Proceedings of the 2005 Winter Simulation Conference
M. E. Kuhl, N. M. Steiger, F. B. Armstrong, and J. A. Joines, eds.

EVALUATING HOSPITAL PHARMACY STAFFING AND WORK SCHEDULING USING SIMULATION

Charles W. Spry
Mark A. Lawley

School of Industrial Engineering
Purdue University
West Lafayette, IN 47907, U.S.A.

ABSTRACT

With increasing healthcare costs, an aging population, and a shortage of trained personnel it is becoming increasingly important for hospital pharmacy management to make good operational decisions. In the case of hospital inpatient pharmacies, making decisions about staffing and work scheduling is difficult due to the complexity of the systems used and the variation in the orders to be filled. In order to help BroMenn Healthcare make decisions about staffing and work scheduling a simulation model was created to analyze the impact of alternate work schedules. The model estimates the effect of changes to staffing and work scheduling on the amount of time medication orders take to process. The goal is to use the simulation to help BroMenn find the best schedule to get medications to the patients as quickly as possible by using pharmacy staff effectively.

1 INTRODUCTION

Healthcare costs across the United States have been increasing, and from 1993 to 2000 drug costs as a percentage of total healthcare cost doubled to 8.5% (McRee 2002). In order to fight this trend it is vital that hospitals effectively utilize their pharmacy staff. There is currently a shortage of licensed pharmacists, and the expansion of pharmacies into groceries and large retail stores has added to the difficult task of finding enough qualified pharmacists to work in hospitals. The ASHP survey by Pedersen et al. (2002) found a hospital pharmacist position vacancy rate of 7%. An increase in the use of pharmacy technicians has occurred due in part to the shortage of pharmacists, resulting in changes to the roles of pharmacy staff. Simulation can be used to find the best utilization of pharmacy staff and to help save money while improving healthcare delivery to the patient population.

In recent years simulation has been used as a tool to analyze operations in several areas of healthcare. Models have been used to evaluate staffing plans and to analyze patient throughput efficiency. Areas studied include emergency departments, surgery departments, clinics, radiology departments, laboratories, pharmacies, and other areas. One such study by Wong et al. (2003) used simulation to redesign the pharmacy processes at a hospital. The model focused on the benefit to turnaround time and order accuracy that a physician order entry system may have.

This model was created for BroMenn Regional Medical Center (BMRC), a 224 bed not-for-profit hospital located in Normal Illinois. The inpatient pharmacy at BRMC is staffed 24 hours per day to fulfill the patients' medication needs. The pharmacy has a goal of 120 minutes to process a prescription order and have it delivered to the patient. The goal of the simulation model is to find the best work schedule to keep this turnaround time as low as possible throughout the day.

2 PHARMACY OPERATIONS

In order to effectively simulate any system a detailed understanding of all processes is required. There are several processes that are common to all hospital pharmacies, and several processes that are specific to each pharmacy. Hospital pharmacies may use different systems for documenting, filling, and delivering prescription orders. This section details the pharmacy operations at BRMC.

2.1 General Operations

The model simulates the in-patient pharmacy which fills prescription medication orders for patients admitted to the hospital. Unlike in a retail pharmacy, the operational pharmacists do not interact directly with the patients. There are however clinical pharmacists that interact with the patients, doctors, and nurses to consult about proper medication selection and administration. These clinical pharmacists were not included in the model since they do not participate in the order processing system. The pharmacy is staffed with at least 1 pharmacist 24 hours per day.

The pharmacy operational personnel consist of pharmacists, technicians, and IV technicians. Currently at the busiest time of day (11 am – 5 pm) there are as many as 4 pharmacists, 4 technicians, and 1 IV technician. In the early morning the only staff on duty is 1 pharmacist.

Patient prescription orders are created as needed by a patient's doctor, then sent to the pharmacy by one of several methods. Orders may arrive by fax, computer printout, phone (followed by another format), or by the hospital pneumatic tube system. The majority of orders arrive via the tube system, which is also used to deliver the filled orders back to the patients.

Computer generated patient medical administration records (MARs) are used by 64.4% of hospitals (Pedersen et al. 2002). At BRMC the patient MARs are kept in a computer system. Each prescription must be entered into this system, then checked by a pharmacist to ensure there is nothing in the patient's history or other medications that would interact with the prescribed medication. Updating and checking these MARs is one of the main functions performed in the pharmacy.

There are several different strategies used by hospitals to deliver medications to patients. Floor-Stock distribution is becoming commonplace in average and large sized hospitals. Floor-Stock distribution utilizes some type of medication dispensing equipment that is located in the patient areas rather than in the pharmacy. Some larger hospitals use a Decentralized Pharmacy system with satellite pharmacies operating in different areas of the hospital. Another common strategy is called Unit Dose, where drugs are packaged into unit of use doses and pharmacists review orders before drugs are dispensed to patients (McCarthy and Schafermeyer 2001). Some more advanced systems use automated robots to deliver orders throughout the hospitals, and pneumatic tube delivery has become very popular in newly constructed hospitals. The use of exchangeable carts for each area in the hospital is very common, and some hospitals simply use personnel to deliver orders as they are prepared. The systems used depend on management preference, hospital size, and hospital budget.

At BRMC the initial dose is normally delivered by the pneumatic tube system. If a prescription calls for the patient to take the medication for multiple days the subsequent maintenance doses are delivered by a daily medication cart exchange. This cart exchange allows the pharmacy to work ahead on the known orders during the night. It also makes the delivery quick and easy since there is a drawer for each patient in each area's cart. This initial dose and maintenance dose delivery system is the same for IVs and Meds, but the carts are filled and delivered at different times.

Another useful method utilized by BRMC is the SureMed system. SureMed machines are located in each nurses area and hold the commonly used and emergency medications for each area. The machines hold the medication, and if a patient needs a medication kept in the machine the pharmacist needs only to check the patients MAR and release the medication to the nurse. This allows the pharmacy to prepare the common medications in batches and allows quicker delivery to the patient. The machines must still be restocked by pharmacy staff, and the timing of this restocking is one of the decisions considered by the model.

2.2 Normal Order Flow

As prescription orders arrive in the pharmacy there are several steps which depend on the type of order that must be completed before a prescription is delivered to the patient. In the model all orders were considered to be in one of three groups: Med, IV, or SureMed. Each of these order types can be classified by priority as a normal or a stat order. Stat orders are the higher priority, and are processed before the normal priority orders, which use a FIFO system for prioritization.

The first step for every order type is entry into the computer system. This step can be performed by a pharmacist or a technician, and must be completed before the order is filled. If this entry is done by a technician, the order must be verified by a pharmacist before it can be filled.

After a pharmacist has verified the order entry the next step depends on the order type. If the order is for a medication available in the SureMed machine in the patient's area the order is released and the nurse will have access to the proper medication in the machine. If the order is for an IV a label will print in the IV preparation room, and the staff working in the IV room will prepare the IV for the order. This is done by either an IV technician or a pharmacist if there is no IV technician on duty. If the order is for a medication, it is moved to the Med-pick area. The correct medication is then selected by either a technician or a pharmacist and placed on a counter with the order.

The next step is to check that the order was filled correctly. This check must be done by a pharmacist, and if the order was filled by a pharmacist, there is an attempt to have it checked by a different pharmacist if possible. Both IV and Med orders are checked at this point for proper drug, labeling, dosage, route, and patient.

Once the order has been checked by a pharmacist the last step is to deliver the order. Most orders are delivered by the pneumatic tube system, in which case the medication and paperwork are loaded into a cartridge and placed into the tube. Some medications cannot be sent by the tube, and another delivery method must be used. This other method may be to call the patient's nurse and have them come to the pharmacy, a pharmacy technician may deliver the order, or another staff member from outside either area may deliver the order. Once the order is delivered the nurse is responsible for administering the medication. A flowchart summarizing the order flow is shown below in Figure 1.

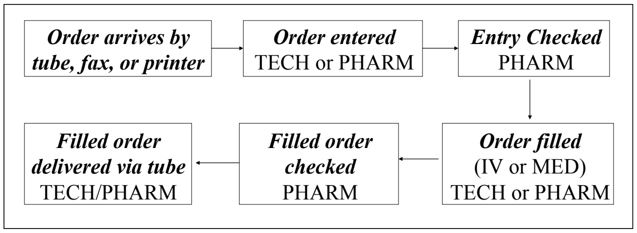

Figure 1: New Order Flowchart

2.3 Additional Pharmacy Tasks

While the normal order flow provides the bulk of the pharmacy workload, there are several other vital operations that the pharmacy must perform everyday. The time of day that these tasks are performed is flexible, and this creates an opportunity for the model to find the schedule of these tasks which optimizes the order turnaround time.

The SureMed system must be refilled in order to keep up with patient medication needs. Currently the pharmacy refills the machines twice a day, at 10 am and 6 pm. In order to fill the machines a technician checks the computer generated inventory list of each machine, and picks the medications needed to fill each machine. Next a pharmacist must verify that the picked medications are indeed what the machines need. Once verified the technician visits each machine, refilling it with the picked medication.

The filling, checking, and delivery of the IV and Med carts is another set of tasks that must be completed daily. As previously mentioned, these cart exchanges are used to work ahead on the orders that are known in advance. While the time of day that these carts are filled, checked, and delivered can be changed, the schedule needs to be the same day to day so the nurses and doctors will know when to expect the day's medications. Changing the times of the Med cart is one of the options considered in the model.

Another task that is somewhat flexible is the ordering and stocking of the daily drug order. Everyday the technicians compile a list of drugs that are running low and send out a restock order. The restock order arrives the following day, and must be unloaded and stocked into the medication storage areas. This process takes approximately three hours per day, and the work was included in the model, but the time was not an option that was changed.

One of the first things you notice if you visit the pharmacy during the busier times of the day is that the phones are constantly ringing. The pharmacy staff receives calls from doctors, nurses, and other hospital staff throughout the day with questions and requests. It is very important that the model account for these interruptions, as they can greatly alter the time it takes to process and order.

3 THE SIMULATION MODEL

The model was created using AutoMod 11.1 Student Version (Banks 2004). AutoMod allows the user to create detailed logic to control the system in order to make the model perform realistically. The software is tailored to the manufacturing setting, but if you think of prescriptions as parts being manufactured and employees as a machines with processing times it is easy to see the similarities.

3.1 Data Collection

Aside from gathering information on the general process flow there were four other types of data collected for the model input: order type distribution, order inter-arrival distribution, processing times, and phone call data.

One week of orders were analyzed to understand the distribution of the different types of orders and the order inter-arrival times. When an order arrives in the pharmacy it receives a time stamp. BroMenn staff looked at the type and time of each order and created a tally sheet for each hour of the day. From this tally sheet the percentage of each type of order (see Table 1) and the number of orders per hour (see Table 2) was determined. The inter-arrival times are assumed to be exponentially distributed with a mean time between orders found from the total per hour.

Table 1: Breakdown of Order Types

Type of order / Priority of order	Percent of orders
Med Orders	45.4%
IV Orders	10.4%
SureMed Orders	44.2%
Stat Orders	6.3%
Normal Orders	93.7%

Table 2: Mean Time Between Order Arrivals

Hour of the day	Inter-arrival mean (sec)	Hour of the day	Inter-arrival mean (sec)
1am-2am	165	1pm-2pm	61
2am-3am	631	2pm-3pm	87
3am-4am	1091	3pm-4pm	60
4am-5am	300	4pm-5pm	62
5am-6am	500	5pm-6pm	87
6am-7am	667	6pm-7pm	65
7am-8am	177	7pm-8pm	91
8am-9am	77	8pm-9pm	73
9am-10am	71	9pm-10pm	132
10am-11am	85	10pm-11pm	177
11am-12pm	55	11pm-12am	129
12pm-1pm	55	12am-1am	1200

The processing times for each step in the process were discussed with the pharmacy staff, and it was decided that using a triangular distribution would be sufficient, as there was not enough time or resources to conduct a complete time study. A consensus was reached on the minimum, maximum, and most frequent amount of time required for each step in the normal order filling process. A summary of the times used in found in Table 3.

Table 3: Processing Time Information (Seconds)

Process	Min	Mode	Max
Enter Med	45	60	120
Enter IV	60	120	180
Check Med Enter	45	60	120
Check IV Enter	60	120	180
Fill IV	120	240	360
Fill Med	45	75	105
Check Fill	30	45	60
Deliver	30	45	60

The last set of information collected gave an idea about the length and time between phone call interruptions. The time and duration of each call was recorded for 11 hours from 9 am through 10 pm and the data was analyzed. Figure 2 shows the distribution of time between calls. Based on this data the model assumes that the time between calls is exponentially distributed with a mean of 3 minutes. Next the distribution of the time spent on the phone for each call was analyzed. Figure 3 shows the distribution of the length of time spent on each phone call. Again it was decided to assume the call duration distribution is exponential, this time with a mean of 1 minute. This study was performed during the busier time of the day, so a less frequent distribution needed to be applied to the slower times of the day. For the model all interruptions use the 1 minute length, but from 7 am-11 pm the model assumes 3 minutes between calls, and 10 minutes from 11 pm - 7 am.

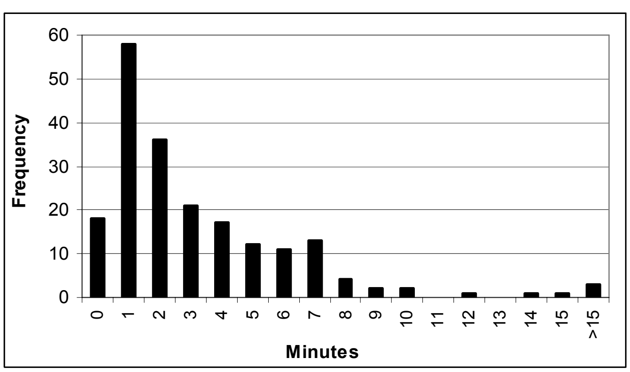

Figure 2: Time Between Phone Calls

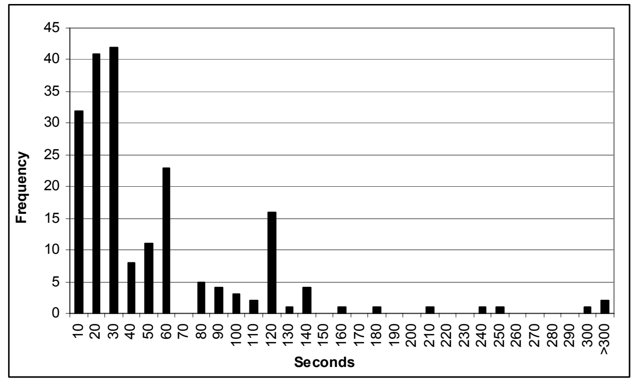

Figure 3: Duration of Phone Calls

3.2 Model Logic and Processes

The backbone of the simulation model is the logic code. This file tells the simulation how each part of the model should interact, in order to replicate the real world situation. The model uses different types of entities including; Processes, Resources, Queues, Loads, Load Attributes, Variables, and Order Lists. The following sections cover the entity definitions and logic code.

3.2.1 Resources, Loads, Queues

In this model resources are used to model the pharmacy staff. Each staff member is modeled as a resource that is brought up and taken down according to their schedule and used by the orders as they flow through the system.

There are two types of loads that flow through the system. The first type are 'order' loads. Each of these loads represents a prescription order. They are created following the order arrival distribution previously defined, and flow through the processes until the order is complete. The second type of load is used as a 'dummy' load. These do not represent any actual part of the system, but rather are used to initialize the processes that are needed, but not called by the order loads.

For each step in the system there are 2 queues. The first queue is of infinite length, and holds the orders waiting to be processed. This is also where the orders are sorted by priority. After the infinite waiting queue there are single capacity queues for each step in the process. These queues hold the orders that are currently being processed.

3.2.2 Load Attributes, Order Lists, Variables

To identify the characteristics of each prescription order, every order load has a set of defined load attributes. There are attributes assigned when the load arrives that note the time of arrival, assign the type of order (SureMed, IV, or Med), and assign a priority. As the orders progress through the system there are attributes to tell which resource performed each step. Finally, as the orders are completed an attribute notes the time the order is finished. Using the arrival and finish times the program calculates the total time in the system.

Order lists are used between each main process. These order lists make sure that the stat orders are processed first. After each step the order is moved to the next order list and asks for the next available resource. The order lists allow for the resources to process the orders in the order they are needed as well as by the priority level.

There are many variables used within the code to make decisions and keep track of information. There is an hour variable, which is updated to make decisions dependent on the time of day. There are variables defined to represent the arrival distributions, the processing times, and the order type ratios. Variables are also used to track the total time and total number of orders finished each hour. Finally, variables are used to represent each option being considered, and as these variables are changed different portions of the logic are called so that all of the scenarios can be run without changing the code.

3.2.3 Processes, Logic Code

The building blocks of the code are the processes. Each process is triggered by an arriving load, then goes through some operations, and sends the load to the next process. There is an arrival process that creates the order loads, assigns their attributes, and sends them to the first step. They then flow between processes until they are completed.

In addition to the processes that guide the orders through the system there are several other processes. There is a process that keeps the hour of the day. There are processes which bring up and take down the resources based on the staff schedule. There are special processes that represent the additional tasks which are being investigated, such as the SureMed and the cart fill. There is also a process for the phone call interruptions. All of these entities and processes are included in the logic code in order to make the simulation represent the pharmacy operations.

4 SIMULATION OUTPUT

4.1 Experiment Design

To use the model an experiment must be set up to evaluate the various options that the pharmacy management would like to consider. The model looks at different levels of 3 options: SureMed, Cart Exchange, and Staffing.

The SureMed option has two levels to consider, either filling the machines once in the morning, or once in the morning and once in the afternoon. If done once there will be some redesign required of what medications are stocked in the machines, and it will take longer to do the fill. Currently the twice per day level is used.

The Cart Exchange option has three levels to consider. The model only looks at the pharmacists checking the carts because there is a part time technician whose sole responsibility is to pick and fill the medication cart each day, and the time this person works can be adjusted to fit the best option. The current level used is to have the cart filled in the evening, and checked by the overnight pharmacist whenever they have time, from midnight until 7 am. To model this option 120 dummy loads arrive every night at midnight and each take 1 minute of the pharmacist's time. After each of these loads is completed the pharmacist checks for other normal orders before continuing to work on the cart fill. The second level is to have the pharmacists check the cart in the afternoon, when there are more pharmacists on duty. For this level the model takes down 2 pharmacists for 1 hour from 2 pm until 3 pm. The third option is to have one of the pharmacists in the morning work from 8 am until 10 am checking the order.

The third option being considered is the staffing level. The first level is the current staffing plan. The second level is to add an additional 8 hours for an IV tech in the evening. The third level is to add an additional technician in the evening. It is obvious that adding staff will improve performance, the question is whether or not the improvement is enough to justify the addition of new staff.

In addition to the three options the model was also run at two different order volumes. The order volume is based on data collected over a one week period that was described as an average week. Since the hospital patient census can vary from week to week and is affected by seasonal effects it was decided to run the model at an increased order volume as well. In order to represent the busier weeks the number of orders per hour was increased 150%. The pharmacy management decided this would be representative of the busiest week in the pharmacy and would show how the changes to the three options would affect the system at its busiest.

Considering all combinations of the three options there are 18 possible scenarios which were each run at both the average and high order volumes. For each scenario the model was run for 25 replications of 10 days each. The model only considers weekdays, since the weekend staffing is not a current concern. The model was checked to make sure that the system is stable each morning, thus running for 10 consecutive days does not add any day to day buildup of orders. This means that there is no need for the model to go through a 'warm-up' stage. Results were collected from this experiment and analyzed to determine the best scenarios.

4.2 Model Output

The pharmacy staff decided that the model performance metric that is the most important to analyze is the average time an order spends in the system, and this should be measured each hour of the day. In order to interpret these results many charts were created so that the pharmacy management can visualize the effect of each change to the system. The preceding 3 charts are examples of the ones created to compare the levels of each option. Each chart shows the average turnaround time for each hour of the day for each scenario. The time shown is that of IV and Med orders, SureMed orders are omitted since they only go through the first two steps and would create misleading data.

Figure 4 shows the effect of changing only the staffing level. As expected adding evening staff improves the turnaround time in the evening and into the early morning. What was not clear was whether it would be better to add a normal technician or an IV technician. The graph shows that an IV technician would give the greater improvement.

Figure 5 shows the effect of changing only the time of the cart fill operation. This time there is not an obvious choice. The current 'night' checking is better except for the early morning hours, which is the concern that is being addressed. The afternoon check helps the early morning some, but makes the evening performance worse. The morning check greatly improves the early morning performance, is similar to the current in the evening, but is worse in the late morning time. The morning check is suggested, since it improves the problem early morning period, and the turnaround time is still acceptable over the midday period.

Figure 6 shows the effect of changing the SureMed policy. As expected filling the machines once in the morning hurts the performance in the middle of the day, but improves performance in the evening and early morning hours. Since changing to a once per day refill has a smaller turnaround time in 16 of the 24 hours, and since the 8 hours where the turnaround time is worse stay under the goal of 120 minutes it is suggested to try to change to a once in the morning SureMed refill. Charts were also created for changing combinations of options, and analyzed for interactions between the decisions.

The initial data used in the model was based off of a typical week in the pharmacy, but when the hospital census increases, the number of orders increases. In order to account for seasonal and high census effects the model was also run at an order volume 150% of the week that was collected. The same sets of charts were created to see the effect that a dramatic increase in order volume would have on system performance. This analysis can help the pharmacy management decide when to add staff based on increasing hospital patient admissions.

4.3 Conclusion

The BroMenn pharmacy management is using the results from this study to help justify changing the pharmacy operational policy. Since the results are based on some assumptions about the data, the effect of the changes may not be exact, but the direction and relative magnitude can be used to compare the effects of possible changes. As changes are made the model will be further verified, and if other options need to be explored the model can be modified to explore further changes.

5 FUTURE WORK

While this model worked well for the pharmacy that was modeled, it was customized to the point that it could not be used by a different hospital's pharmacy without considerable work to change the logic and data. The next step in this research project is to create a simulation model that can be used by any hospital inpatient pharmacy to evaluate possible changes to their staffing and work scheduling. Making a model that is flexible enough to account for the many different types of systems used by pharmacies that is still able to give accurate results will require in depth study of both hospital pharmacy operations and methods of using simulation to evaluate staffing plans.

This improved configurable inpatient pharmacy model is currently being developed. In addition to being configurable to model several types of systems, the model will also address some of the limitations faced in the BroMenn model. For example the order arrival process is modeled as a non-stationary Poisson process, which is inherently flawed. By setting a different mean for each hour and using the exponential distribution to pick a time between orders there is the possibility of picking an extremely long time between orders, thus skipping over the busier hours and missing many order arrivals. In order to avoid this problem Law and Kelton (2000) suggest the use of a thinning algorithm as a way to truncate the extremely large and unrealistic times between orders. This convention will be used in the future model to more accurately model the non-stationary process.

Another improvement to the model will be the ability to perform a sensitivity analysis on the assumptions of processing time. This will show how any error in the assumption affects the results, and will help to identify which process step is the bottleneck. The current model was very limited, as it used the student version of the AutoMod software. For the future model the full version of the software will be used, allowing for a more detailed model and a greater variety of performance statistics to be collected. In theory the new model will be setup in a way that the data needed would be clear, and a simple questionnaire would provide everything needed to perform the analysis.

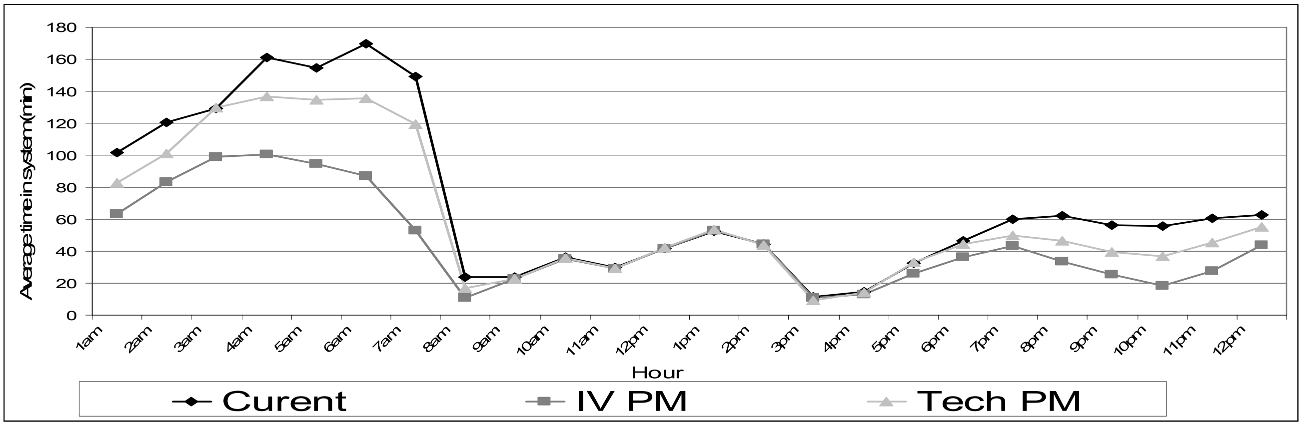

Figure 4: Staffing Options Output

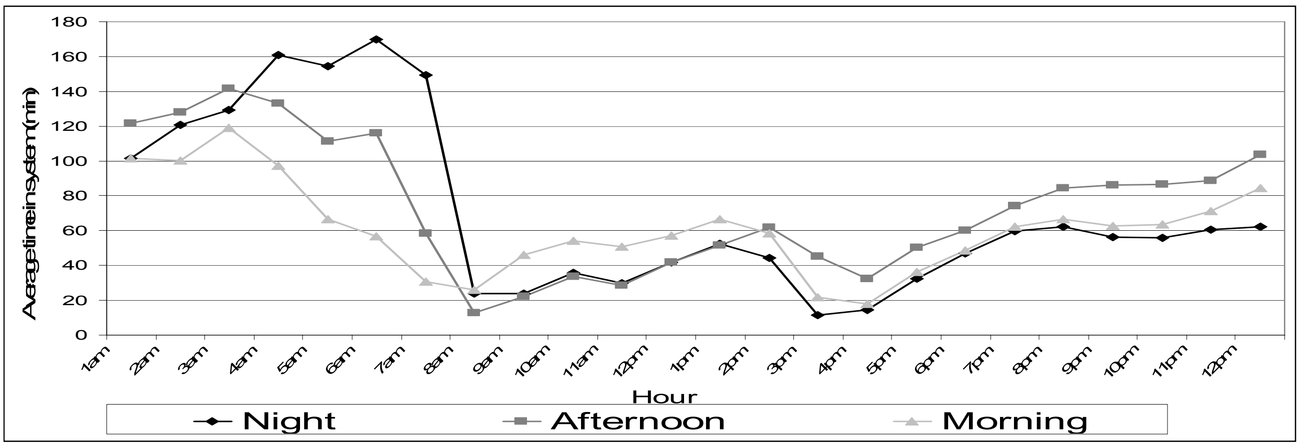

Figure 5: Cart Check Options

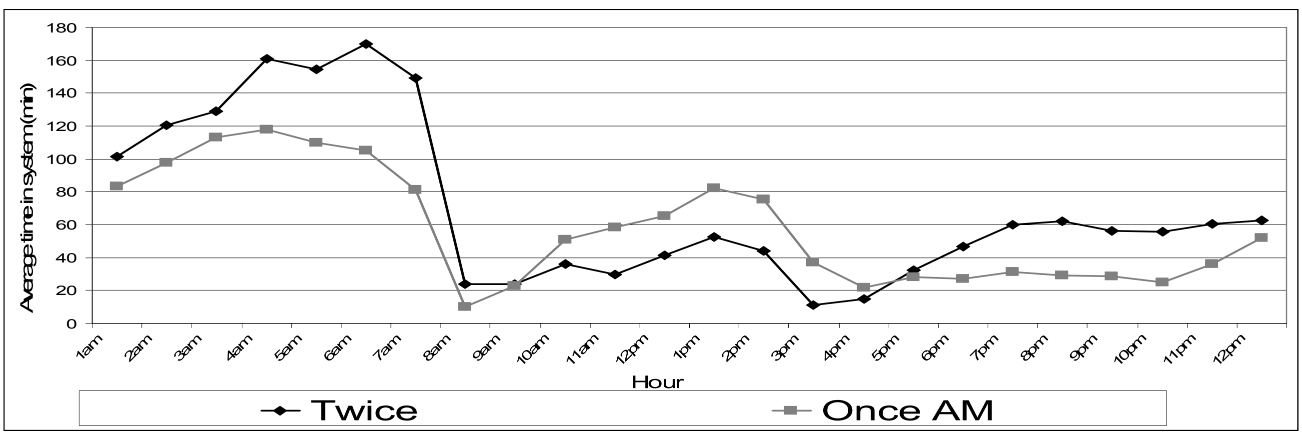

Figure 6: SureMed Options

ACKNOWLEDGMENTS

A simpler version of this model was originally created for a class project, and members of the original group also included Purdue Industrial Engineering Students David Mathews and Tom Mitchell. Thanks to Kathleen Lorenz, Debbie Quain, and the rest of the pharmacy staff at BroMenn for their support in understanding the pharmacy operations and their interest in using simulation as a decision making tool.

REFERENCES

Banks, J. 2004. *Getting started with Automod*. 2nd ed. Brooks Automation, Inc.

Law, A.M., and W.D. Kelton. 2000. *Simulation modeling and analysis*. 3rd ed. New York: McGraw-Hill.

McCarthy, R.L., and K.W. Schafermeyer. 2001. *Introduction to health care delivery: a primer for pharmacists*. 2nd ed. Jones & Bartlett Publishers, Inc.

McRee, T. 2002. Pharmacy staffing: A silent but critical concern. *UCSF Center for Health Professions Report* July 2002.

Pedersen, C.A., P.J. Schneider, and D. J. Scheckelhoff. 2003. ASHP national survey of pharmacy practice in hospital settings: dispensing and administration – 2002. *Am J Health-Syst Pharm*, 60:52-68.

Wong, C., G. Geiger, Y. Derman, C. Busby, and M. Carter 2003. Redesigning the medication ordering, dispensing, and administration process in an acute care academic health sciences centre. In *Proceedings of the 2003 Winter Simulation Conference,* ed. S. Chick, P. J. Sanchez, D. Ferrin, and D. J. Morrice (eds), 1894-1902.

AUTHOR BIOGRAPHIES

CHARLES W. SPRY is a M.S. student in Industrial Engineering at Purdue University. His thesis topic deals with the use of simulation in the improvement of hospital pharmacy operations. He works with the Regenstrief Center for Healthcare Engineering Technical Assistance Program on projects to improve the delivery of healthcare.

MARK A. LAWLEY is an Associate Professor of Industrial Engineering at Purdue University. He received his Ph.D. in Mechanical Engineering from the University of Illinois at Urbana-Champaign. His research interests include discrete event control of systems, and modeling and analysis of resource allocation problems in complex systems. He is also involved in the Regenstrief Center for Healthcare Engineering.