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SIMULATION MODELING MOVABLE HOSPITAL ASSETS MANAGED WITH RFID SENSORS

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ABSTRACT

Discrete Event Simulation (DES) is often used to test the operational efficiency of new systems before they are used in practice. Our focus is on tracking movable assets with Radio Frequency IDentification (RFID) sensors to enable efficient sharing of the assets between hospital departments. In a hospital, patients, equipment, and personnel interact in complex ways. Different types of assets require different models of usage in a simulation program. This paper presents a taxonomy for different movable assets, proposes appropriate simulation models for each asset type, and presents the results of simulating an asset tracking system for one particular movable asset type. In addition, the taxonomy in this paper can help other researchers understand the ways different assets are used, and develop software applications based on RFID sensor data.

1 INTRODUCTION

In hospitals, high-value mobile assets like, IV pumps, blood pressure monitors, beds, wheelchairs, blood, stints, and others are often misplaced, lost, or stolen. It is not uncommon for a hospital to loose 10% of its inventory annually, with its employees spending %25-33 of their time looking for equipment (Wicks, Visich, and Li 2006). For example, a 1550-bed Hospital in Miami, FL had $4 million worth of assets unaccounted for in 2003 (Wicks, Visich, and Li 2006). Another researcher (Glabman 2004) found that it is typical for a 500-bed hospital to lose $1 million per year due to loss, rentals, and personnel inefficiencies.

The root cause of these problems is twofold: First, there are wild fluctuations in patient arrivals and lengths of stay. Second, no one in a hospital has real-time information about where all the movable assets are, because these assets are frequently moved in response to changing asset needs at different locations. In a large hospital with several departments, one department may have several idle asset units left over from a busy period while another department may be experiencing an asset shortage. When the situation is desperate personnel will resort to calling a rental company for prompt delivery of needed equipment. This adds a heavy burden on hospitals' operating budgets.

A recent survey by Spyglass Consulting Group, an independent market research company (Spyglass 2008) shows that RFID healthcare investments are experiencing explosive growth especially among larger health care providers like regional hospitals and academic medical centers. This is because in larger organizations it is more difficult to track objects with manual methods. RFID tracking enables real-time asset visibility. When a department needs more units of assets, personnel can find available units by using a computer terminal interfaced with the RFID tracking system. For example, the IntelliMotion system by General Electric has a web-browser interface displaying items via a floor-plan viewer. Other companies like WaveMark, Intermec, and Radians also offer similar products.

RFID-based object tracking is only the starting point for a new and potentially rich area in software industry. Using RFID sensor data for managing inventory; for mining and visualizing flow of patients, assets and personnel; and for strategic decision support are potentially beneficial applications. Although technology for RFID tracking of movable assets in hospitals has been available for over 10 years, actual software applications built on top of this infrastructure have been disappointingly few and far between. As a starter, a taxonomy comprehensive enough to capture the way all different movable assets are used in a hospital is needed. This taxonomy can serve as the knowledge base for identifying the appropriate simulation models for different hospital assets. The development of such a simulation model would have at least two important benefits:

First, before installing an RFID tracking system, the management team of a hospital may want to assess the potential benefits in their own situation. Second, it can serve as a specification of the way assets are used for the benefit of other researchers not knowledgeable in hospital equipment.

2 RELATED WORK

Simulation and modeling of hospital operations has been studied for a long time. A survey paper by Jun, Jacobson, and Swisher (1999) reviewed 117 papers published before April 1997. The survey paper by White (2005) covers the period from that time till 2005, and cites 41 papers. Independently, Fone et al. (2003) give a list of 182 papers that they have selected by critical review.

Other related works have been in the areas of RFID applications (Wicks, Visich, and Li 2006, Nahas and Deogun 2007, Miller et al. 2006, Amini et al. 2007), data acquisition (Miller et al. 2006, Taneva and Law 2007, Isken et al. 2005),, and queuing analysis of hospital systems (Vermeulen et al. 2009,. Fomundam and Herrmann 2007). A nice introduction to the RFID technology has been presented by Want (2006). In the area of RFID applications, some papers discuss the potential uses and benefits of this technology ((Wicks, Visich and Li 2006, Nahas and Deogun 2007) while others focus on tracking patients (Miller et al. 2006, Amini et al. 2007). However, with the exception of a couple of papers (Boginski et al. 2007, Fuhrer and Guinard 2006) which describe systems for visualizing asset utilizations based on RFID data, there is no paper that applies the RFID technology in any form to achieve an automated asset management system.

Some researchers also argue that high-tech support for hospital management is lagging behind the current technology. Carter (2002) explores the problem and concludes that people in the ranks of hospital management are ignorant of computer science or operations research. The author notes: "… I doubt they appreciate what we have to offer…" On the other hand, researchers in computer science or operations research have little, if any, exposure to the way hospitals operate. According to the article, very few operations research people specialize in health care. Those who have exposure to the field, and who have been involved in a health care project move on to something else. We expect, however, that with the introduction of RFID systems, and the recent emphasis on healthcare information technology by the federal government, the area is likely to see a surge of interest among researchers.

3 TAXONOMY OF MOVABLE ASSETS

In a hospital, patients, assets and personnel move and interact in complex ways. Unlike the assembly line in manufacturing systems, the path followed by a patient is subject to considerable uncertainty. Various decision points exist where consultation occurs with doctors and nurses. The branch taken often depends on these consultations as well as results of lab or X-Ray tests. Along the way, the patient consumes some assets (like blood, serum, and other medicine), makes short-term use of some assets (like wheel chair, portable X-Ray, etc) or gets assigned some assets for the duration of stay in the hospital (like IV pump, bed, blood pressure monitor). Since most of these are high-value assets, hospital managements have considerable interest in managing them effectively.

It is possible to analyze movable assets in a hospital under two major categories: *consumable* assets and *reusable* assets.

Consumable assets: Consumable assets like blood, stint, and medicine can be tracked by low cost passive RFID tags for inventory control, and possibly for sharing between different departments. In addition, RFID tags can help improve quality of patient care and eliminate mistakes. For examples, temperature-sensitive tags can provide accurate tracking to ensure that blood stored at less than optimal temperatures are not administered to patients. Also, RFID tags can be embedded into blister packs of prescription packages to monitor the date and the time a patient opens a package of medicine and takes out a pill. The packaging may be scanned to monitor usage patterns. Although these and other uses of RFID sensors are possible in hospitals (Wicks, Visich, and Li 2006), our focus in this paper is tracking reusable assets for the purpose of sharing them between departments.

Reusable assets: Effective strategies for sharing of reusable assets would increase employee efficiency, minimize emergency rentals and reduce a hospital's asset inventory. Reduced inventory will, in turn, reduce capital investment, maintenance, and depreciation, so the total savings for a hospital can reach millions of dollars per year. We divide reusable assets into two categories:

Queuing assets: For some assets (e.g. portable X-ray, wheelchair, etc) patients can wait for their turn if another patient is using the asset. Usually, patients use these for a short time, and these assets belong to a pool shared by one or more departments.

Non-Queuing assets: For some assets once a need is determined, the patient cannot wait, the asset must be acquired promptly. Typically, these assets are dedicated to their assigned patients for the duration of hospital stay, like blood pressure monitors, and IV pumps. If released from use by a patient, the asset may be given to another patient with that need, possibly, in a different department. We consider three sub-categories of non-queuing assets:

Fixed location: These assets are specialized so that only one department uses them. An example is epidural, which is only used in labor and delivery departments of obstetrics hospitals. These assets are not subject to sharing between departments.

Single-location: These assets are released from use at the same location where they made their initial contact with patients.

Multi-location: These assets move with patients in a treatment path until patient condition is no longer critical, so that their location of release is different from their location of initial contact with patients. Treatment paths follow the links of patient flow diagrams specific for the hospital.

Figure 1 shows the taxonomy of assets we categorized. In practice, for assets in the last two categories above, it is not known in advance if the asset unit attached to a patient is going to be labeled as single or multi-location type of asset until the patient leaves the department. For example most emergency department patients are sent home after triage, so IV pumps released from those patients remain at their original location while those units attached to admitted patients move with patients to whichever department the patients are forwarded from the emergency department.

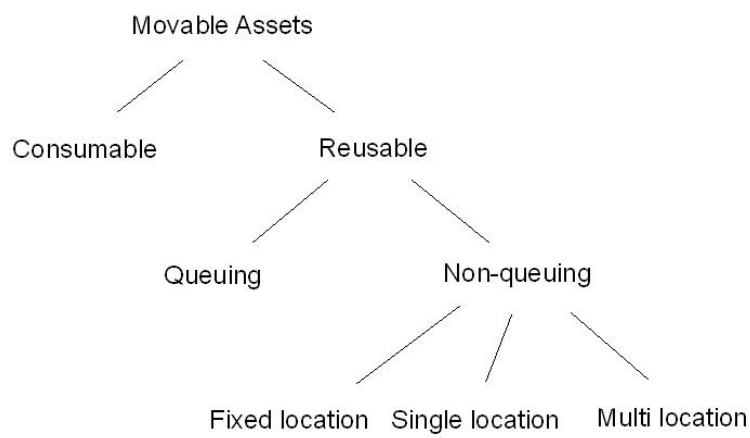

Figure 1: Taxonomy of movable assets for management with RFID sensor data

This distinction between single-location and multi-location movable assets may appear to be superficial at first. However the distinction is important for developing a queuing model as a basis for simulation of asset use. This concept will be further explored in the next section.

4 MODELING MOVABLE ASSET USAGE

Method of use is the primary factor that determines appropriate models to simulate different hospital assets as they are seen by RFID sensors.

Consumable Assets: RFID tracking for consumables is primarily suggested for inventory and quality control. Consumable assets are periodically replenished from a common pool with sufficient emergency reserves at each department. Occasional sharing of these assets may help alleviate possible unforeseen shortages when the central storage is closed. Models for managing such applications are well understood in operations research (Saygin 2007, Abraham et al. 2002). Here we focus on reusable assets as discussed below.

Reusable Assets: We model all reusable assets as servers, with hospital departments corresponding to service centers. Historically, equipment like MRI or X-Ray has been modeled as servers in queuing systems (Vermeulen et al. 2009), however they are not included in our study since they are at fixed locations and they don't need RFID tracking to locate them.

Queuing Assets: The sub-category of Reusable assets that we termed "Queuing assets" includes wheel chairs, portable versions of X-Ray machines, EKG plotters, etc. The defining characteristics of these assets are that immediate access to the asset is *not critical*; patients can wait for their turn if another patient is using the asset. They are only used for a short time by each patient. These assets may or may not have fixed locations where they are normally found when needed. For example, wheel chairs are often left at arbitrary locations after use. With the help of RFID locators, physical asset locations become irrelevant, because they can be easily found when needed.

Depending on the size of a hospital, queuing assets may be shared by the entire hospital or by a subset of departments in the hospital. In the later case, each asset unit must have an *associated* department list (departments to which the asset can *belong*) so that only the personnel at associated departments can see a given asset unit via RFID locators. This mechanism allows logical partitioning of the asset pool between hospital departments. By simply modifying the associated department list for an asset unit, one can reallocate it to a different user group. A scheduling optimizer interfaced with the RFID tracking software, in real time, can achieve dynamic readjustments in allocations of assets between different user groups. Dynamic resource allocation models like those in (Vermeulen et al. 2009, Kirgizlar 2008) are applicable for managing these assets, but to the best of our knowledge there is no paper directly addressing this problem.

Non-queuing Assets: This is the hardest asset type to manage in hospitals. Being small in size, they are frequently lost or stolen; yet they serve *critical* needs in patient care. Hospitals must always have enough number of units so that patients do not wait in queues for using these assets. Usually, these assets stay with patients until completion of treatment.

Fixed location assets: Certain assets are only used at one location depending on their area of specialization. These are not shared between hospital departments. For example, an epidural unit is only used on obstetrics patients. These assets may still be RFID tagged for the purpose of locating them, but not for the purpose of sharing.

Single and Multi-location assets: An important component of a simulation model is inventory keeping. Generally, asset management algorithms that use statistical usage patterns may need to know busy portion of the asset inventory at each location as well as the number of *idle* units. For non-queuing assets there is no fixed location to which a unit belongs. Rather, an asset unit belongs to either where it is being used currently or where it is released from use by a patient.

Although this seems to be a simple enough rule for the purpose of inventorying assets at different locations of a hospital, when RFID sensors detect asset locations, interesting complications arise. When patients move, assets like IV pumps and blood pressure monitors move with their assigned patients. If a patient is moved to a different department, the asset unit assigned to the patient needs to be subtracted from the inventory of the old department, and added to inventory of the new department. One approach for accounting for the effect of these moving assets is to use historical data about percentage of assets that move with patients, and subtract them from the total inventory at their current departments. This calculation can help predict how many asset units will be eventually released by departing patients. This can be a useful piece of information for asset management algorithms.

This still leaves two additional problems to be solved: determination of which asset unit to subtract, and determination of where to add the subtracted unit. These decisions are complex when RFID sensors track the assets since it is difficult to identify whether movable assets are single or multi location by just looking at their current locations based on RFID readings. For example, a patient may be taken to the MRI scanner with the IV pump still attached and returned back to his original bed. A second patient may be initially admitted to the internal medicine, and then transferred to oncology after test results arrive. An IV pump attached to our first patient should be counted in its original department even though RFID sensors would detect it elsewhere, while the IV pump attached to our second patient should be counted at its new location. RFID systems can detect asset movements, but they cannot know why an asset is moving. Indeed, it is not uncommon for patients to take a walk in the corridor with the IV pump still attached, giving a possible false reading to RFID sensors that the equipment has moved to a new department.

To solve these problems, we can consider all assets as being in their last known locations until proven otherwise. The change of inventory location can occur at the time the asset is released from the patient, but it is desirable to make this determination as early as possible. For example, a change of inventory can occur after an asset unit has been at a new location for a sufficiently long time so that temporary visits to new locations do not mislead inventory counts. Additional information can also be used; for example if we know that patients are not normally transferred from department A, to department B, detecting an asset unit that belongs to department A at department B cannot cause a change of inventory.

5 ASSET SHARING MODELS FOR NON-QUEUING ASSETS

In this section, we present our asset sharing model for movable non-queuing assets. Manual methods for managing such assets include hiring special personnel who work around-the-clock to seek and retrieve unused equipment to a central location. Whenever a department needs an asset unit it is ordered from the central location. A company that is in the business of providing such a service to hospitals claims that this method doubles asset utilization, eliminates nearly all emergency rentals, and reduces inventory of assets by about half (AMPP 2008). Simulating this basic strategy for a hospital would show if similar performance improvements are achieved when using RFID tracking systems instead of hiring special personnel.

Note that, as stated, the manual strategy has important details unspecified. For example, it is not clear how often the special personnel would visit each location to seek unused assets, would they still visit a location to seek available units if they recently received an emergency request from that location, what criterion would they use to decide where to look first, would they remove an unused asset unit from a department even if the department is experiencing heavier than usual patient traffic, what precautions would they use to minimize premature asset moves that may lead to another move back, etc.

When managing assets based on RFID sensor data, hospital personnel can see any asset unit anywhere, and pick up any available unit. Therefore, the need for a central location is eliminated. We also adopt a demand-driven approach, where assets are moved to a new location only when there is a need at the new location. This eliminates premature asset moves that may turn out to be detrimental to overall efficiency. The only remaining concern would then be the location from which to move when multiple departments have unused assets units. In this simulation, we consider two asset sharing strategies:

Random: When a department needs a new asset unit, we move an unused unit from another department selected at random.

Minimum utilization: we choose an unused asset unit at the department that has minimum current utilization level. Utilization at a department is measured as the ratio of the number of busy units to the total number of units.

We considered two performance measures:

- The number of times assets are moved between departments over a period of time. This is important, because each asset move takes time away from patient care by hospital personnel. Also, extensive frequency of asset moves can be aggravating for the involved personnel.
- The number of times emergency rentals occurred over a period of time. Assets are rented from external sources when patients are waiting and all asset units in the hospital are in use.

6 SIMULATION

We simulated the above strategies using data from an Obstetrics (OB) hospital in Phoenix (Cochran and Bharti. 2006). The hospital has 215 beds in 7 sub-units as follows:

1. Triage (10 beds).
2. Antre-Partum Non-Monitored (APNM) (14 beds) for patients to wait until delivery, and Antre-Partum Monitored (APM) (16 beds) for high-risk patients.
3. Labor and Delivery (LD) (26 beds).
4. Post Recovery Anesthesia Care Unit (PACU) (6 beds) for C-Section patients.
5. Post-Partum (PP) (48 beds) where patients and infants stay until they fully recover.
6. Medicine/Surgery (MS) (30 beds) for patients requiring specialized care post delivery.
7. Neonatal Intensive Care Unit (NICU) (65 beds) for infants requiring specialized care.

Figure 2 shows the queuing network model for this hospital. Patient arrivals and lengths of stay at different departments are given in Table I. In “Arrival Distribution” column of this table, “Internal” means that patients are routed from other departments; there are no external arrivals. Some departments (e.g. Labor and Delivery) have external arrivals in addition to patients routed from other departments. For these departments, the indicated arrival rate refers to external arrivals only. “Special1” in arrival distributions column refers to the fact that these arrivals are modeled not by a single function, but rather by a special table that represents variations depending on time of day and day of week. Table II shows these parameters. “Scheduled” arrivals to Labor and Delivery refers to C-section or induction patients, who are scheduled between 6:00 am to 6:00 pm only, 4.5 patients per day on weekdays and 3 patients per day on weekends.

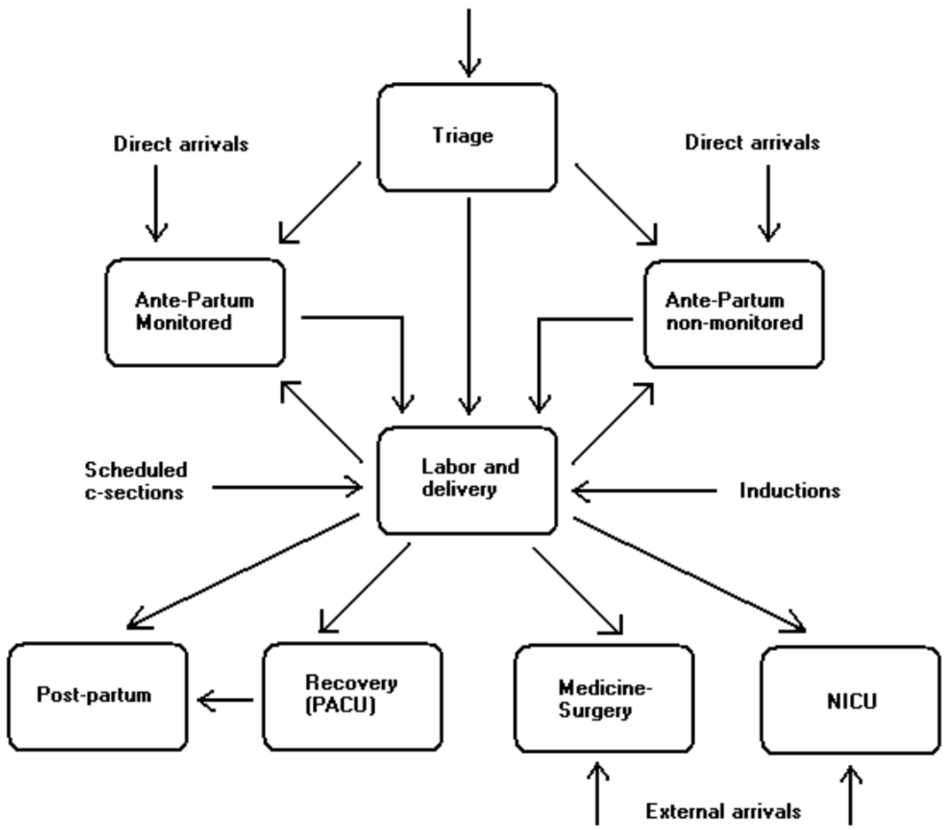

Figure 2: Queuing network model for the simulated hospital from Cochran and Bharti (2006).

Table 1: Patient arrivals (per hour) and LOS (hours) for the simulated hospital.

Department Name	*Beds*	*Arrival Distribution*	*Arrival Param*	*LOS Distribution*	*LOS Param_1*	*LOS Param_2*
Triage	10	Special1		Special2		
APM	16	Exponential	0.0081	Lognormal	126.340	254.030
APNM	14	Exponential	0.0060	Lognormal	126.340	254.030
Labor & Delivery	26	Scheduled	0.6666	Lognormal	8.010	10.070
PACU	6	Internal		Uniform	3.000	4.000
Post-partum	48	Internal		Gamma	3.450	13.550
Medicine-surgery	30	Exponential	0.1350	Lognormal	68.510	74.150
NICU	65	Internal		Exponential	222.750	

Table 2: Patient arrivals (per hour) for triage department

Time from	*Time to*	*Weekday*	*Weekend*
12:00 AM	6:00 AM	1.750	1
6:00 AM	2:00 PM	2.125	2
2:00 PM	12:00 AM	1.750	1

The last three columns of table I show patient lengths of stay distributions. "LOS Distribution" column indicates the name of distribution function fitted. Some distributions are specified by a single parameter while others are specified by two parameters, as indicated at "LOS Param_1" and "LOS Param_2" columns. "Special2" in lengths of stay column of Table I indicates that a special table is used to model the length of stay. This is a combination of five different uniform distributions as shown in Table III.

Table 3: Lengths of stay (days) for triage department

Percentage	*Distribution (parameters)*
57%	Uniform (1.5,2.5)
31%	Uniform (2,4)
8%	Uniform (4,8)
1%	Uniform (8,12)
3%	Uniform (12,24)

Finally, Table IV below shows the branching probabilities of patients as they move from one department to another. Tables I-IV provide all the data we need for simulating this hospital.

The scenario assumed in these simulations is as follows: We assume that the hospital has installed an RFID system so that the number of asset units at each department is perfectly visible. We also assume that the numbers of busy vs. idle asset units are also known at any time for any department of the hospital. Whenever a new patient arrives at the hospital, personnel will check if the receiving department has the required asset. This can be any movable asset, like a blood pressure monitor, that every patient must be assigned one unit. If there is an idle unit, then the patient is assigned one. If the department has no idle units, then personnel will check from the RFID system which department has surplus units. The RFID system will suggest one according to one of the two strategies that we explained in the previous section. When a patient is transferred from one department to another, we assumed a "walking time" of 15 minutes. Similarly, when an asset unit is moved, our simulation program introduces 15 minutes of delay to move the asset. If no department is found with surplus asset units, then personnel will call for an emergency rental. In that case we assume 30 minutes of delay for delivery of required asset.

Random strategy represents the way personnel would use the RFID system by itself without any further optimizations. This would allow hospitals to gauge the benefits of installing RFID systems against their manual management strategies. Since we have no access to how the hospital in our study manages its assets, the question we consider is whether or not the algorithm based on balancing utilization levels would perform better than the random strategy. Typically, queuing systems work smoothly when the utilization is light and resources are plentiful. So it is important to observe the performance under a variety of utilization levels.

We simulated the hospital operations over a period of five years based on asset inventory and patient statistics given above. Here we assumed that the number of beds also represent the number of other asset units; i.e. a hospital with 215 beds also have 215 blood-pressure monitors. For the particular hospital considered in our simulation, the current bed utilization is 63% (Cochran and Bharti. 2006).. Therefore, the base utilization level for blood pressure monitors will also be 63%. To test the performance of our algorithms for different levels of asset utilizations, we reduced the number of blood-pressure monitors at each department by 10, 15, 20, and 25 percent, and observed the attained utilization levels by simulation as 71, 75.5, 81, and 85 percent respectively. For each case, we also observed the number of times blood-pressure monitors are transferred, and the number of times emergency rentals occurred.

Table 4: Branching probabilities of patients for the simulated hospital.

Source	*Destination*	*Percentage*
Triage	Home	58.5000
Triage	Labor and Delivery	38.5000
Triage	Antepartum Monitored	1.6200
Triage	Antepartum Non-monitored	1.3800
Home	Labor and Delivery	11.3300
Home	Antepartum Monitored	4.7300
Home	Antepartum Non-monitored	3.7200
Antepartum Monitored	Home	25.0000
Antepartum Monitored	Labor and Delivery	75.0000
Antepartum Non-monitored	Home	50.0000
Antepartum Non-monitored	Labor and Delivery	50.0000
Labor and Delivery	Antepartum Monitored	7.0000
Labor and Delivery	Antepartum Non-monitored	3.0000
Labor and Delivery	Medicine-Surgery	1.0000
Labor and Delivery	Anesthesia Recovery (PACU)	24.0300
Labor and Delivery	Postpartum	64.9700
Anesthesia Recovery (PACU)	Postpartum	100.0000
Postpartum	Home	100.0000
Medicine-Surgery	Home	100.0000
Home	Triage	80.2200
Neonatal Intensive (NICU)	Home	100.0000

6.1 Simulation Results

Figures 3 and 4 show the results of our simulations. Figure 3 shows the number of asset transfers at different utilization levels according to the two strategies used for asset selection. As can be seen, the strategy that tries to balance current bed utilization levels performs worse than random strategy. When we look at the number of emergency rentals (see Figure 4) again we see that the random strategy performs slightly better. These results may seem counter-intuitive at first, because one may expect that the method based on balancing asset utilizations would perform better. For example, balancing server utilizations minimizes mean delay in queuing networks where an arriving customer uses a server for only a short time, and waits in queue if all the servers are busy. However, when patient queuing is not allowed (for non-queuing asset types), and each patient must be assigned a dedicated server, we are dealing with an infinite-server case. In such queuing systems the number of busy servers is distributed similar to the number that arrive during the mean service time. For example, for the Poisson arrival process the number of busy servers is distributed as a Poisson function, with probability of having i servers busy given by

$$P_i = e^{-N} \frac{N^i}{i!},$$

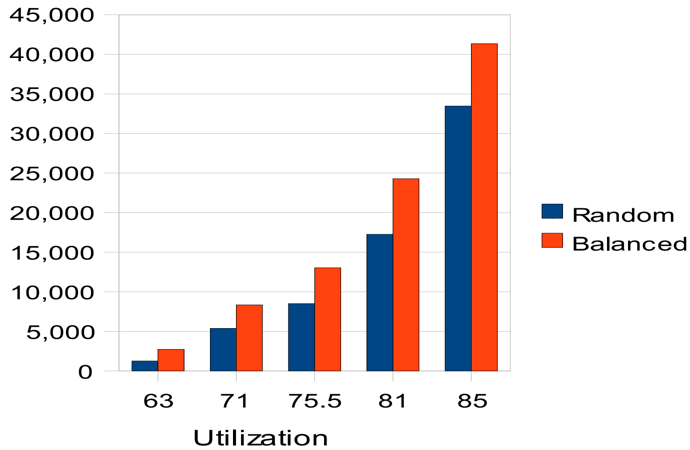

Figure 3: Number of bed transfers between hospital departments over a period of 5 years for different levels of asset utilizations.

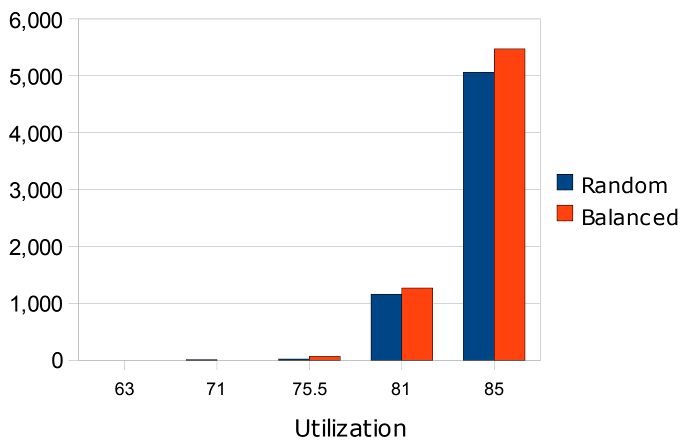

Figure 4: Number of emergency rentals over a period of 5 years for different levels of asset utilizations.

7 CONCLUSIONS AND FUTURE WORK

We developed a system of classifying hospital assets and identified suitable models for managing movable assets with RFID sensors. Then, for one chosen asset category (that includes IV pumps, blood pressure monitors, etc.), we compared the performance of two asset sharing strategies. Our future work will focus on improved sharing strategies for hospital assets that minimize the number of emergency rentals and the number of times assets are transferred between departments. In its current form, our simulation is useful for hospitals to compare their manual methods with the improvement that may be obtained when RFID tracking is used, but without any optimization.

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