Centralized systems: A centralized hospital system has only one unit with one equipment center (a layout example of a unit is depicted Figure 1.) In this unit, cleanable tools are checked out from the unit's center, used, cleaned, and then returned to the center before they are given to the next nurse. On the other hand, sanitizable tools are checked out from the unit's center, used, but then returned to the center to be sanitized before they are given to the next nurse.

Semi-centralized systems: A semi-centralized hospital system has a set of units with a centralized system in each. However, both cleanable and sanitizable equipments are shared among the units' centers. Items are transferred from one unit to another when nurses do not find an available item in the unit s/he is assigned (his/her original unit.) This creates a material-flow in the system that leads nurses to search for equipment in external units when none are

available in the original unit. In that case, the nurse checks out an item from an external unit, but returns it to the center of his/her unit.

Decentralized systems: In a decentralized system, there is one center in which sanitizable equipment is sanitized and checked in/out; the rest is located in the hospital's rooms. In other words, while cleanable equipment is cleaned and left in the room where it was used, sanitizable items are picked by a *collector* from rooms and taken to the center to be sanitized. This collector performs his cycles periodically by visiting rooms, picking items that need sanitization, and taking them to center to be sanitized.

These systems may or may not use the support of a technological infrastructure/framework such as RFID, which has a set of features that allows the organization to run their operations at a certain level of efficiency (see Table 1.) Note that equipment tracking systems in this study are assumed to be accurate and reliable, and the evaluation of different technologies such Active RFID, Passive RFID, and RFID-IR is out of scope.

Table 1: Investigated technological infrastructures

Option	Cost	Features
Manual	Free	- Traditional search for equipment - Equipment collection based on exhaustive search
RFID	Expensive	- Knowledge of the exact location and status of each item - Equipment collection based on visiting necessary rooms only

In this paper, the use of RFID technology is adopted and its impact on the previously-mentioned systems is investigated. Such adoption is based on the assumption that RFID technology adds value to the hospital's logistical system by enabling the lookup of an item in order to know its location and usage-status immediately. Therefore, the use of this technology saves time for the nurse and the collector to find available objects in a decentralized system. Moreover, in a semi-centralized system, where tools can be shared between units, nurses can directly refer to centers where the items are available (without passing by the center of their unit if no item is there.) For centralized systems, the difference that RFID makes is providing knowledge about the status of each item (busy, idle, being sanitized, etc) which might affect the behavior of personnel in the system, but that is out of the scope of this paper.

2. Previous Work

Several current studies are targeting the healthcare sector in order to increase the efficiencies and lower the cost of operations in hospitals while maintaining the provided quality of the patient-care. Amongst the tools that are used to reach such goals are RFID tracking systems. For instance, National Taiwan University with Taipei Medical University has conducted a case study which showed the integration of the RFID system into the medical world at one of the national hospitals in Taiwan [4]. This case study proved that using RFID system in their devices and data management contributed to improvement of operating efficiency as well as better medical service and patient safety. They have suggested that RFID system with some organizational changes would give positive results in any hospital environment. A similar case study has been conducted at the Duke University Medical Center where they have implemented RFID technology to track the hospital beds, sequential compression devices and infusion pumps [5]. During a six-week period, the group has collected and analyzed data, and concluded that with an RFID system, there is an increase in equipment utilization. Furthermore, nurses had a positive impression of the system. In addition, a different study performed by Hakim *et al.* was based on embedding an RFID system in hospitals' asset-monitoring system [6]. They have conducted a Return on Investment (ROI) analysis and evaluation, which justified feasibility of implementing a hospital wide asset-monitoring system with passive RFID tags.

3. Approach

In order to investigate how the different management and operations models perform, and how they are affected by the integration of a specific technological infrastructure, a Java simulation-based model is developed in a flexible way to allow different variable entries. System variables include the type of the system, its technological framework, the number of rooms and units, the number of items being tracked, the demand associated with them, the expected utilization time, and the time needed to travel from one place to another.

Since the main difference between the systems is the way operations are performed, the simulation model was built as a task-oriented one. To be more specific, a hospital is formed from one or more units (e.g. emergency department, intensive care unit, OR department, etc.), where each unit, center, and room is associated with a list of tasks to be performed by the nurse or the collectors. Also, since the personnel are the ones seizing the equipment resources, they are generated according to the given demand rate in a certain place of a hospital. That leads them to follow their corresponding task-list before leaving the simulation system. The constructed tasks that are used in the simulation model are given in Table 2:

Table 2: Constructed tasks used in the simulation model

Task	Description
Delay	Helps advance the simulation clock due to the performance of an operation
Seize	An event that allocates a resource to a nurse, and transfers it from an external unit to the nurse's original unit if these units are different
Release	An event that frees an allocated resource and allocates it to the next nurse waiting in line (if there is one)
TrySeize	A branching mechanism that performs a Seize if possible. If the Seize is successful, the next task in the sequence is performed; else, an alternative task is carried out (usually a search).
Travel	Directs an entity (nurse or collector) to a destination, and then schedules a delay to model the trip duration.
Reoriginate	A Travel to the original place (unit/center/room) of an entity.
Search	A combination of a Travel and a TrySeize that helps visiting new places until a tool is obtained.
Find	A set of lookups and Travels: If a nurse finds an available resource when performing a lookup, s/he travels to it to acquire it. If s/he does not find it when s/he arrives to the destination, s/he redoes the lookup. If s/he does not find any available resource at all, s/he goes and waits in line in the original unit.
Iterate	A loop mechanism that helps iterate over a list of tasks.
Accumulate	Helps leaving equipment in a certain place (the original place of an entity) without releasing it.
Pickup	An event that releases all allocated resources (by entities: nurses) at a certain place and allocates them to another entity (the collector).
Collect	A set of Travels to and Pickups from all the places of a hospital.
LookupCollect	A set of Travels to and Pickups from places where unsanitized equipment is located.
ReleaseAll	An event that releases a whole set of resources at once, such as the case of getting equipment out of a sanitizing room.

1. In the case of a centralized system, the technology does not make a difference because the associated process for each nurse remains the same regardless of the underlying technological frame-work. Table 3 shows such a process:

Table 3: Processes in a centralized system

Centralized			
No Tech/Barcode/RFID			
Cleanable		Sanitizable	
Task	**Significance**	**Task**	**Significance**
Delay	Go to center	Delay	Go to center
Seize	Check out item	Seize	Check out item
Delay	Go to room	Delay	Go to room
Delay	Use item	Delay	Use item
Delay	Clean item	Delay	Go to center to return item
Delay	Go to center	Delay	Sanitize item
Release	Return item	Release	Make item available

2. In a semi-centralized system with no infrastructure, the process for nurses is described in Table 4:

Table 4: Processes in a semi-centralized system with no infrastructure

Semi-centralized			
No Tech			
Cleanable		Sanitizable	
Task	**Significance**	**Task**	**Significance**
Delay	Go to center	Delay	Go to center
TrySeize	Try to obtain item from the center	TrySeize	Try to obtain item from the center
Search	Search for item in case no item is found	Search	Search for item in case no item is found
Reoriginate	Return to original unit	Reoriginate	Return to original unit
Delay	Go to original room	Delay	Go to original room
Delay	Use item	Delay	Use item
Delay	Clean item	Delay	Go to center to return item
Delay	Go to center	Delay	Sanitize item
Release	Return item	Release	Make item available

When RFID technology is integrated in this system, personnel can look up pieces of equipment and their associated location and status before traveling to obtain them. Therefore, the process changes to the following given in Table 5:

Table 5: Processes in a semi-centralized system with RFID

Semi-centralized			
RFID			
Cleanable		Sanitizable	
Task	**Significance**	**Task**	**Significance**
Find	Look up available item and go acquire it	Find	Look up available item and go acquire it
Reoriginate	Return to original unit	Reoriginate	Return to original unit
Delay	Go to original room	Delay	Go to original room
Delay	Use item	Delay	Use item
Delay	Clean item	Delay	Go to center to return item
Delay	Go to center	Delay	Sanitize item
Release	Return item	Release	Make item available

3. In decentralized systems with no infrastructure, the processes for nurses and collectors are described in Table 6:

Table 6: Processes in a decentralized system with no infrastructure

Decentralized					
No Tech					
Nurses generated in a room				Collector generated in a Center	
Cleanable		Sanitizable		Sanitizable	
Task	**Significance**	**Task**	**Significance**	**Task**	**Significance**
TrySeize	Try to obtain item from original room	Travel	Go to center	Delay	Wait before next round
Search	Search for item in case no item is found	Seize	Check out item	Collect	Pick up used items from rooms
Reoriginate	Travel to original room	Reoriginate	Go to original room	Reoriginate	Go to center
Delay	Use item	Delay	Use item	Delay	Sanitize items
Delay	Clean item	Accumulate	Leave tool in the room	ReleaseAll	Make items available
Release	Leave item in the room			Iterate	Repeat from 1st task

When RFID is integrated, two things change: the Search task becomes a Find task and the Collect task becomes a LookupCollect task; and that is because RFID allows personnel to know where equipment is before they start a trip to go seize it.

4. Real-world Case Analysis

To compare the efficiency of the three systems and to investigate the impact of the integration of RFID technology in hospitals, the simulation models developed above are used on the same hospital. However, it is hard to find a large-scale real-world hospital, where all systems can be adopted, as well as collect the time required to move from one place to another. In the short-term of this research, it is hence opted to simplify the task of acquiring a space-model by constructing a synthetic hospital. This hospital consists of 10 units where each one has 36 rooms and one equipment center, as depicted by Figure 2. Note that in the decentralized system case, only one center is used for sanitization whereas the other nine are not visited at all. From the temporal aspect of trips, it takes one time period to move from one room to its adjacent places, whether the move is horizontal or vertical (a time period of 15 seconds is used.) Diagonal moves are not allowed; therefore, to move from Room 1 to Room 8 for example, it takes 2 time periods since the individual has to perform one horizontal step and one vertical step. Even though our used software library does not support spatial representation just yet, this hospital layout helps us generate the matrix of travel-durations from one place to another.

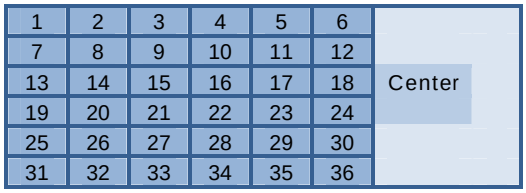

Figure 2: Layout of synthetic hospital

Table 7: Simulation input data

Variable	Value/Distribution
Number of units	10
Number of rooms	36
Number of items	40
Demand rate	1 item per 5 min
Usage time	Triangular(10,15,20)
Sanitization	Triangular (5,7,10)
Cleaning	Triangular (2,3,4)

In the experiment, each simulation model is run for 10 replications with a warm-up period of 50 simulation minutes and a runtime of 10080 simulation minutes (1 week) with the input data presented in Table 7 (time values are in simulation minutes.) The performance mea-sure is the time spent to acquire an item in the hospital (time-to-get) by a nurse or by a collector. The simulation results are shown in Table 8 and graphed in Figure 3.

Table 8: Results of simulating the three hospital systems

System	Infrastructure	Equipment	Avg(time-to-get)	St.Dev
Centralized	None	Cleanable	15.5434	0.2368
		Sanitizable	15.5806	0.3573
	RFID	Cleanable	15.5434	0.2368
		Sanitizable	15.5806	0.3573
Semi-Centralized	None	Cleanable	16.3753	0.5594
		Sanitizable	16.3869	0.8945
	RFID	Cleanable	10.2482	0.8541
		Sanitizable	10.0580	0.5874
Decentralized	None	Cleanable	8.0558	1.6064
		Sanitizable - Nurse	11.2019	0.4315
		Sanitizable - Collector	7.5580	0.7262
	RFID	Cleanable	5.3323	1.6184
		Sanitizable - Nurse	8.3087	0.2858
		Sanitizable - Collector	7.3782	0.1581

According to these results, the decentralized system is the most efficient one for both types of equipment (cleanable and sanitizable,) whether there is a technological infrastructure or not, whereas the semi-centralized system with no infrastructure is the least efficient. Also, RFID technology does have a positive impact on both the decentralized and semi-centralized systems. In fact, the semi-centralized one is the system benefiting the most from the technological infrastructure due to the significant reduction in the performance measure (about 38%.) For the collector's time to acquire an item, there is an improvement with the introduction of RFID, but it is insignificant. In conclusion and according to the studied simplified model, if a hospital cannot afford a technological infrastructure, it is recommended to implement a decentralized system. If a hospital has a semi-centralized system, the hospital is urged to integrate RFID technology in its system to move from the least efficient system to the third best. Finally, if a hospital is under construction, it is advised to avoid the implementation of a centralized system for it is not efficient while there is no room for improvement.

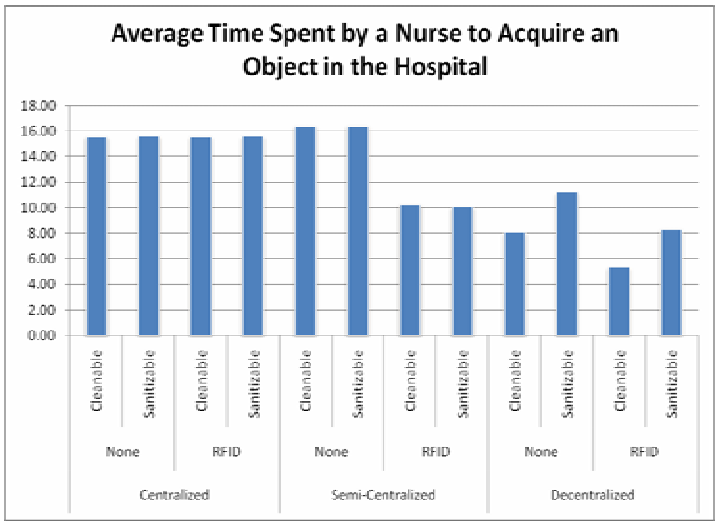

Figure 3: Results of simulating the three hospital systems

5. Future Work

In the constructed Java simulation model, the displacement of an entity from one place to another is modeled through the time it takes to perform such a trip. This time variable can be a constant, or can be drawn from a given distribution. An improvement to this work would be to include spatial representations to places in order to model 2D dimensions and velocities. This will help acquiring more accurate results due to the accountancy of a whole new level of details for trips made by the simulated entities such as obstacles, hallways, stairs, elevators, etc. This expansion will also aid in exploring the effect of the number of units and their size on equipment management.

Also, the decentralized system seems to have the best performance in terms of the time spent searching for equipment. However in real life, such a system has the least security and its equipment is the most subject to loss and theft. Therefore, a good expansion of this study is to incorporate issues such as loss and theft in the simulation model and see the impact caused by RFID.

Finally, the hospital model is a synthetic one; it would be more desirable to see results from simulating a real-world hospital. A hospital with the ability to adopt all three systems is to be found, and its characteristics and dimensions are to be used as input data for the simulation model. Furthermore, different demand levels of various items can be

better estimated and used, a fact that provides the opportunity to systematically analyze the effect of different demand rates on the target performance measures.

6. Conclusions

This paper focuses on evaluating different hospital systems (centralized, semi-centralized, and decentralized) that can either have no technological infrastructure or have an RFID system, which enables tracking equipment and its status in hospitals. The systems are studied thoroughly and the process through which the associated equipment goes through is identified. A task-oriented approach is used to model these processes in a Java simulation environment. According to obtained results, the best system in terms of nurse's average time to reach the equipment is the decentralized system with an RFID framework. This is true for both cleanable and sanitizable equipment. Also, the integration of RFID technology does make a difference in both the decentralized and semi-centralized systems, with the semi-centralized one benefiting the most from the technology. Finally, the authors suggest as future work the expansion of the model though the integration of spatial representation, the incorporation of loss and theft in the hospital models, and the adoption of an adequate real-world case scenario for the developed simulation.

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