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By

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ISYE 495 – Final Report

Northwestern Medicine: EVS Throughput Improvement

May 5th, 2019

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Executive Summary/Abstract

This paper covers the background, methods, and results of the Environmental Services (EVS) Throughput Improvement project at Northwestern Medicine's Kishwaukee Hospital. Patient throughput at hospitals is closely related to the experience of its patients. At Kishwaukee hospital, increased demand for inpatient services resulted in high occupancy rates and thereby undesirable patient throughput patterns. The project addresses patient throughput related problems at the hospital by seeking to improve the EVS bed turnaround process. This process is defined as the time from when the EVS system is notified that a bed is ready for turnaround, to the time that the room is prepared for the next patient. The primary objective of the project is to reduce the cycle time of the process. The project considers improvements to the scheduling, communication, and standardization of this process by delivering data supported process improvements, industry best practices, and tools for improved communication and feedback. The project succeeds in sustainably reducing the cycle time for the bed turnaround process. Additionally, the project analyzes the effects of factors related to patient throughput using an ARENA discrete event simulation model. The factors analyzed are the bed turnaround time, the patient discharge time, and the number of hospital beds.

Table of Contents

Executive Summary/Abstract iv

List of Tables vii

List of Figures viii

1. Introduction 1

2. Background and Motivation 1

   2.1. Hospital Background 1

   2.2. Project Motivation 1

3. Problem Description 3

4. Project Parameters 4

   4.1. Objectives 4

   4.2. Scope 5

   4.3. Deliverables 6

5. Assumptions 6

6. Initial Observations 6

   6.1. System Description 6

   6.2. Shadowing 8

   6.3. Best Practice Review 12

7. Data Collection and Analysis 15

   7.1. Data Collection 15

   7.2. Data Analysis 16

8. Recommendations 21

   8.1. Mid-Shift 21

   8.2. Front Loading 22

   8.3. Dashboard 22

8.4. Queue Based Triggers 25

9. Throughput Simulation 27

9.1. Model Ideation 27

9.2. Assumptions 27

9.3. Data Analysis 28

9.4. Replications 30

9.5. Validation 31

10. Results 32

10.1. EVS Throughput 32

10.2. Simulation 34

11. Conclusions 35

12. Ethics 36

Appendix - A 37

List of Tables

Table 1 – EVS Performance at Northwestern Hospitals 5
Table 2 – Number of Beds per Unit at Kishwaukee Hospital 7
Table 3 – EVS Staffing Levels 8
Table 4 – Crosswalk of Industry Practices 14
Table 5 – ID Definitions 28

List of Figures

Figure 1 – 9 AM Occupancy Percentage 2
Figure 2 – Average Boarding Time 2
Figure 3 – Kishwaukee and System EVS Performance 3
Figure 4 – EVS Turnaround Process Map 11
Figure 5 – Run Chart of Demand by Month 17
Figure 6 – Run Chart of Demand by Week 17
Figure 7 – Histogram of Daily Demand 18
Figure 8 – Probability Plot of Daily Demand 18
Figure 9 – ANOM of Daily Demand 18
Figure 10 – Moving Average of Hourly Demand 19
Figure 11 – Average Minute by Minute Notify and Assign Rates and Queue Length 21
Figure 12 – Front Loading Concept 22
Figure 13 – Sample Dashboard 24
Figure 14 – Queue Based Trigger Decision Tree 26
Figure 15 – Bed Management Processing Distribution 30
Figure 16 – Two-Sample T-test with Box Plot (ED Boarding Time) 31
Figure 17 – Two-Sample T-test with Box Plot (LOS) 32
Figure 18 – Performance FYTD 33
Figure 19 – Average Turnaround Time Comparison 33
Figure 20 – Simulation Results (Facility Expansion of 1 Bed) 34
Figure 21 – Simulation Results (EVS Project) 34
Figure 22 – Simulation Results (All Capacity Projects) 35

1. Introduction

The prompt and predictable boarding of hospital patients is vitally important to their confidence, comfort, and health outcomes. When a healthcare facility cannot situate its patients efficiently, it not only affects the patients but also presents challenges to the associated healthcare workers. Due to the connection between room readiness and patient throughput, the coordination of patient discharges and the preparation of the rooms are of great interest in the realm of healthcare process improvement. The EVS (Environmental Services) Throughput Improvement project relates directly to this issue. This report documents the methods, proposals, and results of the project. To address the problem this project focuses on a few key areas: the coordination, scheduling, and communication of EVS staff. Although the improvement of the EVS bed turnaround performance is the focus, another key deliverable of this project is a discrete event simulation model. The purpose of the model is to evaluate the effects of various efficiency improvements on patient throughput.

2. Background and Motivation

2.1. Hospital Background

Northwestern Medicine (NM) is an integrated academic healthcare system comprised of ten hospitals and more than 300 outpatient facilities in the Chicago metropolitan area. NIU senior design group was asked to focus specifically on Kishwaukee Hospital. Beginning as a community hospital in DeKalb, IL, Kishwaukee became part of NM in 2015.

2.2. Project Motivation

Over the past year, Kishwaukee Hospital has experienced an increase in demand for inpatient services, and as a result, is operating close to capacity. Figure 1 shows the occupancy percentage at 9 AM for the three non-critical care units of the hospital. Because patients are normally discharged in the afternoon, in order to successfully meet the demand of patients arriving in the morning, the hospital needs to be below 100% occupancy. Management at Kishwaukee Hospital has determined that the ideal 9 AM occupancy is 85%. When the occupancy is greater than 85% at 9 AM, there is a significant risk that the hospital will be unable to successfully meet the demand of incoming patients. As a result, Figure 1 demonstrates that Kishwaukee is frequently operating above the 85% occupancy level.

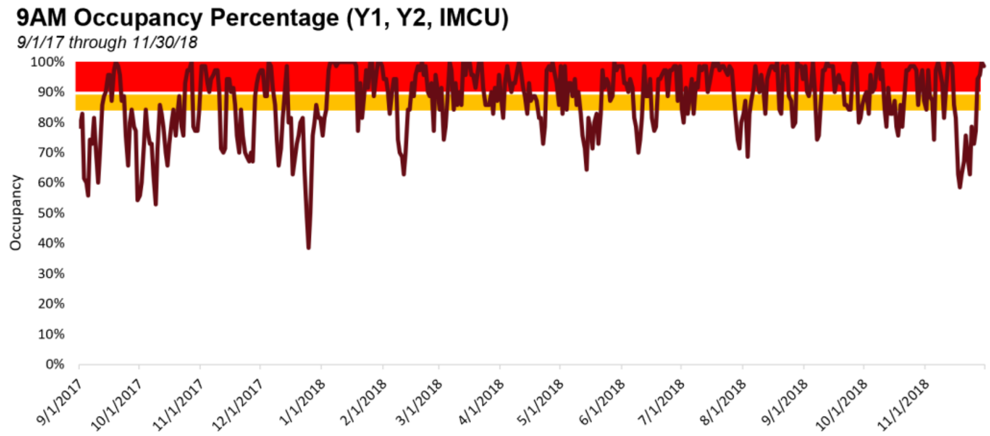


Figure 1 – 9 AM Occupancy Percentage

A direct result of operating at high occupancy is front-end congestion, specifically in the Emergency Department (ED). When beds are not available for incoming patients, a queue forms and patients wait for a long time before a bed can become available. Figure 2 shows the effects of the 9 AM occupancy rate on the ED boarding times. The ED boarding time is the time from when a physician decides to admit a patient to when the patient is transferred to their inpatient room.

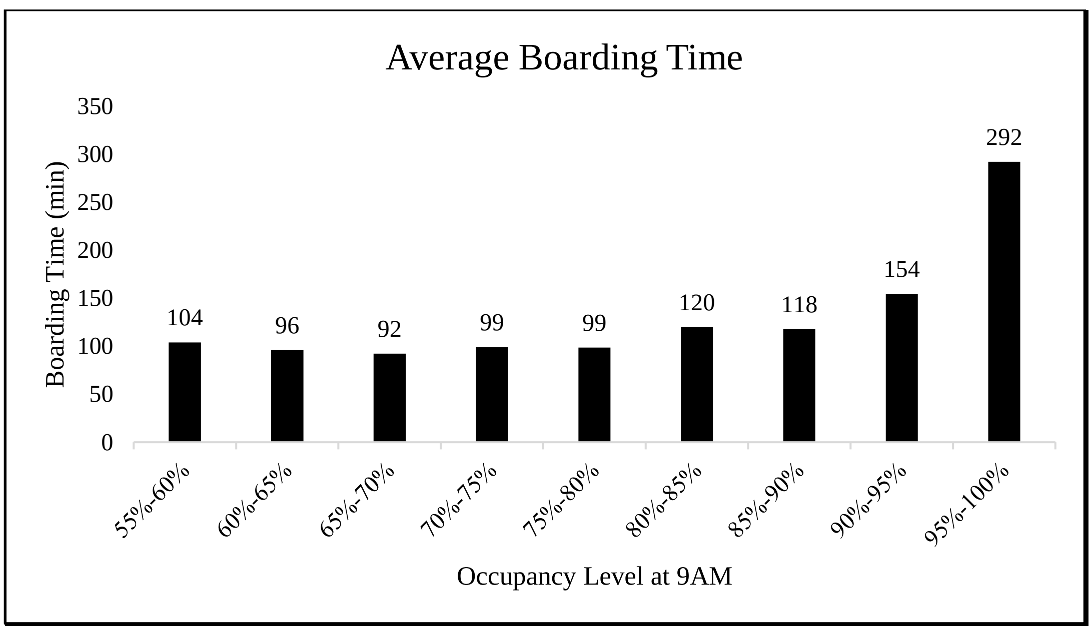


Figure 2 – Average Boarding Time

As the occupancy level approaches 90-100%, boarding times increase drastically. Handling this increasing demand has thus become an area of focus for Kishwaukee Hospital. To satisfy this increasing demand, Kishwaukee is working to expand their capacity. There are two methods of expanding capacity: facility expansion and improving resource utilization. Considering that facility expansion costs 1-2 million dollars per room, management is highly motivated to first improve the utilization of current resources. One of the processes that greatly affects the utilization of capital is the inpatient room turnaround process. Once a patient has been discharged the room must be cleaned and prepared before a new patient can be assigned to the room. This process is called the turnaround process. The impact of reducing this time would allow the hospital to operate at a higher occupancy with less front-end congestion.

3. Problem Description

Environmental Services, or EVS, is responsible for the cleaning of rooms, as well as the cleaning of the general areas of the hospital. Initially, the average bed turnaround time for the Kishwaukee EVS team was 86 minutes longer than the system average, indicating a major opportunity for improvement. Figure 3 shows the average bed turning times for Kishwaukee Hospital as compared to the rest of the NM system.

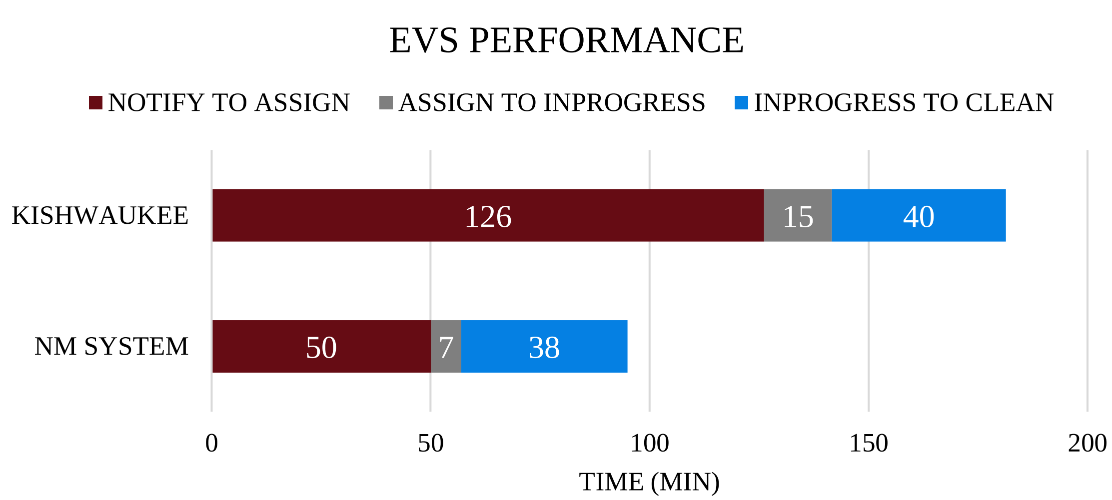


Figure 3 – Kishwaukee and System EVS Performance

These average times are based on bed turnarounds from 9/1/2018 – 12/31/2018. The EVS bed turnaround process is split into three parts: Notify to Assign, Assign to InProgress, and

InProgress to Clean. The Notify to Assign is from when EVS is notified that a room needs to be cleaned to when a technician is assigned to clean that room. Assign to InProgress is from when a technician is assigned to a room to when the technician starts cleaning the room. InProgress to Clean is from the start to the end of the cleaning process. Based on Figure 3, the cleaning times for rooms at Kishwaukee is close to the system average, but the major areas of improvement are the two previous phases. The NIU senior design group has been tasked with analyzing the current state of the EVS process and implementing measures to drastically reduce the room turnaround times.

Additionally, Kishwaukee Hospital desires a better understanding of how different factors within the hospital will affect the overall throughput. To satisfy this, the senior design team will develop a high-level throughput model using Arena software to simulate the flow of patients through the hospital. This will allow the team to manipulate different throughput factors, such as number of beds or demand level, to determine the effect these potential changes will have on the patient throughput.

4. Project Parameters

4.1. Objectives

The overall objective of the EVS project is to reduce the time it takes to turnaround a room after a patient has been discharged. However, a baseline for this process must first be established. The first step in creating a baseline was deciding on an outcome metric. An outcome metric is a metric that accurately reflects the performance of the process and will be used to measure success. The metric chosen was the percent of turnaround less than 120-minutes. The turnaround time is the time between when the EVS staff is notified that a room needs to be turned (notify time) and the time the room is cleaned (clean time). It was decided that the baseline and benchmarking would be based on data from 9/1/2018 – 12/31/2018. This time frame was chosen because it represented the data fiscal year-to-date for Northwestern Medicine. The resulting baseline for Kishwaukee was 52%, meaning that Kishwaukee had turnaround times less than 120 minutes only 52% of the time. Table 1 shows the breakdown of this outcome metric for each hospital within the Northwestern Medicine. Because the percentage for the rest of the system is around 75% or above, the objective of the EVS project is to achieve room turnaround times of less than 120 minutes 75% of the time.

Table 1 – EVS Performance at Northwestern Hospitals

Hospital	% of Turns < 120 Mins
Central DuPage	74.3%
Delnor	77.4%
Kishwaukee	52.6%
Lake Forest	94.3%
Northwestern Memorial	79.2%
Valley West	77.2%

The main objective for the overall hospital throughput model is to allow administrators and analysts at Kishwaukee Hospital to determine the effects of changing key throughput factors. In addition to the EVS Throughput Improvement project, Kishwaukee is working on several other projects designed to improve capacity. This model will help management gain a better understanding of the impact of each individual project, as well as the combined impact of the projects.

4.2. Scope

For the EVS portion of the project, the team will focus on the turnaround process for all 5 inpatient units: medicine/surgery (Y1), telemetry/pediatrics (Y2), intermediate care (IMCU), intensive care (ICU) and Obstetrics (OB). The emergency department (ED) will not be considered, because this unit has its own designated bed turning technician and is outside of the EVS inpatient process.

For the hospital throughput simulation, the team will consider only 4 of the 5 inpatient units (Y1, Y2, IMCU, ICU). OB is not included because it used solely for labor and delivery and is never at full capacity. As a result, it has no impact on the hospital-wide throughput. With that said, the simulation does include OB rooms, but this is only to account for the rare occurrence when a patient starts in OB and is transferred to a traditional bed. Therefore, even though the simulation has OB beds, it only includes OB patients who spend time in an inpatient room. In addition to the impatient units, the simulation will also include the two main sources of admissions, the Emergency and Surgery Departments.

4.3. Deliverables

There are two main deliverables. The first is the improvement of the EVS bed turnaround process. Sub-deliverables in this area are improvements to staff allocation, determination of industry best practices, and process improvement events. The focus of these sub-deliverables is the reduction in cycle time, standardization, and improvement of the bed turnaround process. The second deliverable is the development of a verified and validated discrete event simulation model to analyze the effects of potential capacity improvements on patient throughput.

5. Assumptions

For the purposes of this project it is assumed that the data that has been tracked through the hospital database is largely accurate and indicative of reality. Additionally, it is assumed that historical data is reasonably representative of the near future and that there will not be significant policy, demographic, or other changes that would affect EVS procedures, schedules, or coordination. It is assumed that differences between Kishwaukee's performance and those of other hospitals are not due to a lack of effort by the EVS team, but rather due to policy, methods, and equipment. It is also assumed that improving the EVS performance with respect to bed turnarounds will not lead to unpredictable detrimental effects in other areas of EVS responsibility or other departments within the hospital.

6. Initial Observations

6.1. System Description

The current capacity of Kishwaukee Hospital is 98 beds, spread across five different departments. Table 2 summarizes the number of beds per department in the hospital.

Table 2 – Number of Beds per Unit at Kishwaukee Hospital

Beds	
Medicine/Surgery Unit (Y1)	36
Telemetry/Pediatrics Unit (Y2)	24
Intermediate Care Unit (IMCU)	12
Intensive Care Unit (ICU)	12
Obstetrics (OB)	16
Total	**100**

The discrepancy between the total beds in Table 2 and the hospital's capacity is caused by 2 pediatric rooms on Y2. These rooms are not certified to hold adult patients. As a result, they are idle most of the time. Y1 has the largest number of beds, with 36, and the ICU and IMCU have the least number of beds with 12 beds each. It is important to note that while OB has 16 beds, this department rarely is operating at capacity. The EVS department is responsible for cleaning all of these rooms, as well as the rest of the hospital, including rehabilitation areas, general areas like hallways and lobbies, and doctor's offices. The senior design team is in the process of obtaining a more comprehensive list of the EVS duties to gain a fuller understanding of the overall demand.

For fiscal year 2019, EVS budgeted for 35 full time employees, based on the cleanable square footage of the hospital and the labor required to clean it. However, as of January, there were only 25 full time employees, meaning the team was understaffed by 10 full time employees.

The work day is split into three shifts, where Shift 1 is from 7 AM – 3:30 PM, Shift 2 is from 3 PM – 11:30 PM, and Shift 3 is from 11 PM – 7:30 AM. There is a half hour overlap between the shifts to account for shift change. During each shift, technicians are assigned tasks, and there is a set number of designated "bed technicians" that only turn rooms. Those who are not designated bed technicians are responsible for completing tasks elsewhere in the hospital, like cleaning general areas or collecting waste from the units. During the first shift, there are four bed technicians and during the second shift there are two bed technicians. Table 3 summarizes the staffing level based on shift. Based on this data, all shifts are understaffed.

Table 3 – EVS Staffing Levels

Staffing Levels By Shift			
	Shift 1	Shift 2	Shift 3
Hours	7:00 am-3:30 pm	3:00 pm-11:30 pm	11:00 pm-7:30 am
Budgeted Employees	9	14	2
Actual Employees	7	11	1

6.2. Shadowing

The first step in the project was shadowing the EVS technicians to gain a better understanding of the process. The three senior design team members shadowed on three different days separately; two shadowed during the week and one shadowed on Sunday to capture differences between weekdays and weekends. All team members shadowed from 1 PM – 5 PM, which allowed them to observe two hours of the first shift, shift change, and two hours of the second shift. The team was able to make some initial observations immediately after shadowing. At the beginning of the project, the EVS team was very understaffed, and the effects of this became apparent during shadowing. The hospital budgets for EVS technicians every fiscal year based on "cleanable square footage," meaning the needed staff level is determined based on the area that needs to be cleaned. In January, the department was understaffed by ten full-time employees. Consequently, EVS technicians felt very overwhelmed by their work, which led to overall low morale on the team. Additionally, many technicians voiced that despite their hard work, they felt that they were underappreciated by the management, and that their concerns and suggestions were not being addressed. Many noted that a direct result of this is that they did not feel a sense of urgency to complete their tasks anymore and worked at their own pace. This was especially true on Sunday. Demand was not high on this specific day, and it was observed that technicians worked at their own pace and even worked together to complete rooms faster, which is not standard practice. Based on these observations, the team made sure that the staff would be included and taken into consideration in future improvement ideas.

Another initial observation was the problems with the pager system used. When a patient is discharged, the charge nurse or staff member in charge of discharging patients puts in a request for the room to be cleaned. This request is sent to the EVS department through Epic. Once the EVS department is notified, a room is assigned to a technician, and the technician is notified of this through their pager. However, the senior design group observed that for a large number of instances, the pagers simply do not work. Technicians are not notified of their assignments, so rooms sit in the queue for longer before they are cleaned. Consequently, Kishwaukee Hospital is currently in the process of updating this system to a smartphone system to reduce the chances of malfunction.

Additionally, it became apparent that Kishwaukee's EVS team did not have a standardized approach to handling a long queue of rooms. At peak demand hours, the queue often became so long that the technicians assigned to bed turning could not handle the work load. To combat this, management would call technicians doing other tasks within the hospital, like cleaning common areas, to come and help clean rooms. Rather than plan for this demand and schedule staff accordingly, or even have a standardized method to handle high demand, Kishwaukee employed a reactive policy that disrupted technicians' work.

A key deliverable from shadowing is the process map, which outlines the EVS room cleaning process from the discharge of a patient to the start of the room cleaning. EVS management also helped the team clarify their understanding of the basic process. Figure 4 shows the process map.

Within the map, orange boxes refer to processes out of the scope of the project, green boxes refer to processes from Notify to Assign, and blue boxes refer to processes from Assign to Clean. Red dashed lines refer to pain points in the process.

As mentioned before, after a patient has been discharged, Epic is notified. However, these two things do not always occur simultaneously, due to human error. It was observed that a nurse could discharge a patient, walk them down to the exit, and then come back and put in the discharge. This means that there could be delay in between the actual discharge time and the discharge time input into Epic. After the request has been sent, Epic checks if the technician assigned to the sector that contains the room is free. If they are, then Epic sends a notification to the technician of the room that needs to be cleaned. If they are not free, Epic checks to see if the backup technician is free. If the backup is free, Epic sends a notification, otherwise the room waits in the queue until one of the technicians is free. Management also has the ability to manually assign rooms. If management sees that there is a technician free, they may assign him/her a room that is not within their sector. However, this type of manual assignment strategy is not standardized, and is a reactive strategy rather than a proactive one. After a technician is paged their room assignment, he/she walks to the room, checks in using the phone, marking the room as InProgress, and begins cleaning. After the cleaning is done, the technician uses the phone to check out of the room, and the room is marked as clean.

CURRENT STATE PROCESS MAP	
Company Name	Northwestern Medicine: Kishwaukee Hospital
Process Map	EVS Room Turnaround
Drawn By	Micah Volle, Dan Field, Leena Ghrayeb
Date	February 8th, 2019

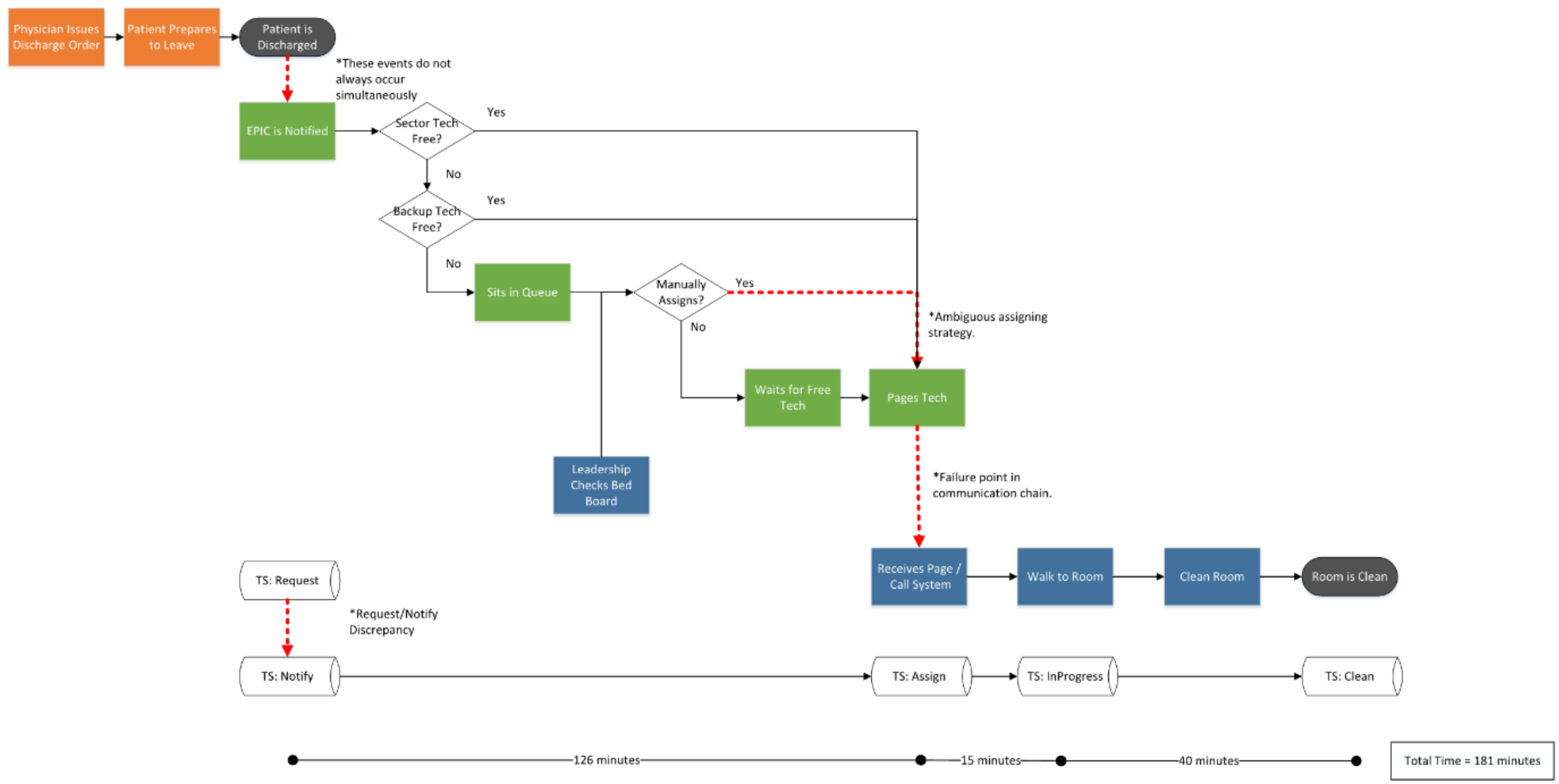


Figure 4 – EVS Turnaround Process Map

6.3. Best Practice Review

After the team understood the EVS process at Kishwaukee, it became necessary to examine the practices of high performing hospitals within the system. Two different hospitals were chosen: Delnor and Huntley. Delnor hospital has 158 beds, while Huntley has 128. Delnor Hospital is slightly bigger than Kishwaukee but outperforms Kishwaukee by a large margin, which can be seen in Table 1 Additionally, Delnor has undertaken and completed a similar EVS improvement project. Huntley hospital is also slightly bigger than Kishwaukee but has not implemented the pager system and requires nurses to make a call to notify EVS of a room that needs cleaning. Despite their system being less automated, Huntley still outperforms Kishwaukee and is closer to the system average, as also seen in Table 1. Thus, the team wanted to contact these two hospitals to determine key practices that helped them maintain high performance. These meetings were held over the phone with lead engineers and management at each of the hospitals. Table 5 summarizes the main practices at each of the hospitals.

It is important to note that Delnor is better staffed than Kishwaukee, as they only had three full time positions vacant. However, some key practices that they employed to satisfy their demand were staggered start of their employees, a split staffing model, and clearing the queue. Their bed turning technicians arrived at 1 PM, rather than 3 PM, to accommodate for peak demand around 2 – 3 PM. Additionally, they assigned more bed turning technicians during the first half of second shift to accommodate for peak demand during the time and allowed technicians to make up for other tasks during the second half of the shift. To clear the queue, when additional help is needed, all technicians are called to clean beds and return to their other tasks afterwards. This contrasts with Kishwaukee's reactive policy to a long queue.

Huntley's practices include part time positions, moving their shifts, forecasting discharges, and building morale. To accommodate for peak demand during the middle of the day, they hired a part time technician to help turn beds from 1 PM – 5 PM. To avoid shift change during peak demand hours, they moved their shifts forward by one hour. To make sure that they plan properly for peak demand, they use real time predictions of the number of discharges for the day, as well as the times of the discharges. Additionally, they make sure that team morale is high by communicating to staff the previous day's performance and recognizing and thanking staff when they perform well or handle a high demand well. The practices of both Delnor and Huntley are taken into consideration when brainstorming ideas to implement at Kishwaukee.

Hospital	Best Practice	Description	Logic
Delnor	Stagger Start	Bed turning techs arrive at 1pm instead of 3pm.	The number of discharges begins to increase at 1pm. This helps match resources with demand.
	Half and Half Staffing Model	During second shift, assign more techs to turn beds with the expectation they will perform ancillary tasks later in the shift.	Discharges are very frequent at the start of the shift but are usually finished by 6pm.
	Clear the Queue	When additional help is needed to turn rooms, the entire EVS staff will work to completely clear the queue.	In order to reduce the number of times other EVS techs have to be pulled away from their work, it is best to completely clear the queue so that a second help request is not need.
Huntley	Utilize Part Time Positions	Hire part time EVS techs that work from 1pm-5pm.	The peak of the discharge curve occurs between 1pm-5pm. This provides additional help exactly when it is needed.
	Build Morale	Highlight the work accomplished from the previous day at the shift huddle.	The process of turning rooms can feel overwhelming, but having the work recognized is very encouraging.
	Restructure Shifts	Move all of the shifts forward by 1 hour.	Shift change is a disruptive process and current practice has shift change at the peak of the discharge curve (3pm). By moving the shifts forward, the disruption occurs after the peak discharge time.
	Forecast Discharges	Participate in the daily bed planning meetings and obtain a prediction of the number of discharges and when they will occur.	The forecast allows the EVS team to plan for extraordinary demand.

Table 4 – Crosswalk of Industry Practices

7. Data Collection and Analysis

7.1. Data Collection

Modern hospital operations are carefully tracked using electronic health records (EHRs). One of the leading EHR systems is Epic, which is used by Northwestern Medicine. Using Epic, a patient's care is carefully documented and tracked. Furthermore, Epic is so integrated into hospital operations that even non-clinical activities are tracked and managed using the software. Due to the extensive electronic documentation of hospital operations, this project has been able to collect the necessary data using Northwestern Medicine's EHR system.

The data used in this project came from four datasets: (1) EVS throughput, (2) hospital throughput, (3) ED throughput, (4) hospital census. The EVS throughput data was pulled from Northwestern Medicine's Enterprise Data Warehouse (EDW) using a report called "EVS Throughput Data". While data can be pulled directly from Epic, it is preferred that data is pulled from the EDW. The EDW contains the data collected in Epic and has pre-built reports that provide easy access to important types of data. Each row in this dataset represents a room that needs to be cleaned. The data contains multiple timestamp for each step in the turnaround process. The timestamps include the notify time (when the EVS team was notified that the room needed to be cleaned), the assign time (when a tech was assigned to that room), the in-progress time (when the tech started cleaning the room), and the clean time (when the tech finished cleaning the room). For the remainder of the report, the assign time will refer to the time between the notify timestamp and the assign timestamp, the in-progress time will be the time between the assignment timestamp and the in-progress timestamp, and the clean time will be the difference between the in-progress timestamp and the clean timestamp. The turnaround time is the sum of these three components as show in Equation 1. A complete list of the available fields in this dataset and a description of what they represent is provided in Table A-1 in the Appendix.

$$Turnaround\ Time = Assign\ Time + InProgress\ Time + Clean\ Time \quad \textbf{(1)}$$

The next dataset, hospital throughput, provides critical information regarding the flow of patients through the hospital and is the primary dataset used in the throughput model. Unlike the first dataset, this data was pulled directly from Epic. In this dataset, each row represents a patient who occupied a bed on one of the four inpatient units at Kishwaukee Hospital. While there are reports available in the EDW that provide similar information, they do not include several necessary pieces of information including the origin of the admission and when the bed was requested. Furthermore, the EDW reports do not include outpatients who, for a variety of reasons, sometimes occupy inpatient rooms. Therefore, by creating a custom report in Epic all of this information was included in a single dataset.

The main purpose of last two datasets is to calculate the bed management processing time, which is discussed in more detail in the next section. The ED throughput dataset comes from an EDW report called "ED System Toolkit". Each row in the dataset represents a patient encounter in the ED. The primary piece of information gleaned from this report was the bed request to bed ready time. The hospital census provides the census of each inpatient unit at Kishwaukee Hospital at 9AM. This data was pulled from the EDW report "Flexible Daily Census".

7.2. Data Analysis

This data analysis section focuses exclusively on the analysis relevant for the EVS throughput improvement. The analysis associated with the simulation is included in the simulation section of the report.

The first step in the analysis of the EVS throughput data was to review and clean the data. During this process there were two minor issues observed. The first issue involved duplicate rows. The cause of this anomaly was not identified but it is easily corrected using the "remove duplicates" feature in Excel. The exact procedure that was followed was to first select the data table, then click the remove duplicates values, and then select only three fields, "PAT_ENC_CSN_ID", "NOTIFY_DATE_TM", and "NOTIFY_TIME_TM". The second issue was blank data values within the time fields. The cause of this issue was not identified but there are only a small number of these occurrences. The solution was to fill the blanks with the average values from the dataset.

As mentioned before, an initial step in the project was to determine a performance baseline and benchmark Kishwaukee's performance against other Northwestern hospitals. After creating a baseline, the next step was to examine the turnaround demand. The process of analyzing bed turnaround demand began with checking for seasonality and progressively looks at more specific factors. Figure 5 is a run charts that look at the average daily demand by month and figure 6 is a run chart that looks at the total weekly demand by week. Both of these run charts have a 19-month horizon and show no seasonal patterns.

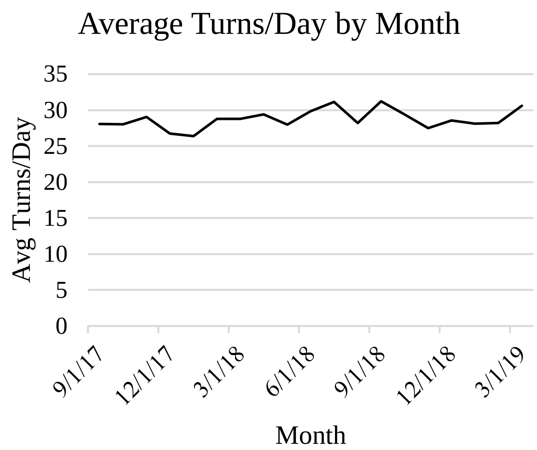


Figure 5 – Run Chart of Demand by Month

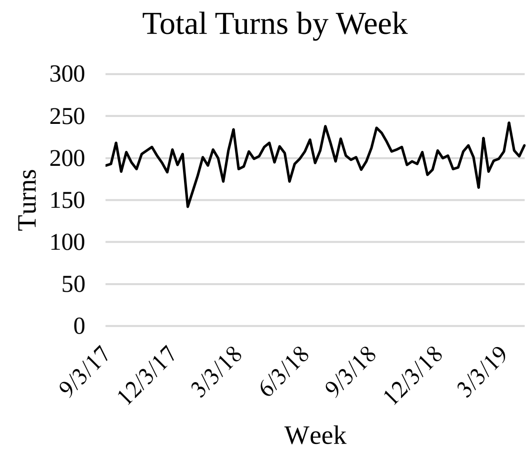


Figure 6 – Run Chart of Demand by Week

The demand was then analyzed by day of week. After verifying the daily demand was normally distributed using a histogram (Figure 7) and a probability plot (Figure 8), an analysis of means was conducted. Figure 9 shows the demand is significantly impacted by the day of week. While Sunday and Monday are significantly below the population mean, Tuesday – Friday are significantly higher than the population mean. As a result, this should be taken into consideration when planning the staff schedules. If there are EVS tasks that only need to be completed once a week, it would be advantageous to schedules these tasks on Sunday or Monday.

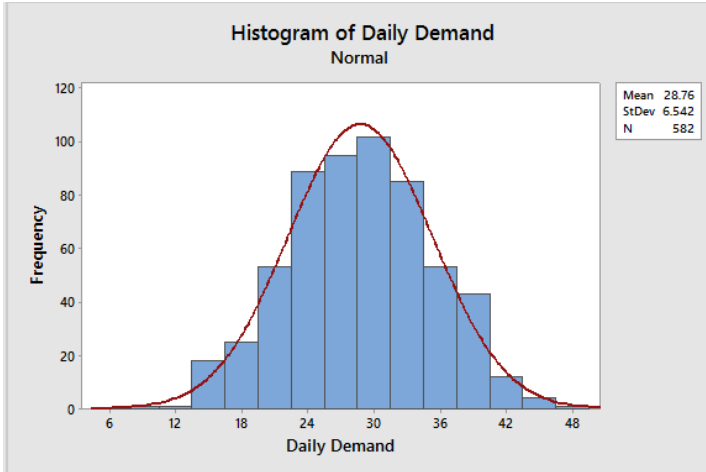


Figure 7 – Histogram of Daily Demand

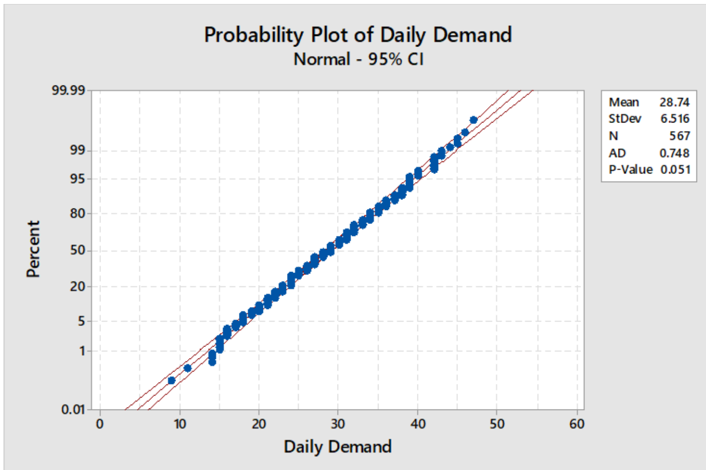


Figure 8 – Probability Plot of Daily Demand

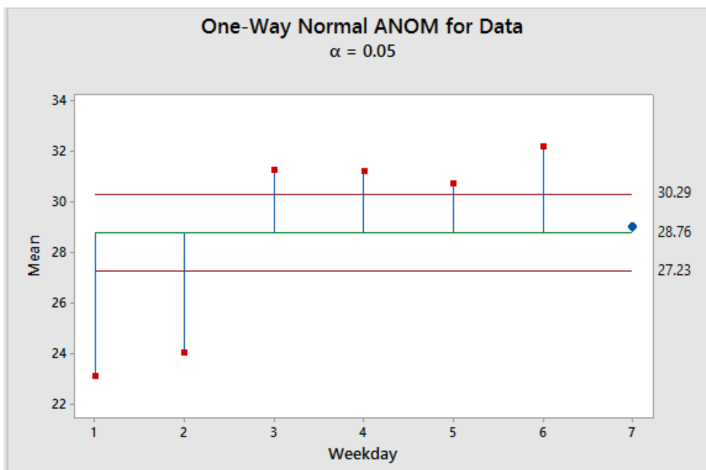


Figure 9 – ANOM of Daily Demand

The final element in the demand analysis looks at how the demand fluctuates by time of day. Given that the exact time of demand is highly variable, a formal statistical analysis was not an option. Therefore, to verify that demand follows a consistent pattern throughout the course of the day, moving average run charts that looked at the number or requests during a specified time period were created for every day between 6/1/2018 and 12/31/2018. The moving average considered the values of the actual time period and the time periods before and after. The result is figure 10, which shows that the demand follows a consistent pattern. The demand gradually increasing during the morning, peaks at mid-afternoon and decreases into the night.

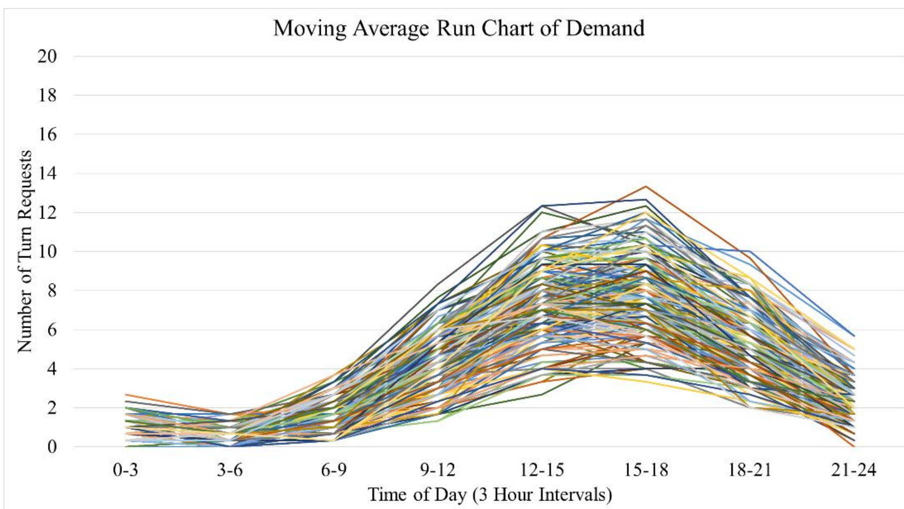


Figure 10 – Moving Average of Hourly Demand

Having verified the consistency of this behavior, a more detailed analysis was conducted to look at the EVS demand, as well as the EVS assignment performance and the average queue length. While the average demand rate and the average assign rate are easily calculated, the average queue length is more challenging. To calculate the average queue length by time of day, the follow technique was used to retrospectively calculate the queue length. This method also allowed the granularity of the turnaround behavior to increase from an hour to a minute. Within Excel, a time line was created from 9/1/2017 through 12/31/2018. The time line was granular to the minute. The notify, assign, and clean timestamps were all grouped using a pivot table and the count of the timestamps were then placed on the timeline using the VLOOKUP function. For example, if two rooms were assigned on 3/12/2018 at 14:23, the value 2 would be placed on the timeline at that exact time. Due to slight variances between the timeline time values and the timestamp time values, all time values were converted into integers using Equation 2. These integers were unique and consistent for each minute in time which allowed the data points to be placed on the timeline using VLOOKUP.

$$Time\ Integer = INT(Time\ Stamp * 10000) \qquad \textbf{(2)}$$

The net result was a timeline that indicated exactly how notifications, assignments, and rooms were cleaned during any given minute along the timeline. Table A-2 in the Appendix shows the structure of the timeline. Once the notifications, assignments, and cleanings were placed on the timeline, the queue could be calculated by adding the number of notifications during a minute to the number in the queue during the previous minute and subtracting the number of assignments. Once the timeline data table was created, a pivot table was made from the timeline which was grouped by hour and minute. The values included the sum of notifications, the sum of assignments, and the average of the queue length. To better represent this output, the sum of notifications and assignments were converted to a meaningful rate (rooms per hour). Equation 3 summarizes how this was accomplished

$$\frac{\#\ of\ Timestamps\ (rooms)}{\#\ of\ Days} * 60\ mins = rooms/hour \qquad \textbf{(3)}$$

These values were then smoothed using a moving average. For a given minute, the smoothed value was the average of the data point for the actual minute and the 2 minutes before and after. The end result is Figure 11. In Figure 11, the black line shows the average demand rate, the blue line shows the average rate that resources are being assigned, and the red line shows the average queue length. When the blue line is below the black line, the queue begins to grow. Therefore, this shows that the EVS team begins to fall behind during the lead up to shift change at 3PM. At 3PM the second shift arrives and there is an increase in assignments, but this begins a cyclical pattern that reflects the cycle time for turning a room. The team is not able to satisfy demand until approximately 7PM, at which point the demand rate is less than the assignment rate. This analysis was also conducted for Delnor and is shown in Figure A-1 in the Appendix.

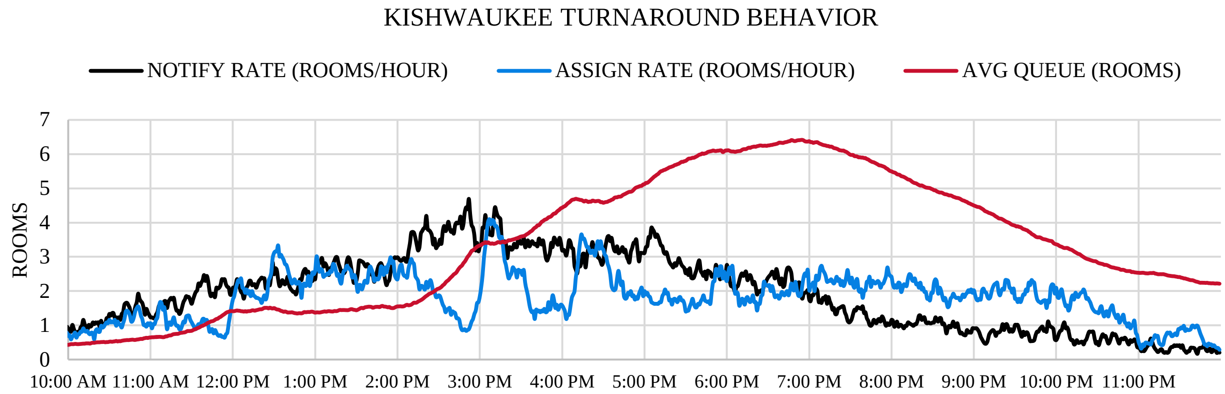


Figure 11 – Average Minute by Minute Notify and Assign Rates and Queue Length

8. Recommendations

8.1. Mid-Shift

The first improvement idea is the addition of a mid-shift. Based on Figure 11, peak demand occurs during the beginning of second shift every day, on average. Staff are unable to handle the demand from this time through 7 PM, as seen by the steady increase in the bed queue length. However, after 7 PM, during the second shift, there is an excess of manhours available, as staff's capacity exceeds the demand. Thus, a mid-shift is proposed, from 12 PM – 8:30 PM. It is proposed that one or two additional technicians be added to only help with bed turning during these times. It is important to mention that the team does not propose hiring new staff, but rather reallocating existing staff from the second shift to a mid-shift. As previously mentioned, there are only two bed turning technicians designated during the second shift and additional technicians are called from their tasks reactively if the queue becomes too long. Thus, an extra technician during the middle of the day would allow bed turning to continue even through shift change, minimizing disruption and the growth in queue length. Recognizing great value of this specialized shift, Kishwaukee Hospital began implementing the shift on January 24th. While the non-traditional working hours initially created a barrier to implementation, EVS management offer the added benefit of having the weekends off. Therefore, the mid-shift is staffed by a person who has committed to work the shift Monday-Friday. While this does mean the shift is not worked during the weekends, the demand analysis confirms that demand is lower, which justifies the absence of this shift on the weekend.

8.2. Front Loading

Another improvement idea is frontloading. Based on Figure 11, the assign rate of technicians per minute is less than the notify rate all day until around 7 PM. This means that the demand for clean rooms exceeds the number of technicians being assigned to clean rooms, which allows the queue to continue to grow. However, after 7 PM, the assign rate is above the notify rate, meaning technicians are able to keep up with the demand as it occurs. Thus, the idea behind frontloading is shifting those manhours after 7 PM to the beginning of the second shift to match resources with the demand. EVS technicians are responsible for other tasks around the hospital, like cleaning common areas and collecting waste, however these tasks are not as time sensitive as turning around rooms. Thus, staff schedules should be reorganized such that staff are turning beds at the beginning of the second shift, when peak demand occurs, and spend the rest of their shift doing other non-time-sensitive tasks. This recommendation was implemented on April 1st. Figure 12 summarizes this idea.

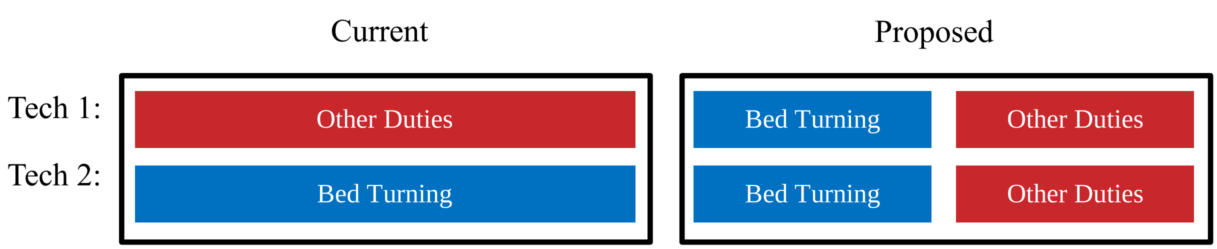


Figure 12 – Front Loading Concept

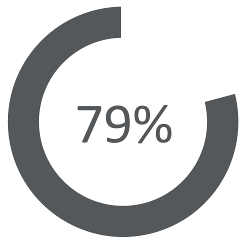
8.3. Dashboard

Another recommendation idea is the performance dashboard. This was first presented to EVS management the second week of March and has been used since. This dashboard allows management to easily gauge their performance but is also a good way to communicate performance to the EVS staff. Involving the staff and making them aware of their performance, and praising good performance, is key in keeping the team aware and maintaining continuous improvement. Figure 13 shows a sample dashboard. The dashboard is very easy to update, as management simply has to copy and paste previous week's performance from their electronic system into an Excel sheet, which generates this dashboard for them. The senior design team ensured that EVS management is aware of how to update the dashboard, which will allow them to update it weekly.

The dashboard is split into four parts. The first part summarizes the previous week's performance. It reports the percentage of bed turns that were less than 120 minutes, the percent of bed turns less than 90 minutes, the average time per turnaround, and the number of bed turns per shift (first and second shift). The second part summarizes the turnaround volume per day of the week, by shift, and reports the total number of bed turns per day. The third part shows the process metric, or percent of bed turns less than 120 minutes by day of the week, per shift. This also reports the total percentage of bed turns less than 120 minutes per day. The fourth part of the dashboard shows average time taken to turn a room, per shift, per day of the week. Figure 13 shows a sample dashboard from the week of 4/7/2019.

EVS Throughput Dashboard — Week of: 4/7/19

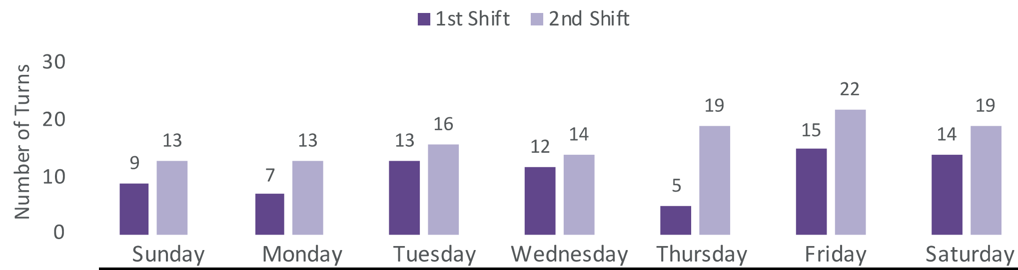
Outcome Metic - Week of 4/7/19



Performance Summary - Week of 4/7/19

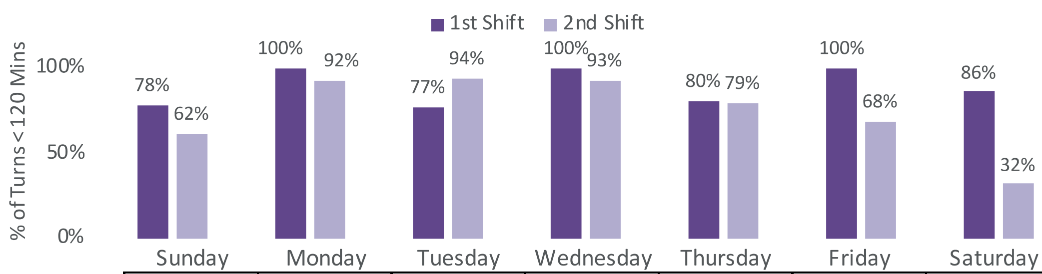
	1st Shift	2nd Shift	Total
Total Turns	75	116	**191**
Avg Turn Time (Mins)	84	116	**104**
% of Turns < 90 Mins	83%	47%	**61%**
% of Turns < 120 Mins	89%	72%	**79%**

Turnaround Volume by Shift and Day of Week



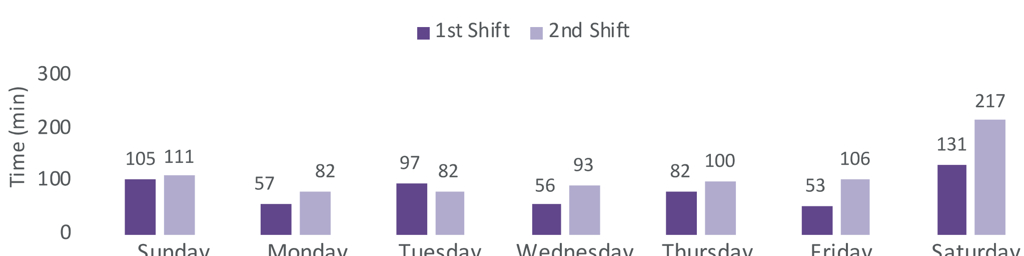
	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
1st Shift	9	7	13	12	5	15	14
2nd Shift	13	13	16	14	19	22	19
Total	**22**	**20**	**29**	**26**	**24**	**37**	**33**

Outcome Metric by Shift and Day of Week



	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
1st Shift	78%	100%	77%	100%	80%	100%	86%
2nd Shift	62%	92%	94%	93%	79%	68%	32%
Total	**68%**	**95%**	**86%**	**96%**	**79%**	**81%**	**55%**

Avg Turn Time by Shift and Day of Week



	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
1st Shift	105	57	97	56	82	53	131
2nd Shift	111	82	82	93	100	106	217
Total	**109**	**73**	**89**	**76**	**96**	**84**	**181**

Figure 13 – Sample Dashboard

8.4. Queue Based Triggers

Additionally, there must be a standardized approach to handling a queue once it overwhelms the designated bed-turning techs. Initially the system was very reactive, pulling technicians as needed in an unstructured manner. Low performance was especially evident on the weekends when EVS management was not present, and EVS staff did not know how to handle long queue situations, letting the queue grow uncontrollably. Inspired by Delnor's "clear the queue" practice, the team proposed that a trigger should be established based on queue length, which prompts management to call staff to clear the bed queue. The goal is to only need to do this once during the shift, as all technicians would be called to clear the queue, keeping it at a manageable level for the rest of the shift.

To determine the optimal number of beds that would define the "trigger point," or point that additional help would be called, the team consulted with EVS management to determine the point at which the queue becomes unmanageable. The team agreed on a trigger point of six beds, at which point three additional technicians are called in to help. These three technicians are called from areas of the hospital that are least busy, or not as time-sensitive. Each technician is responsible for turning 2-3 beds, after which the bed board is checked. If the queue still has more than 4 beds, the EVS leads should contact EVS management, who will advise them further. Otherwise, the additional technicians are sent back to their sectors to continue their previous work. This logic is facilitated by a decision tree, developed by the senior design team. Standardizing work allows not only EVS management and leads to know how to handle long queue situations, but also allows inexperienced EVS staff to follow the correct protocol. Figure 14 shows the decision tree.

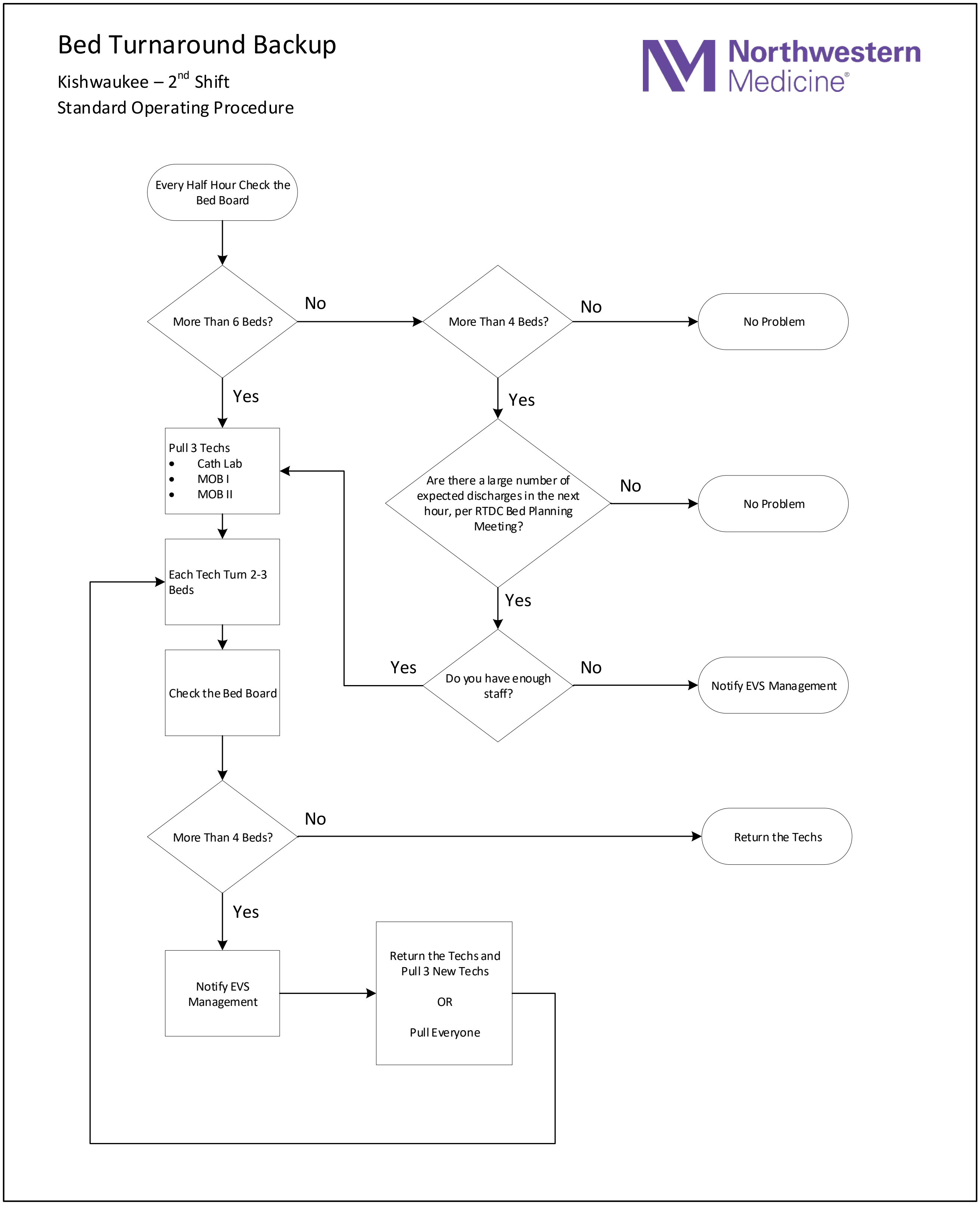


Figure 14 – Queue Based Trigger Decision Tree

9. Throughput Simulation

9.1. Model Ideation

The first part of the throughput model is simply the creation of patients within the system. This is done using a Create module. Read modules then read historical data pertaining to the patient. This data is stored in an Excel sheet, and accessed by the Arena model. Table A-3 in the Appendix shows a sample of this. A sequence of Read modules reads in the interarrival time between patients, patient class (i.e. inpatient, outpatient, observation), the arrival location of the patient (i.e. ED, walk-in, surgery, etc.), the room the patient is assigned to, the patient length of stay (LOS), and the clean time for the room after the patient has been discharged. This logic also can read in multiple rooms and lengths of stay for a patient if that patient is transferred to different rooms within the hospital. There is then a Delay module to simulate interarrival time, using the interarrival times read initially. Figure A-3 in the Appendix shows this logic.

After the patient enters the system and the information has been read, the patient moves to seize a bed. First, the model checks to see if the patient came from the ED or not. If the patient has, then there is a bed management delay, to simulate the time it takes for bed management to assign the patient to an open bed. There is then a Decide module to determine if the patient will seize a 'regular' bed (Y1, Y2, IMCU), an OB bed, or an ICU bed. This assignment is simply based on the room information read initially. To record the boarding time for a patient from the ED, there is an Assign module before the bed management delay, and a Record module after the patient has been assigned to a room. If the patient has not come from the ED, it is assumed that their arrival was planned and they have been pre-assigned a bed, so there is no bed management delay. There is a Decide module as before that assigns the room based on the information read into the model. Figure A-1 in the Appendix shows this logic.

9.2. Assumptions

To develop the discrete event simulation, several assumptions have been made. The three areas where meaningful assumptions are made are patient transfers, bed management, and hospital bed type. Although inpatient transfers are considered in the simulation model, any patients who were transferred more than four times are not considered in the model. All other cases account for 99.7% of patients. The simulation model does not account for time or personnel requirements in bed management. It is thereby assumed that bed management has requisite resources and that the bed assignment processing time is not impacted by the time of day or the day of the week. Lastly, it is assumed that there are only two types of beds: ICU and regular. However, the model does account for the rare cases that an OB patient is transferred from an OB bed to a regular bed.

9.3. Data Analysis

At the specific request of Northwestern Medicine, the high-level throughput model relies heavily on feeding historical data into the simulation. As a result, the first step is cleaning the raw data and transforming it into a format that can be used in the model. The hospital throughput dataset serves as the foundation for this data. Within this dataset the first step in cleaning the data was determining the time a bed was requested. While the ED patients do have a bed request time in the data, the patients arriving from other locations do not have this information. While the exact bed request time is not given for these patients, their arrival is not unplanned, meaning rooms are usually reserved in advanced. Therefore, the bed request time can be simulated by using the arrival time as the bed request time and then prioritizing these patients over the ED patients. Therefore, the request times used in the model represent the actual request times for ED patients and the arrival time of the other patients.

The next two steps of the cleaning process involve replacing text strings with integers that serve as IDs. The IDs can be assigned as attributes and easily used in Arena. The two pieces of information converted to an integer is the patient arrival location and the patient class. Table 5 summarizes the meaning of the IDs.

Table 5 – ID Definitions

Data Field	ID	Description
Class	1	Inpatient
	2	Observation
	3	Outpatient
Arrival Location	0	Other
	1	ED

The next step was incorporating the internal transfers into the throughput data. An internal transfer is when a patient is moved from one bed to a different bed in the same hospital. The most common example is when a patient is in a non-critical care room, but their condition worsens so they are moved to the ICU. While the throughput data does not have information regarding internal transfers, the EVS data indirectly contains this data. For each internal transfer there are three pieces of information that need to be brought over from the EVS data: (1) the time that the patient is moved, (2) the time it takes to clean the room they are leaving, and (3) the room number they are leaving. Each internal transfer requires these three fields. As a result, each additional internal transfer requires adding three columns of data. Therefore, the decision was made to cap the transfers at four. This covered over 99% of the transfers and the 27 patients with more than four transfers were hand edited to minimize the impact on the simulation. The data was transferred into the hospital throughput dataset using the contact serial number (CSN). The CSN is a number unique to each patient stay. While this does mean a patient's transfer and discharge record has the same CSN in the EVS data, the chronological order of a transfer relative to a CSN can be generated. This number can then be concatenated on the end of the CSN. This creates a unique ID that allows each transfer to be correctly placed in the hospital throughput data. Once this data is transferred into the hospital throughput dataset, the time the patient left the room was used to calculate the length of time the patient stayed in the room. This concludes the data required to be fed into the model. An example of the final data used in the simulation is provided in Table A-3 in the Appendix.

While most of the data needed to run the model comes from the hospital throughput dataset, the bed management processing time is not available in this dataset. The bed management processing time is the time it takes bed management to process a bed request. Unfortunately, data on this processing time does not directly exist, but there is data on the time from when a bed is requested to when the bed is ready. From this the assumption can be made that if beds are available when the request is made, the bed request to bed ready time is equal to the bed management processing time. Therefore, to calculate the bed management processing time, the bed request to bed ready times can be gathered from low occupancy days and analyzed. Low occupancy days are defined as days that have less than 65 of the 82 beds occupied at 9AM. This information is gathered from the census dataset. Once low occupancy days are identified, bed request to bed ready times will be taken from the ED throughput dataset and fit to a statistical distribution. Using input analyzer to fit the data to a statistical distribution, it was determined that the bed management processing time be simulated using an erlang distribution. Figure 15 is a screenshot of the results.

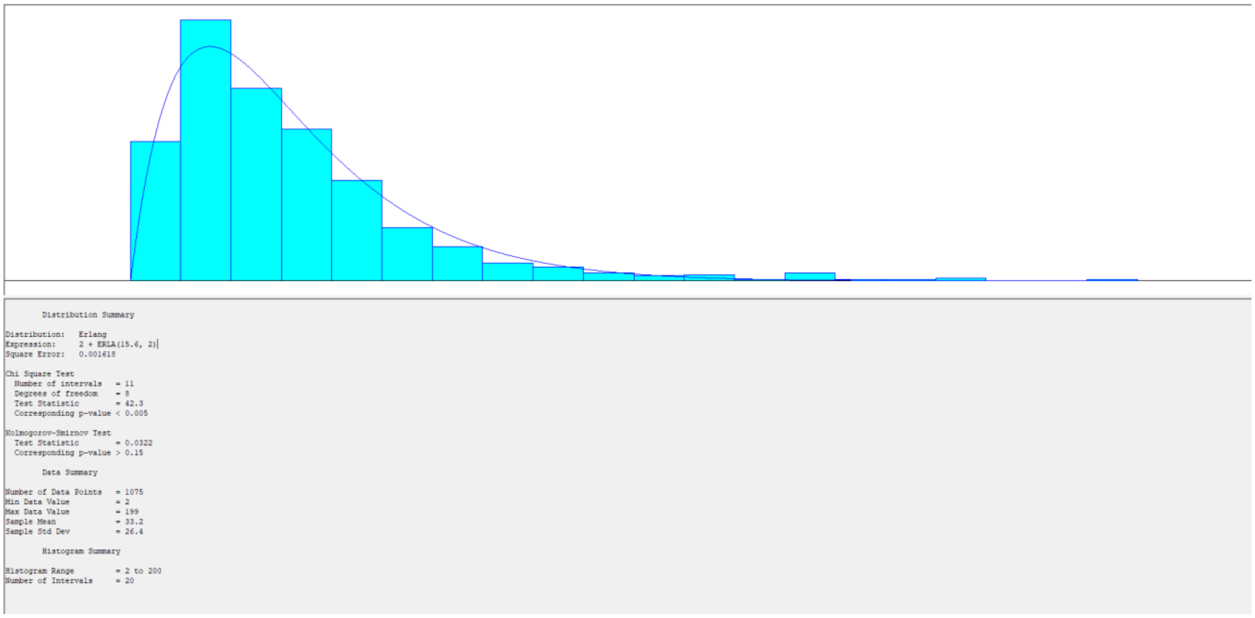


Figure 15 – Bed Management Processing Distribution

A potential concern of fitting this process to an erlang distribution is the flexibility of the distribution. Generally, a process will follow a Normal or Exponential distribution. As a result, our findings suggested that there may be other elements besides the process that exist within the data. After speaking with management, it was confirmed that the process time data does not always reflect the pure processing time. Before bed management can complete a bed request, they have to have access to the initial lab results and various other pieces of information. As a result, bed requests should not be initiated until all of this information is available. Unfortunately, physicians frequently enter bed requests far in advance of this information being available. This results in bed management having to wait for information until they can complete the request. Given that these factors are outside the scope of the simulation and cannot be controlled for, the only option is to proceed with the erlang approximation of the bed management processing time.

9.4. Replications

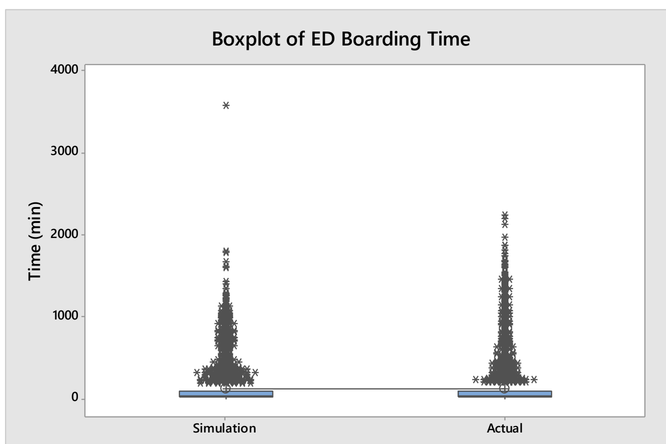
With the model developed, the number of replications has to be determined. Because the ED boarding time in the primary performance metric, the number of replications is calculated based on the precision of this measure's half-width. Standard practice dictates that the desired precision is 5%. Considering the average boarding time is approximately 120 minutes, the ideal half-width is equal to 6. An initial run of 10 replications produced an average boarding time of 120.53

minutes with a half-width of .25. Equation 4 is used to calculate the approximate number of replications need, where n is the number of replications, n_o is the number of replications of the initial run, h_o is the initial half-width, and h is the desired half-width. Using equation 4, it was determined that only one replication is needed to achieve the desired precision.

$$n \cong n_o \frac{h_0^2}{h^2} \quad \textbf{(4)}$$

9.5. Validation

The simulation was validated using two measures, ED boarding time and Length of Stay (LOS). ED boarding time was chosen because it is the metric Kishwaukee management is most interested in analyzing. It is also directly impacted by the bed management processing time. Therefore, it is important to validate that the erlang distribution produces results consistent with reality. Figure 16 shows the p-value to be greater than .05. Therefore, the means of the two populations is not significantly different.



Two-Sample T-Test and CI: ED Boarding Time

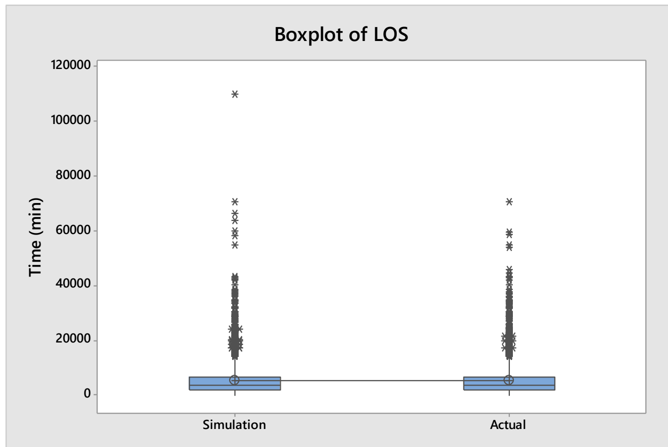
```
Two-sample T for Simulation vs Actual

              N  Mean  StDev  SE Mean
Simulation  5336   120    219      3.0
Actual      5178   125    244      3.4


Difference = μ (Simulation) - μ (Actual)
Estimate for difference:  -4.62
95% CI for difference:  (-13.47, 4.24)
T-Test of difference = 0 (vs ≠): T-Value = -1.02  P-Value = 0.307  DF = 10319
```

Figure 16 – Two-Sample T-test with Box Plot (ED Boarding Time)

The second measure, LOS, was used to verify the patients are staying in the simulation for the appropriate amount of time. Figure 17 shows the p-value to be greater than .05. Therefore, the mean of the two populations is not significantly different.



Two-Sample T-Test and CI: LOS

```
Two-sample T for Simulation vs Actual

                                    SE
               N  Mean  StDev  Mean
Simulation  7339  5166   5365    63
Actual      7323  5160   5231    61


Difference = μ (Simulation) - μ (Actual)
Estimate for difference:  6.7
95% CI for difference:  (-164.9, 178.2)
T-Test of difference = 0 (vs ≠): T-Value = 0.08  P-Value = 0.939  DF = 14652
```

Figure 17 – Two-Sample T-test with Box Plot (LOS)

10. Results

10.1. EVS Throughput

Since the start of the project, turnaround times have steadily improved. The small improvements observed at the beginning of the project can be attributed to the staff's renewed focus on turnaround times and awareness of the project. Then with the gradual implementation of the four recommendations, the performance has continued to improve. Since the implementation of the four recommendations, EVS has been successfully meeting their goal of turning 75% of the rooms in less than 120 minutes. Figure 18 shows the percent of beds that were turned within 120 minutes by week since the start of the fiscal year

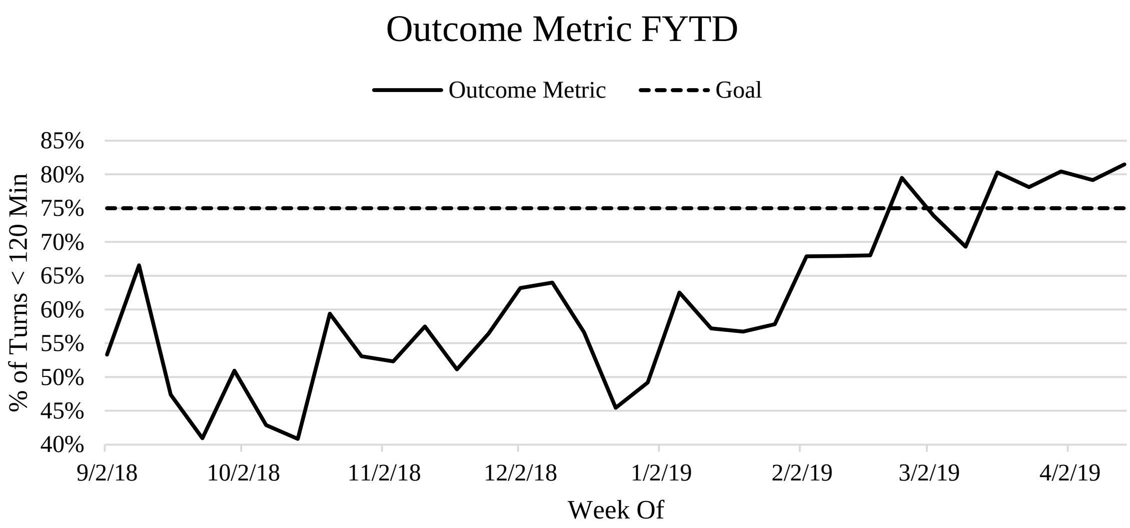


Figure 18 – Performance FYTD

Figure 19 shows a before and after comparison of the EVS turnaround time at Kishwaukee. The "before" data is from 9/1/2018 – 12/31/2018. The "after" data is from 4/1/2019 – 4/31/2019. Having reduced the turnaround time by almost 90-minutes, Kishwaukee's EVS throughput is now on par with the other NM hospitals.

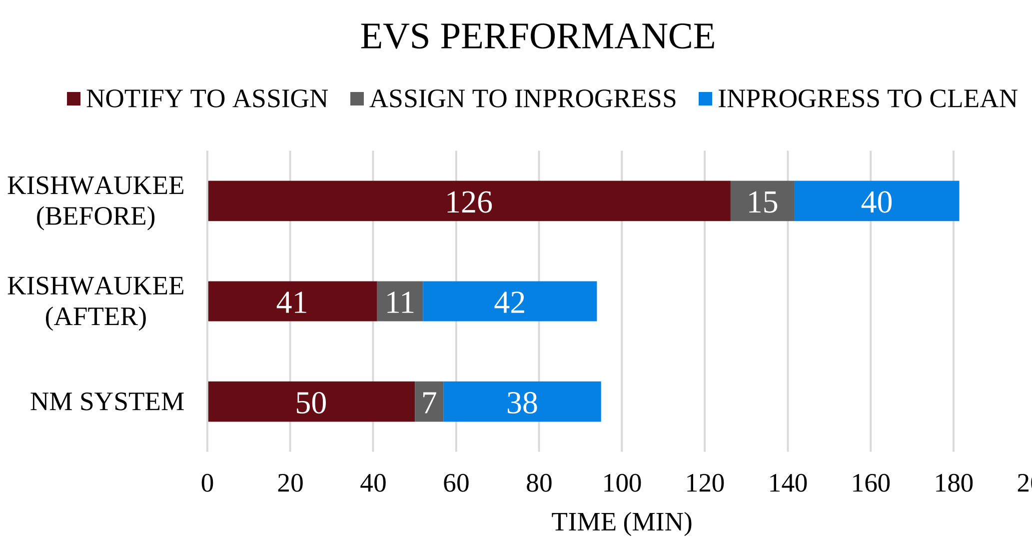


Figure 19 – Average Turnaround Time Comparison

10.2. Simulation

With the successful improvement of the EVS throughput, the simulation can be used to analyze the impact of this project on the hospital's capacity. By adjusting the turnaround times in the simulation to match the current EVS throughput performance the following conclusions can be made. By reducing the average turnaround time to 90-minutes, the average boarding time drops by approximately 12-miniutes. Conducting a two-sample t-test between the two samples results in a p-value of .002, which verifies the change is statistically significant. Another capacity metric the simulation looks at is the percent of patients who have to wait for a bed. This measures how often the hospital does not have an open bed at the time of a patient's bed request. The EVS throughput improvement allows 5% more patients to have a bed readily available when they requested a room. Figure 21 provides a summary of the EVS throughput improvement from the simulation.

EVS Project Impact		
Measure	Baseline	EVS Impact
ED Boarding Time (min)	120.2 (+/- 5.9)	108.0 (+/- 5.5)
% of Patients that Wait for a Bed	29.3%	24.5%

Figure 21 – Simulation Results EVS Project)

Facility Expansion Impact
1 Bed
98.6 (+/- 5.1)
24.4%

Figure 20 – Simulation Results (Facility Expansion of 1 Bed)

To better quantify these results, the simulation was also used to conduct an equivalent bed analysis. As previously mentioned, there are two methods of improving capacity, facility expansion and efficiency improvements. By testing the impact of expanding the facility, it was determined the impact of the improved turnaround times was approximately equivalent to adding 1 bed. Figure 20 summarizes the simulated impact of adding a bed. Considering that Kishwaukee estimates each bed comes at a cost of 1-2 million dollars, the increased capacity generated by this project is of significant strategic advantage.

In addition to improving the EVS throughput, Kishwaukee has been simultaneously working on several other projects to improve capacity. This includes converting two pediatric rooms into full functioning adult rooms and reducing the average discharge time. Using the simulation, the impact of each of these projects can be measured. The combined impact of all the capacity related projects is summarized in figure 22. These findings show that the projects could improve the boarding time by as much as 55 minutes. In addition to this combined impact study, the results of each individual impact study are provided in the appendix.

All Scenarios			
Measure	Baseline	What-if	Change
ED Boarding Time (min)	120.2	65.2 (+/-3.7)	55 (+/-3.7)
% of Patients that Wait for a Bed	29.3%	12.4%	16.9%

Figure 22 – Simulation Results (All Capacity Projects)

11. Conclusions

After the implementation of the team's improvement ideas at Kishwaukee Hospital, performance has consistently been above the goal of 75% of bed turns less than 120 minutes. Additionally, the improvements in EVS performance, along with the concurrent projects of adding two additional beds and discharging patients an hour earlier result in an overall savings of 55 minutes in boarding time, meaning on average, patients have to wait 55 minutes less to be admitted into an inpatient bed. The greatest impact of these improvements is in the patient experience, as patients wait less and are ultimately more satisfied with their experience. Given that a key performance indicator within healthcare is patient satisfaction, these improvements are very significant.

In the future, a control plan will need to be developed to maintain high performance. This control plan has three main elements. The first is maintaining the dashboard, simply so that management is aware of their performance. The second is to conduct a weekly review, which entails recording the key performance indicators for a given week, critically evaluating performance, and recording assignable causes if the performance deviates from the goal. The third is to establish a control policy, or a plan of action, if performance consistently deviates from the goal.

12. Ethics

The NSPE engineering code of ethics is critical to any engineering project, and as such, holds true for projects in healthcare settings. All ethical canons were adhered to throughout this project, but three were of significant interest. First, Canon 1: "Hold paramount the safety, health, and welfare of the public." To adhere to this canon, the project team followed all mandatory hospital protocols such as supplying background checks and obeying mandatory vaccination requirements and worked only in designated areas of the hospital. Next, Canon 4: "Act for each employer as faithful agents or trustees." To adhere to Canon 4, the project team ensured that propriety information was not shared or utilized for any reason besides those communicated with the NM team. Additionally, the project team made contributions to support the long-term success of the company. Lastly, Canon 5: "Avoid deceptive acts." The project team adhered to Canon 5 by communicating the limitations of its work and offering complete transparency in all project endeavors.

Appendix - A

Table A-1– Available Data Fields and Descriptions

Date Field	**Explanation**
Date	Equal to "EFFECTIVE_DATE_TM".
TYPE	Specifies if the turnaround is a discharge or a transfer.
BED	The specific bed being turned.
DEPARTMENT_NAME (group)	The hospital.
DEPARTMENT_NAME	The unit.
DEST_UNIT	If it is a transfer it specifies where the patient is going.
PAT_ENC_CSN_ID	An ID that is unique to a patient visit.
ROOM_NAME	The room being turned.
EFFECTIVE_DATE_TM	When the patient is discharged.
Request Time	
NOTIFY_DATE_TM	When the bed shows up on the EVS bed board.
NOTIFY_TIME_TM	
ASSIGN_DATE_TM	When a tech is assigned to clean a room. A tech can only be assigned one room at a time.
ASSIGN_TIME_TM	
INPROGRESS_DATE_TM	When the tech starts to clean the room.
INPROGRESS_TIME_TM	
CLEAN_DATE_TM	When the room is clean.
CLEAN_TIME_TM	
DIFF_ASSIGN_TO_CLEAN_MIN	Field Name Self Explanatory
DIFF_ASSIGN_TO_INPROGRESS_MIN	Field Name Self Explanatory
DIFF_EFFECTIVE_TO_NOTIFY_MIN	Field Name Self Explanatory
DIFF_INPROGRESS_TO_CLEAN_MIN	Field Name Self Explanatory
DIFF_NOTIFY_TO_ASSIGN_MIN	Field Name Self Explanatory
DIFF_NOTIFY_TO_CLEAN_MIN	Field Name Self Explanatory

Table A-2– Sample Timeline

TIME	VLOOKUP	NOTIFY	ASSIGN	CLEAN	QUEUE	MINIUTE OF DAY	HOUR OF DAY
1/30/2018 3:09	431301312.00	0	0	0	4	189.00	3
1/30/2018 3:10	431301319.00	0	0	0	4	190.00	3
1/30/2018 3:11	431301326.00	0	0	0	4	191.00	3
1/30/2018 3:12	431301333.00	0	0	0	4	192.00	3
1/30/2018 3:13	431301340.00	0	0	0	4	193.00	3
1/30/2018 3:14	431301347.00	0	0	0	4	194.00	3
1/30/2018 3:15	431301354.00	0	0	0	4	195.00	3
1/30/2018 3:16	431301361.00	0	0	0	4	196.00	3
1/30/2018 3:17	431301368.00	0	0	0	4	197.00	3
1/30/2018 3:18	431301375.00	0	0	1	4	198.00	3
1/30/2018 3:19	431301381.00	0	0	0	4	199.00	3
1/30/2018 3:20	431301388.00	0	0	0	4	200.00	3
1/30/2018 3:21	431301395.00	1	0	0	5	201.00	3
1/30/2018 3:22	431301402.00	0	0	0	5	202.00	3
1/30/2018 3:23	431301409.00	0	0	0	5	203.00	3

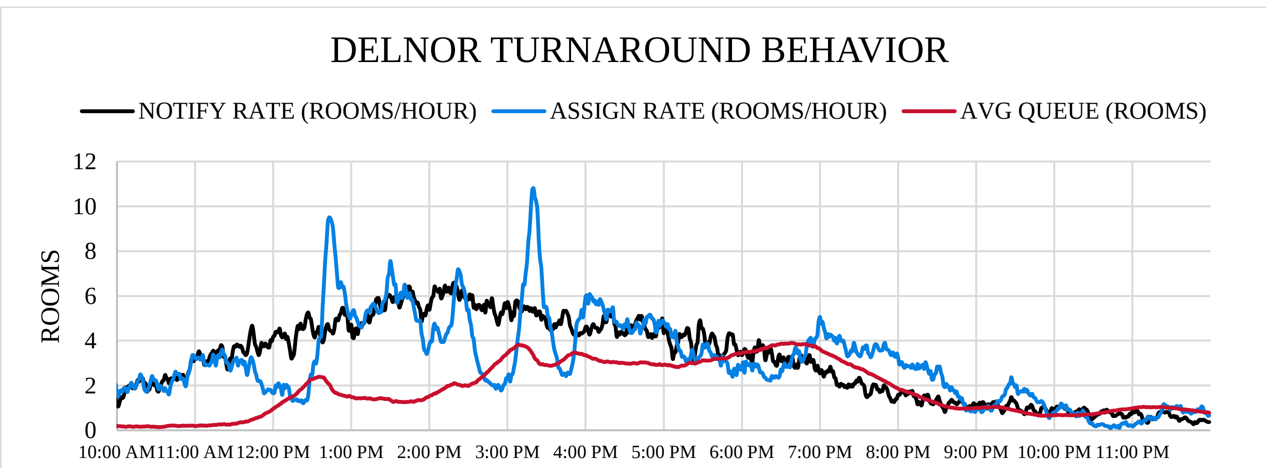


Figure A-1 – Average Minute by Minute Turnaround Behavior at Delnor

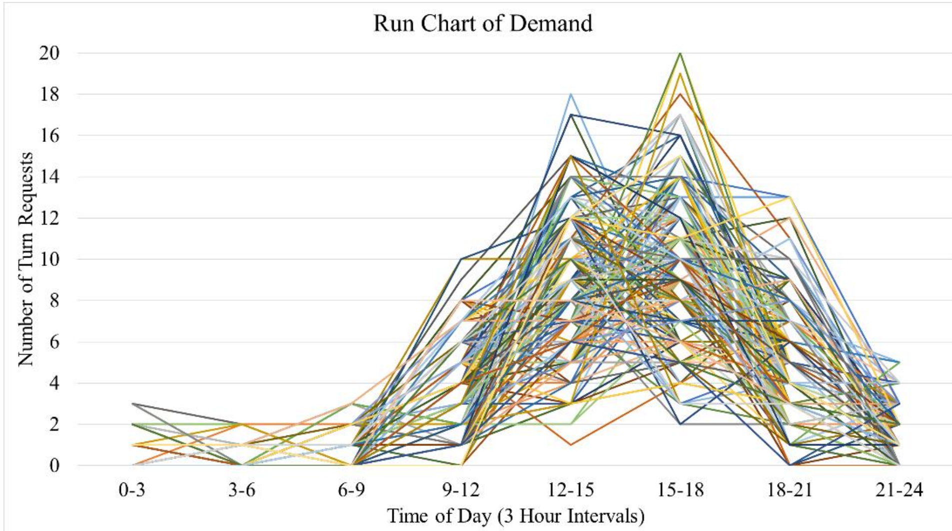


Figure A-2 – Daily Demand Run Chart

Table A-3 – Sample Input Data

INTERARRIVAL	CLASS	ARRIVAL_LOCATION	1_ROOM	2_ROOM	3_ROOM	4_ROOM	1_CLEAN	2_CLEAN	3_CLEAN	4_CLEAN	1_DELAY	2_DELAY	3_DELAY	4_DELAY
1038.00	1	1	2010	0	0	0	140	0	0	0	18572	0	0	0
245.00	1	1	1013	0	0	0	119	0	0	0	16985	0	0	0
211.00	1	1	1025	2009	2411	2403	110	0	111	235	2685	562	11879	7525
1082.00	1	1	1030	2409	2404	2033	100	362	86	188	8221	5370	2093	7247
1226.00	1	1	1028	1006	1011	0	20	143	66	0	4268	4400	11363	0
43.00	1	1	2412	2012	0	0	160	61	0	0	2970	11075	0	0
2687.00	1	1	2009	1009	0	0	140	274	0	0	7482	5811	0	0
122.00	1	1	2030	0	0	0	77	0	0	0	11484	0	0	0

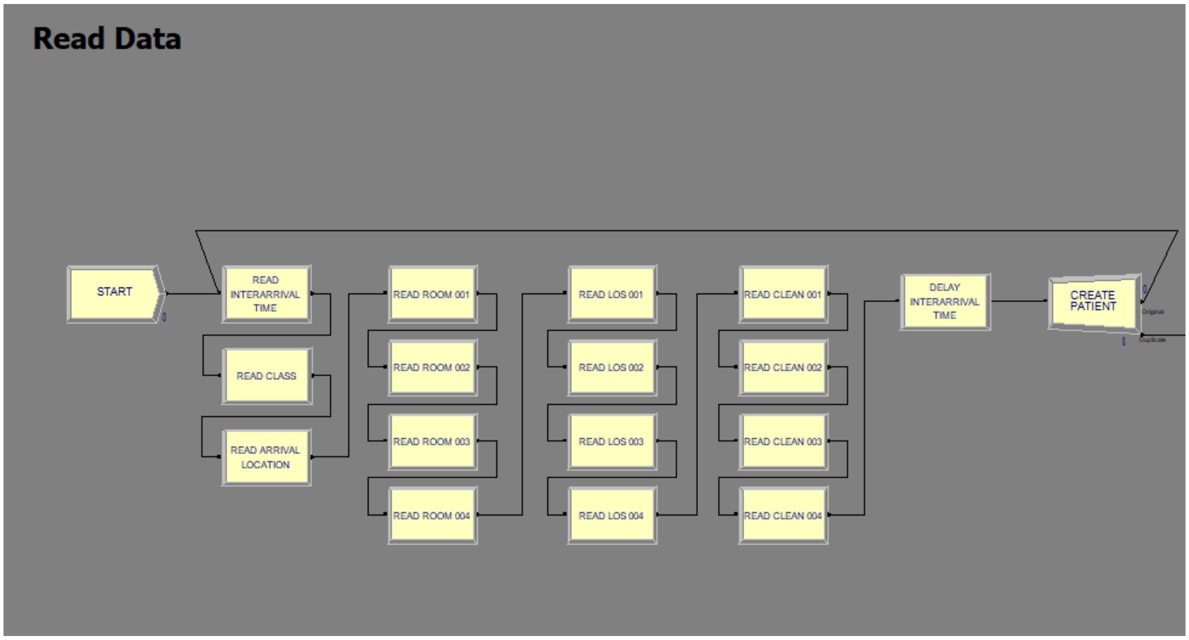


Figure A-3 – Read Data Simulation Logic

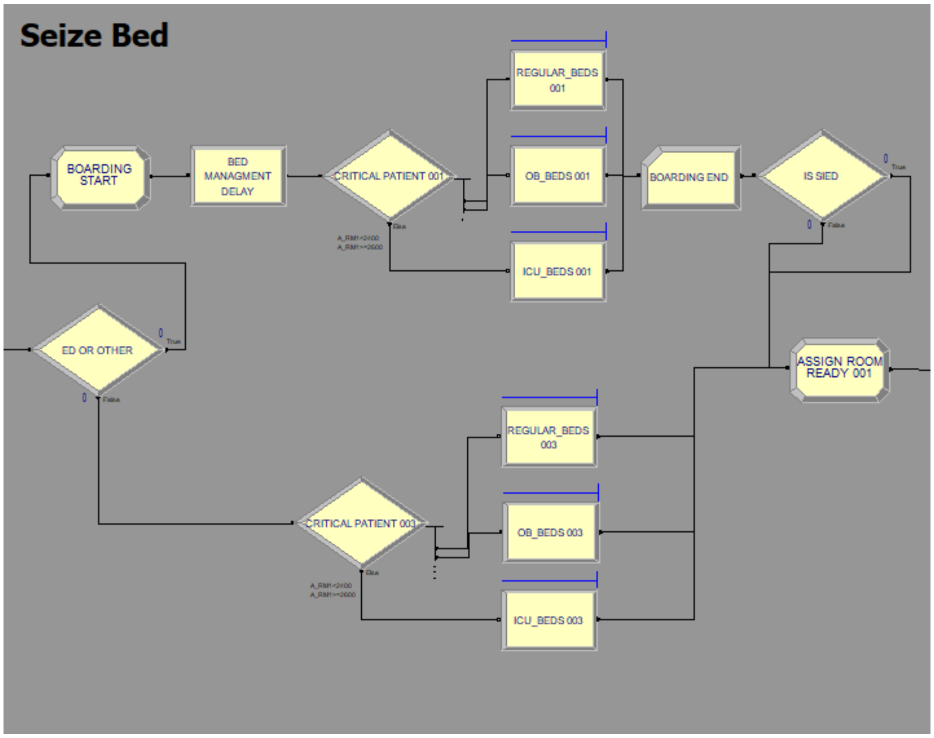


Figure A-4 – Bed Seizing Simulation Logic

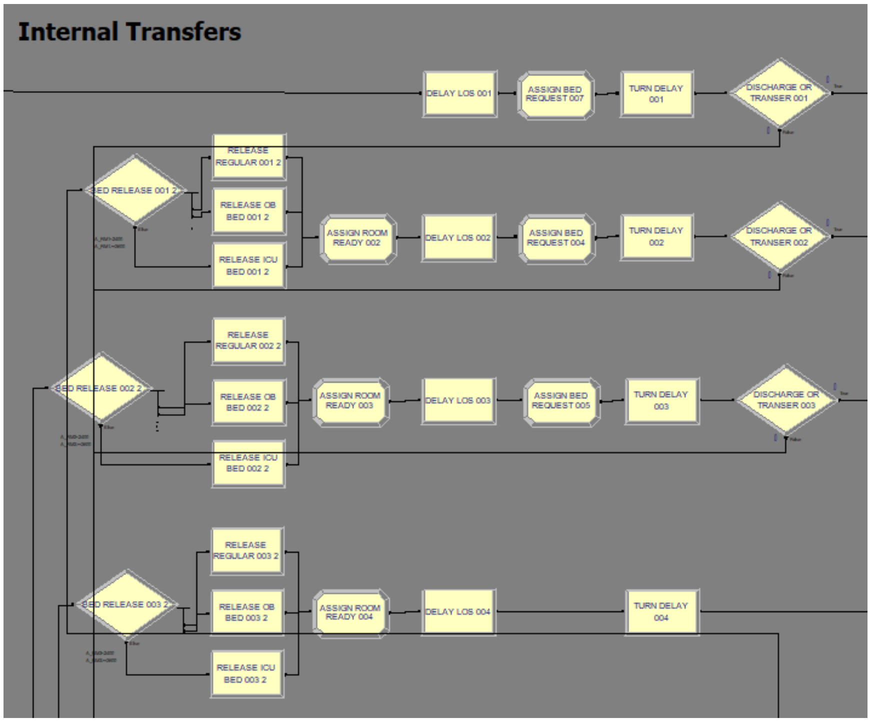


Figure A-5 – Internal Transfers Simulation Logic

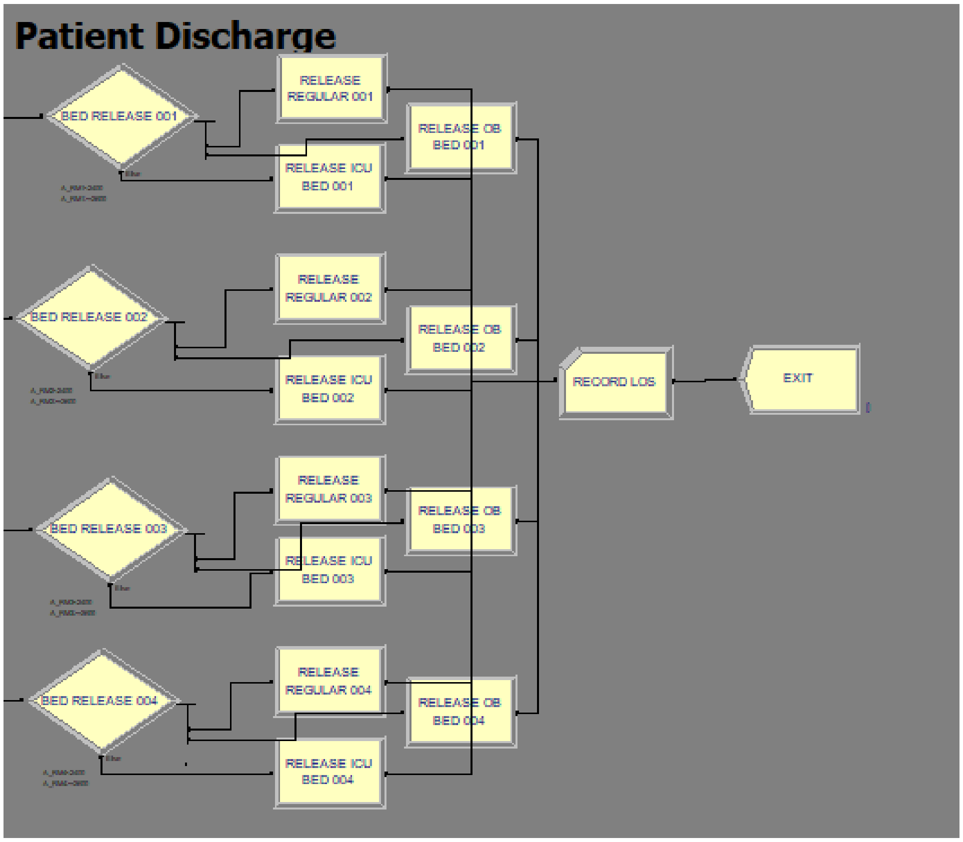


Figure A-6 – Patient Discharge Simulation Logic

Add Two Regular Beds			
Measure	Baseline	What-if	Change
ED Boarding Time (min)	120.2	81.9 (+/- 4.4)	38.28 (+/- 4.4)
% of ED Patients that have to wait for a bed	29.3%	19.9%	9.4%

Figure A-7 - Simulation Results (Add 2 Beds)

Reduce the Average Turnaround Time to 130 Min			
Measure	Baseline	What-if	Change
ED Boarding Time (min)	120.2	114.0 (+/-5.7)	6.18 (+/-5.7)
% of ED Patients that have to wait for a bed.	29.3%	26.7%	2.6%

Figure A-8 - Simulation Result (Average Turnaround Time 130 Min)

Reduce the Average Turnaround Time to 90 Min			
Measure	Baseline	What-if	Change
ED Boarding Time (min)	120.2	108.0 (+/- 5.5)	12.2 (+/- 5.5)
% of ED Patients that have to wait for a bed.	29.3%	24.5%	4.8%

Figure A-9 - Simulation Result (Average Turnaround Time 90 Min)

Discharge Patients an Hour Earlier			
Measure	Baseline	What-if	Change
ED Boarding Time (min)	120.2	103.0 (+/-5.4)	17.2 (+/-5.4)
% of ED Patients that have to wait for a bed.	29.3%	23.3%	6.0%

Figure A-10 - Simulation Result (Discharge 60 Min Earlier)

All Scenarios Except EVS			
Measure	Baseline	What-if	Change
ED Boarding Time (min)	120.2	70.6 (+/-4.0)	49.6 (+/-4.0)
% of ED Patients that have to wait for a bed.	29.3%	15.3%	13.9%

Figure A-11 - Simulation Result (All Scenarios Except EVS)