Creating a Simulation Model of INTEGRIS Women's and Children's Services and Evaluating Needed Capacity

Senior Design Project Report

Spring 2020

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Submitted in partial fulfillment of the requirements of the course, IEM 4913, Senior Design and the Baccalaureate degree requirements of the School of Industrial Engineering and Management at Oklahoma State University

Executive Summary

The 4th floor of The INTEGRIS Baptist Medical Center in OKC houses Women's and Children's Services, a unit which cares for expecting mothers and women going through labor. This unit operates 24 hours per day and 7 days per week and is operated using three sub-units: Triage, Labor Delivery & Recovery (LDR), and Postpartum. The Senior Design Team (SDT) worked in collaboration with the INTEGRIS Continuous Improvement Team (CIT) to create a simulation model to verify whether the recent recommendations in the capacity allocation of the sub-units, made in response to capacity shortages, adequately service the demand.

The SDT began their investigation with a debriefing of previous analysis completed by the CIT. Their study characterized the arrival times, length of stay, and current capacity in each sub-unit. It was found that there was great consistency in admissions, transfers, and discharges both daily and seasonally. The capacity issues experienced by the Women's and Children's Services did not appear to be a result of swings in demand in any one sub-unit. Instead, the sub-units experienced insufficient capacity to meet patient demand. Bottlenecks on the 4th floor caused the typical flow of patients to be altered and compounded capacity issues exhibited in the three sub-units. These observations indicated that there was a need to do a detailed capacity analysis of the 4th floor and to this end we developed a discrete event simulation model.

The SDT began the creation of a simulation model by fitting distributions to the data using MATLAB. These distributions were later used to create the simulation model submitted by the SDT. Then, Simio was used to construct a representation of 4th floor operations. The model was verified by peer review and test runs. There were no logical errors in the model and patient flow correctly depicted actual operations. The model was validated by comparing actual demand and length of stay from 2019 data to the results generated by the model. This comparison confirmed that the model accurately represented current operations in Women's and Children's Services.

After the simulation model baseline was completed, various alternatives to increase capacity were tested with experiments in Simio. The following alternatives were considered to resolve the capacity issues experienced by the Women's & Children's Services:

- Triage sub-unit
    - 4-bed option: increased capacity by 1 bed
    - 5-bed option: increased capacity by 2 beds
    - 6-bed option: increased capacity by 3 beds
- LDR/Postpartum sub-unit
    - Add rooms: added rooms to the LDR/Postpartum sub-units
    - LDRP: combined the LDR/Postpartum sub-units by converting all beds in both sub-units to include equipment necessary to care for both LDR and Postpartum patients

Analysis of the Triage sub-unit showed that the 5-bed option was the most effective method to increase capacity. This alternative decreased wait times by 93%. The 5-bed option incurred a greater cost than the 4-bed option due to physical renovation and equipment acquisition costs. However, unlike the other alternatives, the 5-bed option did not require physical separation of the sub-unit and a subsequent decrease in sub-unit visibility. Reduction in sub-unit visibility had a significantly negative impact on the 4th floor.

Analysis of the LDR and Postpartum sub-units showed that a combination of adding rooms and the LDRP alternative was the most effective way to mitigate capacity issues. Significant improvements were realized by implementing this change and adding five additional rooms to the unit. This alternative decreased the number of patients who experience wait times by 92% and decreased patient wait times by 72%. Unfortunately, the Women's & Children's Services did not have the ability to increase capacity in either of these sub-units at all. This restriction made the LDRP alternative the only one available for them to resolve capacity issues. Implementation of this plan will decrease the number of patients who experience wait times by 57% and decrease patient wait times by 49%. Conversion to LDRP rooms was less costly than increasing the overall capacity of the two sub-units separately. Additionally, less time was required to clean and maintain the rooms because patients will not require room transfer during their stay. This additional benefit serves to streamline processes on the 4th floor and will help the unit the meet patient demand.

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1.0 Project Summary

INTEGRIS is Oklahoma's largest not-for-profit and state-owned health care system. The organization owns and operates multiple hospitals, specialty clinics, family care practices, and centers of excellence. The 4th floor on the Main Campus of the hospital contains the Women's and Children's Services, a unit which cares for expecting mothers going through labor. This unit operates 24 hours per day and 7 days per week. There are three sub-units on this floor, detailed below, that are often running out of available rooms to provide patient care:

- **Triage:** Most patients begin their visit in this sub-unit. Patients are given an initial assessment here and are also provided with outpatient services (pregnancy tests, blood tests, among others.)
- **Labor, Delivery, and Recovery (LDR):** Patients are prepared for delivery, undergo delivery, and rest immediately after delivery.
- **Postpartum (PP):** Patients rest during an extended recovery phase.

The capacity issue experienced by Triage, LDR, and PP have been documented and assessed by the Continuous Improvement department at INTEGRIS. The SDT worked in collaboration with this department to continue the analysis by creating a simulation model to confirm the recommendations made by CI.

Based on the visits and discussion conducted by the SDT, there are two key observations of the current situation in the Women and Children's unit. The first is that each patient is brought in on an urgent basis based if they are in labor and how far along they are in the labor process. The unit also has performance objectives that include minimizing the number of patients that are unable to be transferred to their appropriate unit based on capacity and minimizing patient wait times (particularly in the Triage sub-unit).

The SDT created a capacity model to confirm recommendations made by the Continuous Improvement team to allow the Women and Children's Services Unit to meet their internal objectives. The scope of this project included all operations which occur within the unit.

2.0 Previous Analysis

2.1 Flow of Patients in Triage, LDR, and Postpartum

In the ideal process, pictured below in Figure 1, patients arrive and are initially cared for in either the Triage or LDR sub-units (Triage or LDR). If the patient is scheduled for an elective induction, they are sent directly to the LDR sub-unit to undergo care. Otherwise, the patient is assessed by clinicians in the Triage sub-unit. Once a patient receives care in the Triage sub-unit, patients are either discharged or admitted into the LDR sub-unit.

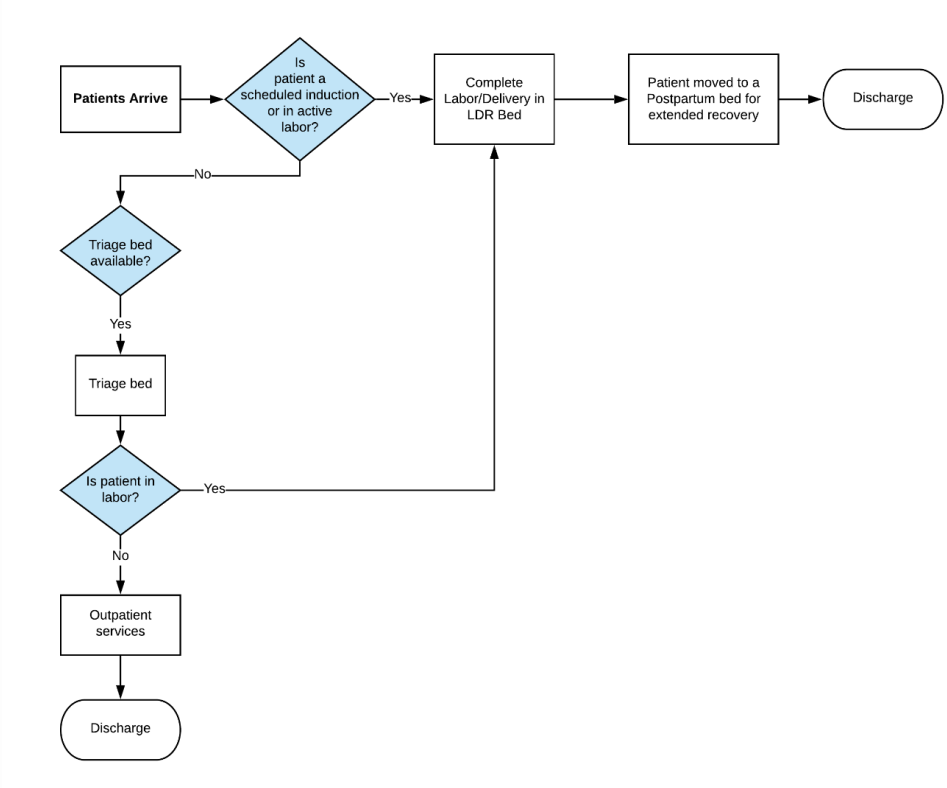

Figure 1: Ideal Patient Flow

Although Figure 1 is a visualization of the ideal patient flow, currently the unit is facing capacity issues and are instead following the patient show pictured in Figure 2. If patients enter through the Triage sub-unit and are entering active labor they are typically transferred to the LDR sub-unit. However, if there are no beds available, the patients will deliver the child in the Triage sub-unit. Following delivery of the child and immediate recovery, the LDR patients are typically transferred to the PP sub-unit for extended recovery if a bed is available. If a bed is not available, they are not physically transferred and continue rest and recovery in the LDR sub-unit. Following the extended recovery period, the patient is discharged.

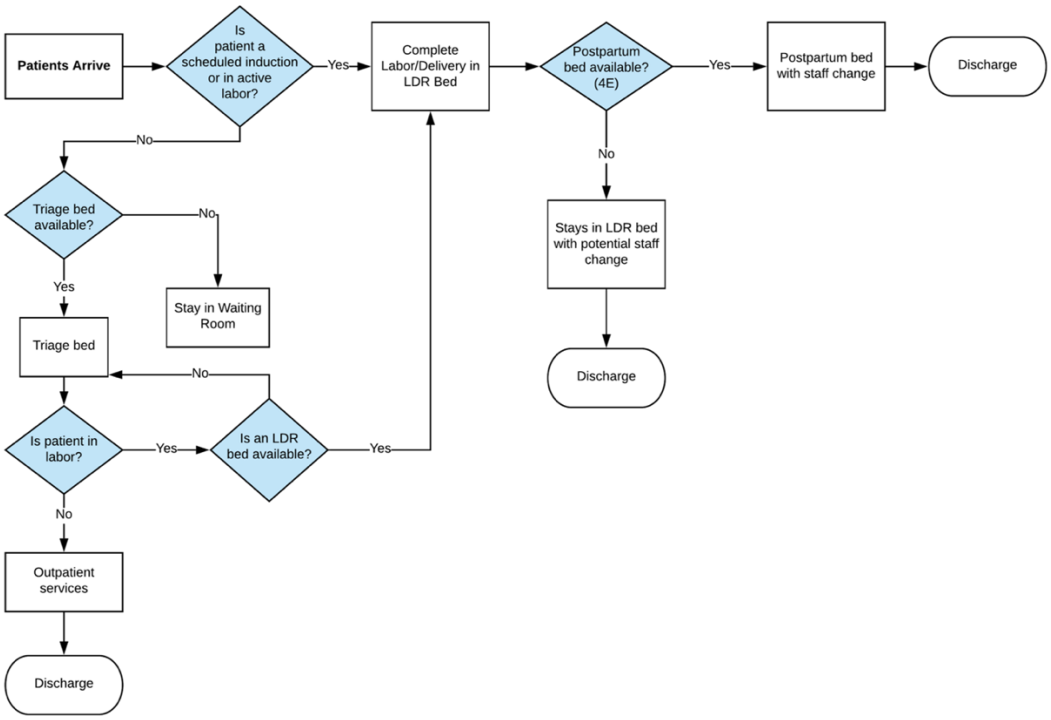

Figure 2: Flow of Patients when there are Capacity Issues

2.2 Project Background

Women's and Children's Services have experienced significant growth in demand from 2018 to 2019. A detailed summary of that growth can be viewed below in Table 1. If this growth continues, it is important that the unit be prepared for an influx in patients and do not run into capacity issues.

Table 1: Demand of Women and Children's Services in 2018 and 2019

Metric	2018	2019	% Change
No. of Deliveries	2,625	3,289	+ 25%
Hours of Labor Delivery	27,251	33,196	+ 22%
Hours of Delivery Recovery	4,936	6,288	+ 27%
No. of Outpatient Visits	3,515	4,203	+ 20%
Hours of Outpatient Labor	8,047	10,099	+ 26%

2.3 Trends in Admissions, Transfers, and Discharges

Prior to the arrival of the SDT, the INTEGRIS Continuous Improvement Team collected data regarding admissions, transfers, and discharges of patients for the 4th floor. An explanation of this analysis and the trends discovered are below. In-depth graphic depictions of these trends can be found in Appendix A.

Patients are admitted into the LDR sub-unit 24 hours per day, 7 days per week. During the week, the sub-unit sees a consistent frequency of admissions, transfers, and discharges. Admissions and transfers are consistent and higher than the rates seen on weekends. This trend occurs because elective inductions are more often scheduled on weekdays rather than weekends. Discharges are consistent and highest on Wednesday – Sunday. The weekends have higher rates for discharge because patients stay, on average two days in the Postpartum sub-unit.

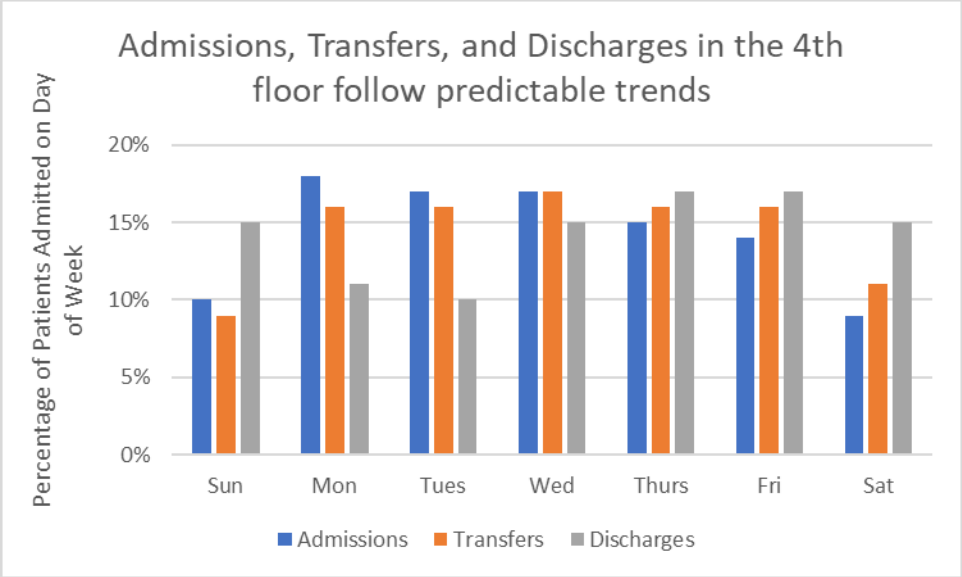

Figure 3: Simplified Admissions, Transfers, and Discharges Trends of 2019 based on Day of Week

Admissions, transfers, and discharges were also analyzed with control charts by the INTEGRIS Continuous Improvement team. These control charts can be viewed below in Appendix A. It was found that there was no significant seasonality regarding demand experienced by the sub-unit. There was an anomaly experienced by the sub-units in February, but it was found that this was caused by external factors and could be discounted when drawing trends and conclusions.

There is great consistency experienced in admissions, transfers, and discharges both daily and seasonally. From this observation, the SDT concluded that capacity issues experienced by the 4th floor were not a result of wide swings in demand in any one sub-unit. This conclusion indicates that any capacity issues are systematic and experienced daily. It was important for our team to note this conclusion in our analysis to narrow down the field of investigation.

3.0 Methodology

The SDT completed the following four phases that are outlined below:

1. Analysis
    a. Attended debrief meeting presented by INTEGRIS to be updated on project progress to date.
    b. Received raw data and prior analysis from INTEGRIS.
    c. Modeled length of stay in each sub-unit by fitting patient data to statistical distributions.
2. Modeling
    a. Created flow chart of operations in Women's & Children's Services.
    b. Created simulation model of Women's & Children's Services with Simio.
3. Testing
    a. Quantified capacity needed to meet internal objectives in Women's & Children's Services.
    b. Examined impact of alternative solutions.
    c. Determined best solution to resolve capacity issues within Women's & Children's Services.
4. Recommendations
    a. Provided findings and simulation model to the INTEGRIS Continuous Improvement team.
    b. Presented final report of findings to the INTEGRIS Continuous Improvement team.

4.0 Current State Operations

4.1 Arrival Times of Each Patient

There are two groups of patients that arrive – outpatient and inpatient. Outpatient is the group of patients that arrive to the Triage sub-unit, but do not transfer to the LDR sub-unit and are sent home. The second group of patients are inpatient. This group of patients includes all women that go through the LDR sub-unit, whether they are induced or begin laboring in the Triage sub-unit.

Figure 4 below shows the outpatient arrival times in a single day of each patient in 2019. The time is shown as 00:00 – 23:59 hours. For outpatient, there is a clear spike in admission times from 09:00 – 19:00. This spike is due to most patients that are receiving any type of routine testing arrive during typical working hours. The lowest number of admissions happen during the early morning hours, when staffing is the lowest in the Women and Children's Unit, and when there are no scheduled patients.

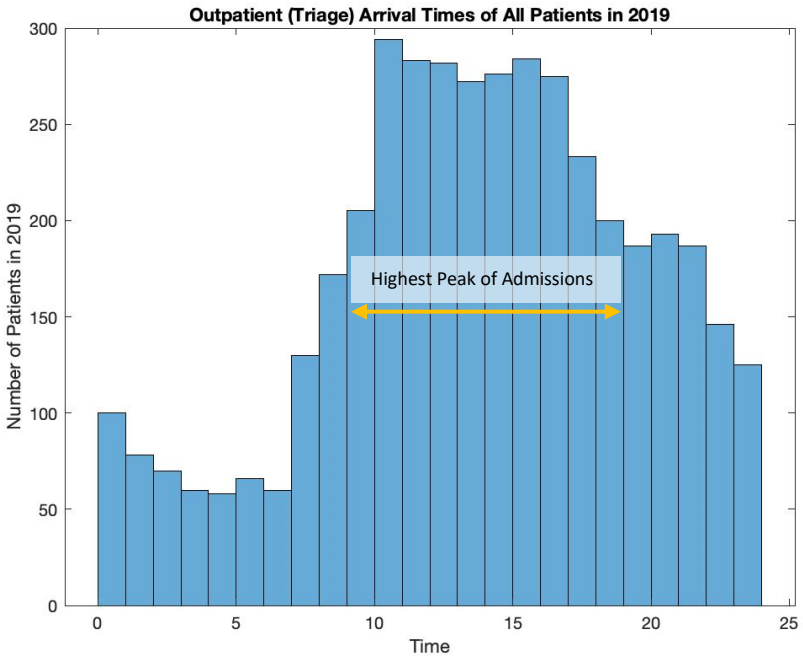

Figure 4: Outpatient Arrival Times of all Patients in 2019

Figure 5 below shows the inpatient arrival times in a single day of each patient in 2019. The time is shown as 00:00 – 23:59 hours. For inpatient arrivals, there is a wide variability in the arrival times of each patient with the largest peak from 07:00 – 08:00, and the second large peak from 19:00 – 20:00. The large group of patients arriving in the morning is due to the doctors arriving to begin their day. Women who are scheduled for an induction typically arrive in the morning, and women who come in the night before and are not far enough along in labor are also asked to come back in the morning when their contractions occur in shorter time intervals.

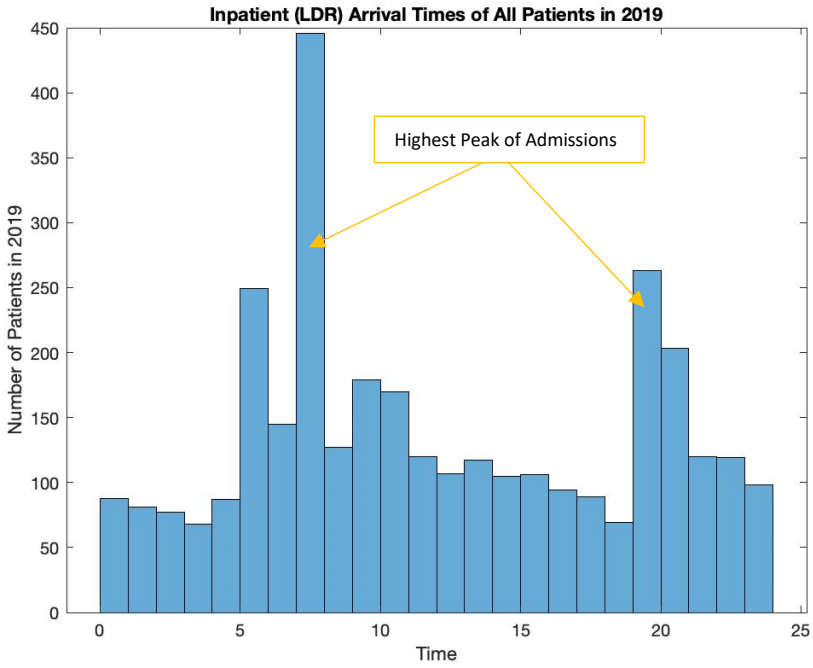

Figure 5: Inpatient Arrival Times of all Patients in 2019

4.2 Length of Stay in Sub-units

There is a wide variability in the amount of time each woman spends in the sub-units of the Women and Children's Services. These times change depending on how far along a woman is in labor, how long a woman is in labor, the way a baby is delivered, and how the woman recovers.

The length of stay in the Triage sub-unit averages 2.4 hours, with approximately 95% of patients between 1.4 and 3.4 hours. The patients that spend the shortest amount of time in triage were either far enough along in labor and were able to be moved to the LDR unit quickly or are told to return in a matter of hours. The patients that spend extended amounts of time in the Triage sub-unit were unable to be transferred to the LDR & Postpartum sub-units due to insufficient capacity in the facility.

The length of stay in the LDR sub-unit ranges from 6 minutes to 96 hours. This large range occurs due to capacity issues and patient variability. Some women are rushed into an LDR room if they enter the unit while in active labor, meaning they are only in this unit for a matter of minutes. However, other women are unable to be transferred to the PP sub-unit after delivering the child, and spend days in the LDR sub-unit for their recovery. Most patients spend 5-10 hours in the LDR sub-unit. A graphical representation of the LDR length of stays from 2019 is shown in Appendix B.

The length of stays in the PP sub-unit are the longest because this sub-unit exists for extended patient recovery. The range is form 16 hours to 98 hours. The variability occurs either due to possible complications after birth, or due to women being moved as rooms become available. On average most women spend 50-55 hours in this sub-unit. A graphical representation of the LDR length of stays from 2019 is shown in Appendix B.

4.3 Current-State Capacity

During 2019, each of the three sub-units exceeded their capacity. Refer to Figures 6, 7, and 8 for a visualization of how often these sub-units were over capacity in 2019. A summary of current capacity and the percentage of 2019 in which resources were insufficient for the sub-units can be viewed in Appendix C.

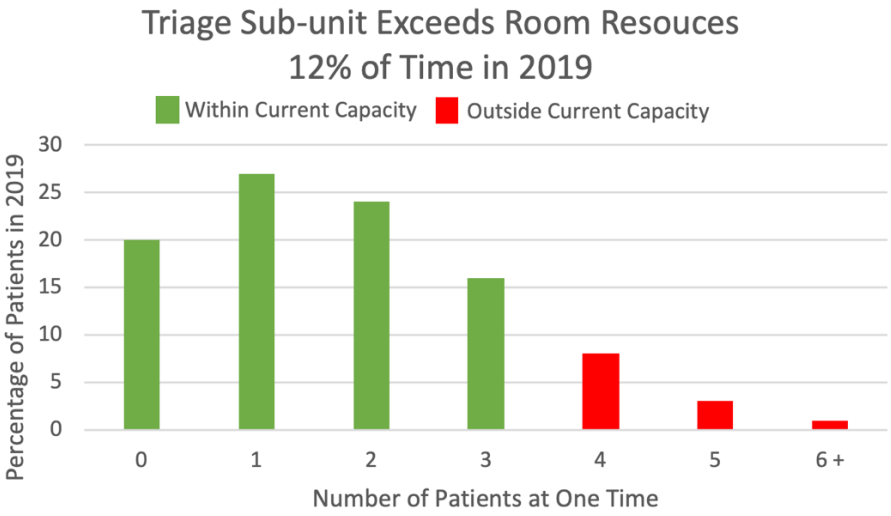

Figure 6: Triage Sub-Unit Exceeding Room Resources

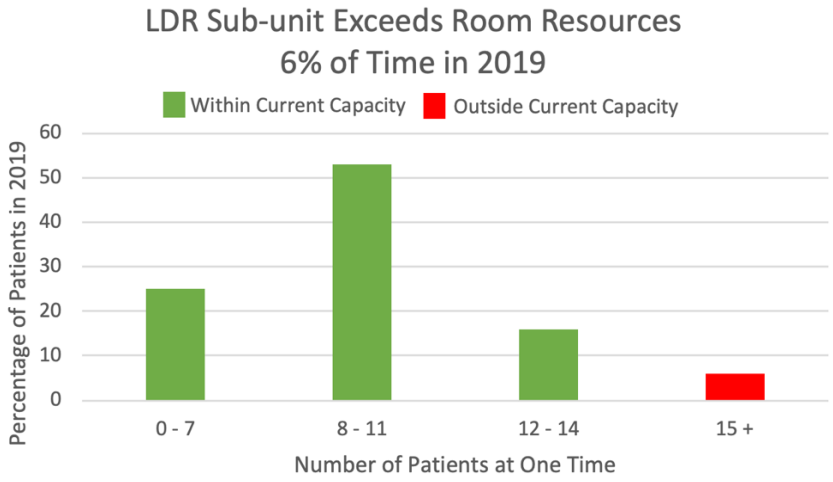

Figure 7: LDR Sub-unit Exceeding Room Resources

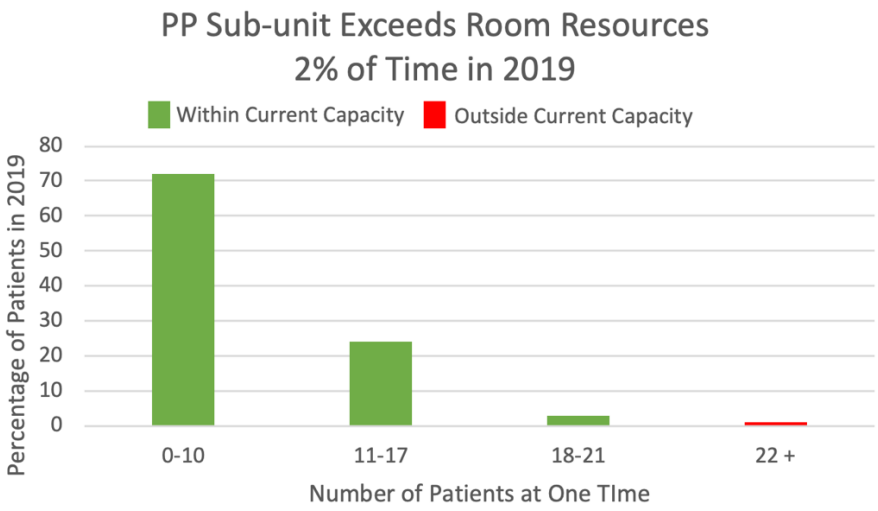

Figure 8: PP Sub-unit Exceeding Room Resources

5.0 Modeling

5.1 Fitting Distributions to 2019 Data

After analyzing the arrival times of patients and the current length of stay data in each sub-unit, the SDT organized the data to fit it into the simulation in a program called Simio. The team did this using MATLAB, a computing program developed by MathWorks. MATLAB was the chosen to fit the data into distributions because it could handle the 3000+ data points gathered in 2019.

First, the SDT fit distributions for the length of stay of the LDR and PP sub-units. These distributions were later input into the processing times of services which represented the sub-units. Graphic representations of MATLAB distributions and their fit to actual data can be seen in Appendix C. The program fit several distributions to the provided data, and then completed a Chi-Squared goodness-of-fit test to find the best fit. A summary of the distributions which fit actual data the best can be viewed below in Table 2. A Chi-squared test was not performed on the Triage length of stay distribution because data was not available to create a distribution fit. Instead, the average length of stay estimated during previous analysis conducted by INTEGRIS staff was used to approximate the average length of stay in the sub-unit.

Table 2: Distribution Parameters

Sub-unit Length of Stay (hours)	Distribution	Chi-Squared Goodness-of-Fit Test
Triage Processing Time	Normal(2.4,0.5)	N/A
LDR Processing Time	Lognormal(2.53178,0.787634)	Passed
PP Processing Time	Lognormal(4.09674,0.341887)	Passed

The team was unable to gather exact data on the length of stay time in the Triage sub-unit. To overcome this challenge, the SDT instead used estimates created by the INTEGRIS Continuous Improvement Team. It was finally decided to use a Normal distribution with a mean of 2.4 hours and a standard deviation of 30 minutes to represent Triage's length of stay.

There was an additional challenge in fitting distributions to model the arrival times of patients. These arrival times would not fit a distribution that could be inputted into Simio. To overcome this challenge, the SDT utilized the histogram of patient arrival seen in Appendix C and the equation below to calculate distinct hourly arrival rates over a 24-hour period. After organizing this data, it was fit into Simio based on the proportions of patients arriving in each hour in a single day. How these proportions (rates) were calculated is shown below in Equation (1):

$$\mathbf{N_i} = \text{Total number of patients arriving in hour i} \tag{1}$$

$$\mathbf{D} = \text{Total number of days data was collected}$$

$$\text{Proportion (Rate) of Arrivals} = \frac{\mathbf{N_i}}{\mathbf{D}}$$

The results from this process was used as input in a time varying rate table to model the arrival of patients into the system. The complete table used in Simo can be seen below in Table 3.

Table 3: Arrival Table Used in Simio

Starting Offset Time	Ending Offset	Inpatient Arrivals (LDR) Rate (events per hour)	Outpatient Arrivals (Triage) Rate (events per hour)
00:00:00	01:00:00	0.2410	0.2739
01:00:00	02:00:00	0.2219	0.2137
02:00:00	03:00:00	0.2109	0.1819
03:00:00	04:00:00	0.1863	0.1644
04:00:00	05:00:00	0.2383	0.1589
05:00:00	06:00:00	0.6821	0.1810
06:00:00	07:00:00	0.3972	0.1644
07:00:00	08:00:00	1.2219	0.3562
08:00:00	09:00:00	0.3479	0.4712
09:00:00	10:00:00	0.4900	0.5612
10:00:00	11:00:00	0.4657	0.8054
11:00:00	12:00:00	0.3287	0.7753
12:00:00	13:00:00	0.2932	0.7726
13:00:00	14:00:00	0.3205	0.7452
14:00:00	15:00:00	0.2876	0.7562
15:00:00	16:00:00	0.2904	0.7781
16:00:00	17:00:00	0.2575	0.7534
17:00:00	18:00:00	0.2440	0.6383
18:00:00	19:00:00	0.1890	0.5479
19:00:00	20:00:00	0.7200	0.5123
20:00:00	21:00:00	0.5560	0.5288
21:00:00	22:00:00	0.3287	0.5123
22:00:00	23:00:00	0.3260	0.4000
23:00:00	00:00:00	0.2680	0.3424

5.2 Structure of Baseline Simulation Model

A visualization of the simulation model can be viewed below in Figure 9. Each of the three sub-units was modeled with a server object in Simio. The Length of Stay Distributions were input into the servers of the "Processing Times" fields. A summary of the components used in the simulation model can be viewed below in Table 4. For the remainder of Section 5.2 and in Section 5.3, sub-units will be referred to by their simulation name. Add-on processes in the three servers are responsible for the entirety of the routing logic input into the model.

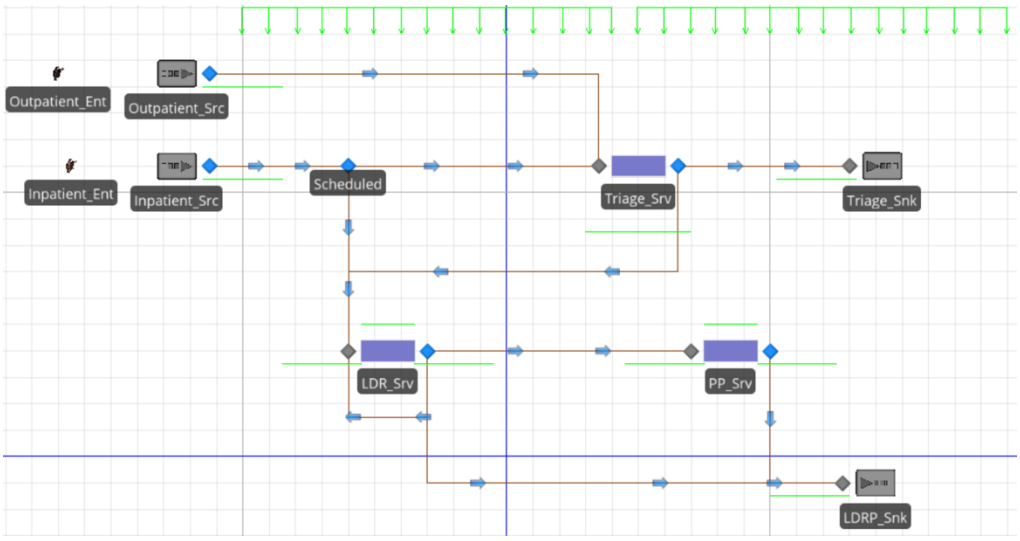

Figure 9: User Interface in Simio

Table 4: Summary of Components Used in Simulation Model

Designation in Simulation Name	Definition
Inpatient_Ent	Entities in the simulation represent individual patients who visit the LDR and Postpartum sub-units. These patients do not visit the Triage sub-unit if they are scheduled inductions. Otherwise, they visit all three sub-units.
Outpatient_Ent	Entities in the simulation represent patients who only visit the Triage sub-unit.
Inpatient_Src	Patients who go through labor enter through the inpatient source.
Outpatient_Src	Patients who do not go through labor enter through the outpatient source.
Triage_Srv	This server represents the triage sub-unit.
LDR_Srv	This server represents the LDR sub-unit.
PP_Srv	This server represents the Postpartum sub-unit.
Triage_Snk	The first sink in the simulation shows patients discharged from the Triage sub-unit.
LDRP_Snk	The second sink in the simulation shows patients discharged from the LDR and Postpartum sub-units.

Entities arrive into the system through two sources. The patients who will go through labor enter through *Inpatient_Src*, and the patients who receive only outpatient services enter through *Outpatient_Src*. Each source is controlled through time varying rate tables. There is a separate rate table for inpatients and outpatients. Induction patients in the simulation proceed directly to the *LDR_Srv*. Every other patient proceeds to the *Triage_Srv*. If a patient receives only outpatient services, they exit the system through the *Triage_Snk*. If a patient seen in the *Triage_Srv* needs further care, they are routed to the *LDR_Srv*. Once they receive care in this area, patients are routed to the *PP_Srv* to undergo rest and recovery, if there is a bed available. If there is not a bed available, the patient rests and recovers in the *LDR_Srv*. This situation is modeled in the simulation by re-routing patients recently exited from the the *LDR_Srv* back into the same server to undergo rest and recovery. Once patients complete the recovery portion of their stay, they are to exit the system through the *LDRP_Snk*. In both the *LDR_Srv* and *PP_Srv*, the arrival of the next patient is delayed for 30 minutes through an add-on process to simulate time required to clean the recently vacated room.

Routing in the simulation model is accomplished primarily with model entity state variables and add-on process triggers. A detailed list of all the model entity state variables and their descriptions can be viewed below in Table 5.

When entities enter the system, they are first given two state assignments, *Induction* and *PatientType*. First, it is determined whether an individual patient is a scheduled induction or a drop-in patient. This assignment is represented through the state variable *Induction*. It is created through a discrete distribution which mimics the actual proportion of induction patients versus total patients seen on the 4thfloor. In 2019, about 6.5% of these patients were elective inductions. Secondly, it is determined whether non-induction patients receive only triage outpatient services or whether they need to be routed to the *LDR_Srv*. This assignment is represented as the state variable *PatientType*. This assignment is made at each source. Patients originating from *Outpatient_Src* are classified as type 1 patients and routed to the *Triage_Snk*. Patients originating from *Inpatient_Src* are classified as type 2 patients and routed to the *LDR_Srv*. These state assignments are accomplished by an add-on process which acts on individual entities as they leave the source.

Table 5: Model Entity State Variables and Descriptions

Model Entity State Variable	Description
PatientType	Designates type of patient 1 = Triage outpatient services only 2 = Triage outpatient services, LDR, and PP
TimesThroughLDR	Records the number of times a patient receives a unique type of care in the LDR sub-unit
TriageWaitCheck	Indicates if a patient waits for transfer to LDR sub-unit services after receiving care in the Triage sub-unit 0 = patient does not wait 1 = patient waits
Induction	Designates if a patient is an elective induction or not 1 = elective induction 2 = not an elective induction
TriageCompletionTime	Records the DateTime an individual patient exists the Triage sub-unit
TriageEnterTime	Records the DateTime an individual patient enters the waiting room to be seen in the Triage sub-unit
LDRStart	Records the DateTime an individual begins care in the LDR sub-unit
BeforeTriageWaitCheck	Indicates if a patient waits to receive care in the Triage sub-unit 0 = patient does not wait 1 = patient waits

Five output/tally statistics calculate data of particular interest to this project. These are summarized below in Table 6. It is important to note that average waiting times only consider the patients who experience a wait time. Patients who do not wait for service do not affect average waiting times reported. It is also important to note that the *LDRProcessingTime* tally statistic reports average length of stay for care traditionally done in the LDR sub-unit. This tally statistic does not take into account the time required for patients to rest and recover when they cannot be transferred to the Postpartum sub-unit.

Table 6: Output/Tally Statistic Report for Simulation

Output/Tally Statistic	Description
LDRWaitingTimeReport	Reports average waiting time only for patients who wait for transfer to the LDR sub-unit
LDRProcessingTime	Reports the average length of stay for patients undergoing care contained within the scope of the LDR sub-unit's scope
TriageWaitingTimeReport	Reports average waiting time only for patients who wait for care in the Triage sub-unit
LDRPatientsWaitingReport	Reports the cumulative number of patients who wait for transfer to the LDR sub-unit
TriagePatientsWaitingReport	Reports the cumulative number of patients who wait for care in the Triage sub-unit
LDRPatientsNotTransferredReport	Reports the cumulative number of patients who are unable to be transferred to the Postpartum sub-unit

The model created by the SDT contains graphic and visual displays of the output/statistics outlined above. A depiction of the reporting interface can be viewed below in Figure 10. Circular/linear gauges and status labels accomplish the following in real time as the simulation is ran:

- Records the total number of patients who wait for care through status labels
- Records the total number of patients who cannot be transferred from the LDR sub-unit to Postpartum sub-unit through status labels
- Displays the current remaining capacity in the Triage, LDR, and Postpartum sub-units through circular gauges
- Displays the average patient wait time through linear gauges

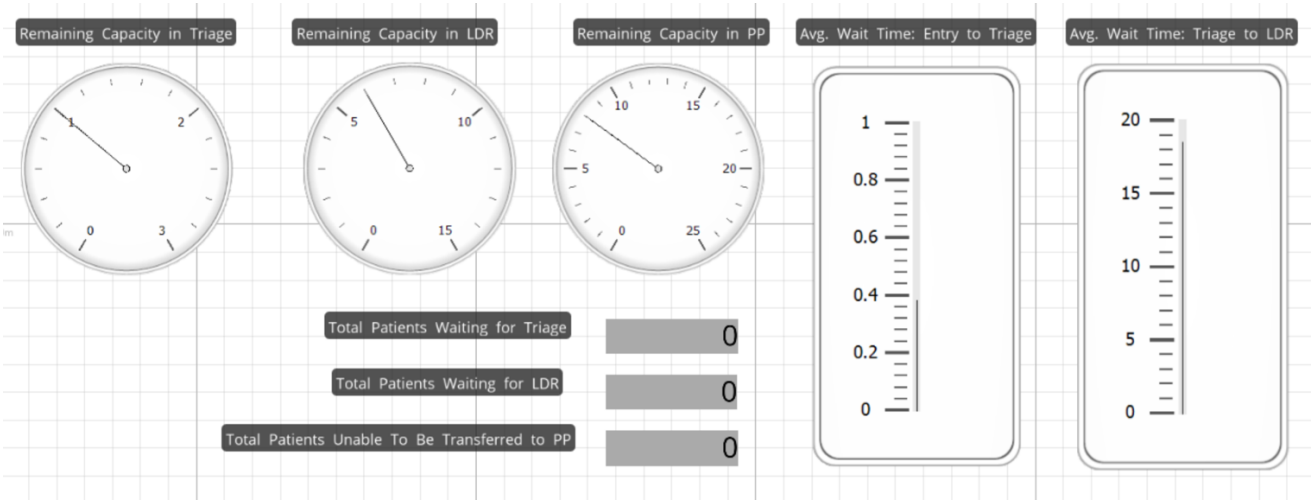

Figure 10: Visualization of Output/Tally Statistic Reports in Simio

5.3 Validation and Verification of Current State Simulation Model

To verify that the simulation model operated as intended, the SDT checked the logical operations with faculty and reviewed the process step-by-step. No logical errors were located and the patient flow was found to work as intended.

To validate that the simulation model accurately represents the current operations of the Women's and Children's Services Unit, the SDT ran the baseline model with 500 replications. Each experiment was run for the duration of 1 year and featured an additional warm-up period of 100 days. Then, actual measurements of throughput and length of stay in each sub-unit were compared to the confidence intervals generated by the experiment. This comparison can be viewed below in Table 7. Comparisons between the actual 2019 data and confidence intervals support that the model closely approximates current operations in Women's and Children's Services.

Table 7: 2019 Data Compared to Simio Confidence Intervals for Validation

Measurement	Actual 2019 Data	Result from Simulation Model
No. of deliveries	3,289	3,328 ± 5
No. of outpatient visits	4,203	4,234 ± 6
Avg. length of stay in Triage sub-unit (hours)	2.4	2.40 ± 0.001
Avg. length of stay in LDR sub-unit (hours)	18.37	17.15 ± 0.02
Avg. length of stay in Postpartum sub-unit (hours)	64.64	63.75 ± 0.04

5.4 Current State Capabilities and Analysis

Through running the baseline simulation model, the SDT found that Triage, LDR, and Postpartum sub-units do not possess sufficient capacity to meet their current patient demand. The sub-units also do not have the capacity to account for the continued growth of the sub-unit.

In 2019, 7,516 patients waited for care in the Triage sub-unit and they waited on average 43 minutes for care. Similarly, 933 patients waited for care in the LDR sub-unit and they waited on average 16.78 hours for care. Finally, 867 patients had to undergo rest and recovery in the LDR sub-unit instead of the Postpartum sub-unit.

Due to the unit currently running over capacity, an alternative solution is needed to account for current requirements and future growth. Refer to the following sections for a numerical analysis on the alternatives.

5.5 Alternatives for Improvement and Structure of Alternative Simulation Model

5.5.1 INTEGRIS Predicted Alternatives

The INTEGRIS Continuous Improvement team found that the 4th floor does need expansion to meet rising demand. The alternatives they considered to realize this capacity increase are as follows:

- Alternatives to Increase Capacity in the Triage sub-unit
    - **4 Bed Option:** convert a room currently used for emergency overflow to increase total sub-unit capacity to four rooms.
    - **5 Bed Option:** renovate two rooms across the hall from the Triage sub-unit to increase total sub-unit capacity to five rooms. Do not convert the room that was previously used for emergency overflow.
    - **6 Bed Option:** convert a room currently used for emergency overflow and renovate two rooms across the hall from the Triage sub-unit to increase total sub-unit capacity to six rooms.
- Alternatives to Increase Capacity in the LDR and Postpartum sub-units
    - **Add Rooms:** Add additional rooms to each sub-unit.
    - **LDRP:** Convert rooms in both the LDR and PP sub-units to LDRP rooms to make it unnecessary for patients to need transfers between the sub-units.

There are 3 criteria INTEGRIS used to evaluate the alternatives:

- The impact on ability to see patients in a timely manner.
- The impact on sub-unit visibility.
- The total implementation cost (includes construction and new equipment cost).

For each alternative regarding the Triage sub-unit, there are pros and cons based on visibility, patient flow, and costs. Below, Table 8 shows these pros and cons based on the respective option.

Table 8: Pros and Cons of Triage Alternatives

	Alternative 1: 4 Bed Option	**Alternative 2: 5 Bed Option**	**Alternative 3: 6 Bed Option**
Pros	• Increased Capacity: Increase capacity by one bed.	• Increased Capacity: Increase capacity by two beds. • Co-located to Triage: These two rooms will be in the same area as the three current Triage rooms.	• Max Increased Capacity: Increase capacity by three beds. • Five Rooms Co-Located: Five of the rooms will be in the same vicinity.
Cons	• Decreased Visibility: This room is in a different hallway, so there is no visibility of all triage beds for the staff at a single time. • Patient Flow: This room is in a different hallway, so the patients would not physically flow through each sub-unit as they did before when this room is utilized. • Equipment Costs: Reconfiguring this room into Triage will cost money for equipment.	• Constriction Costs: Will require renovation of offices to Triage rooms. • Equipment Costs: Reconfiguring these rooms into Triage will cost money for two sets of equipment.	• Decreased Visibility: One of the rooms will be located in a different hallway, so there is no visibility of all triage beds for the staff at a single time. • Patient Flow: One of the rooms is located in a different hallway, so the patients do not physically flow through each sub-unit as they did when this room was not utilized. • Construction Costs: Will require the renovation of offices to make two Triage rooms. • Equipment Costs: Reconfiguring these rooms into Triage will cost money for three sets of equipment.

For each alternative regarding the LDR and PP sub-units, there are pros and cons based on increasing capacity, construction costs, patient flow, equipment, and real-world feasibility. Below, Table 9 shows these pros and cons based on the respective option.

Table 9: Pros and Cons of LDR and PP Alternatives

	Alternative 1: Add Rooms	**Alternative 2: LDRP**
Pros	• Increased Capacity: By physically adding rooms, the unit will be able to house more patients and allows room for growth of Women and Children's Services.	• Minimize Cleaning Time: There will be no transfer from LDR to PP so there is no cleaning needed of the PP room. • No Physical Transfers from LDR to PP: Eliminate time spent physically transferring sub-units. • Real-World Feasibility: The Women and Children's Services staff has received approval for this alternative. • Increase Unit Flexibility: Removed bottle-necks that occur in the sub-units when they are separated.
Cons	• Constriction Costs: This requires large construction costs to completely build a new area. • Patient Flow: There is no space on the current 4th floor to add rooms, so by expanding it would be in a different area, so the patients would not physically flow from Triage to LDR as they did before. • Equipment Costs: Equipment for configuration of room. • Real-World Feasibility: The Women and Children's Services staff was told by INTEGRIS executives that physically adding rooms is not possible at this time due to budgets. • Care Cost: With adding more rooms, more staff will be needed to care for patients.	• Equipment Costs: Will have to spend money adding equipment for LDR to PP rooms and adding PP equipment to LDR rooms • Room for Growth: Does not give the unit the same amount of room for growth.

5.5.2 Testing Improvement Alternatives

The SDT evaluated the alternatives for improvement through experiments in Simio and through the creation of an alternative simulation model. The Triage sub-unit was analyzed both separately and combined from the LDR and Postpartum sub-units to see the effects of each. In other words, the 4-bed, 5-bed, and 6-bed options to increase capacity in the Triage sub-unit were tested without changing the current capacity in the LDR or Postpartum sub-units, while also running an experiment with each alternative for Triage and LDR/Postpartum simultaneously. The SDT found that the changes made in the Triage sub-unit were independent from the changes made in the LDR and Postpartum sub-units, and the results did not change from when the SDT ran them alternatives separately. However, the results generated from simulation experiments run with both alternative options can be found in Appendix F. Due to that, the SDT continued to run the experiments separately, and those results are shown below. This change was modeled through experiments run in Simio. Similarly, the proposed action to add beds in the LDR and Postpartum sub-units was tested without changing the Triage sub-unit's current state capacity of three beds. This change was also modeled through experiments run in Simio.

Finally, the SDT created an alternative simulation model to analyze the impact of the second proposed action to increase capacity in the LDR and Postpartum sub-units. This alternative, referred to as the LDRP modification, requires renovation of each room in the two sub-units to eliminate the need for patient transfer. In LDRP rooms, patients undergo delivery, rest, and recovery in the same room. To model this change, the *PP_Srv* was eliminated, and the capacity of the *LDR_Srv* (renamed the *LDRP_Srv*) was increased to reflect the combination of the two sub-units. Processing times previously separated into the *LDR_Srv* and *PP_Srv* were added to simulate the additional time patients spend in each room.

Utilizing the results generated from the experiments and alternative model, the SDT created recommendations for the 4th floor at INTEGRIS. Following this, a final simulation was created to quantify the impact of the full recommendations presented by the SDT. These results will be discussed later in the report.

5.5.3 Analysis of Improvement Alternatives

The results of the Triage sub-unit analysis are summarized below in Table 10. The total number of patients who experience some wait time before receiving care in the Triage sub-unit remains the same despite increasing capacity. However, increasing capacity reduces the average wait times by a significant margin. The 4-bed option decreases wait times by 77%. Adding an additional bed decreases wait times by 93%. Increasing capacity in the sub-unit to 6 beds results in only a marginal improvement and decreases wait times by 98%.

Table 10: Simio Analysis of Alternatives in Triage Sub-unit

Alternative	Total No. of Patients Who Experience Wait Time	Average Wait Time (hours)	% Decrease in Average Wait Time
Current state	7,516 ± 8	1.27 ± 0.003	-
4-bed option	7,508 ± 7	0.10 ± 0.001	77%
5-bed option	7,508 ± 7	0.03 ± 0.0004	93%
6-bed option	7,516 ± 8	0.01 ± 0.0002	98%

The analysis on the LDR and Postpartum sub-units is summarized below in Table 11. In the analysis, the SDT assumed that 98% of patients seen in the 4th floor would be seen without delay, as shown in the 6-bed option for the Triage sub-unit. This assumption was made as a starting point for analysis because INTEGRIS has an extremely high standard to delivering exceptional patient care. Experiments showed that no rooms need to be added to LDR and 11 rooms should be added to Postpartum. If the alternative is utilized, the total capacity of the combined sub-units should be increased by 5 rooms.

Table 11: Alternatives Results from Simio Including Confidence Intervals

Alternative	Total No. Patients Who Experience Wait Time	Average Wait Time (hours)	Total No. Patients Who Are Not Transferred to Postpartum
Current state	933 ± 18	16.78 ± 0.37	867 ± 5
LDR sub-unit: 15 beds Postpartum sub-unit: 33 beds	31 ± 2	4.55 ± 0.24	71 ± 2
LDR sub-unit: 16 beds Postpartum sub-unit: 33 beds	18 ± 1	4.16 ± 0.24	71 ± 2
LDR sub-unit: 17 beds Postpartum sub-unit: 33 beds	9 ± 1	3.82 ± 0.30	71 ± 2
LDRP model: 37 beds (current capacity)	400 ± 8	8.56 ± 0.18	0
LDRP model: 40 beds	144 ± 4	5.97 ± 0.15	0
LDRP model: 41 beds	100 ± 3	5.60 ± 0.15	0
LDRP model: 42 beds	70 ± 3	4.97 ± 0.15	0
LDRP model: 43 beds	49 ± 2	4.63 ± 0.17	0

6.0 Recommendations and Benefits

The SDT recommends that the 5-bed option be implemented to increase capacity within the Triage sub-unit based on the confidence intervals calculated in the summary of results. This option does not reduce visibility for the sub-unit, which is a significant disadvantage of the other alternatives. Although the plan is costlier than the 4-bed option, the 5-bed option decreases patient wait times by an additional 16%.

The SDT also recommends that the LDR and Postpartum convert all rooms to be LDRP rooms. The results of the simulation analysis revealed that the most effective action the 4th floor can take to increase capacity is to convert all rooms to LDRP rooms and add 5 additional rooms to the floor. This plan would decrease the number of patients who experience wait times by 92% and decrease patient wait times by 72%.

However, it is not possible to increase the Postpartum sub-unit enough to meet patient demand because there is simply not sufficient space on the 4th floor to do so. The LDRP modification is the only realistic option available to Women's and Children's Services. Implementation of this plan will decrease the number of patients who experience wait times by 57% and decrease patient wait times by 49%. Conversion to LDRP rooms is also less costly than increasing the overall capacity of the two sub-units separately. Additionally, less time will be required to clean and maintain the rooms because patients will not require room transfer during their stay in Women's and Children's Services. This additional benefit serves to streamline processes on the 4th floor and will help the sub-units meet patient demand. For a visualization of these results, refer to Table 12.

Table 12: Summary of Results from Recommendations

Alternative	Total No. Patients Who Experience Wait Time in the Respective Sub-unit	Average Wait Time (hours)	Total No. Patients Who Are Not Transferred to Postpartum
LDRP model: 37 beds (current capacity)	400 ± 8	8.56 ± 0.18	0
5-bed option	7,508 ± 7	0.03 ± 0.0004	N/A

Appendix A: Trends in Admissions, Transfers, and Discharges Graphics

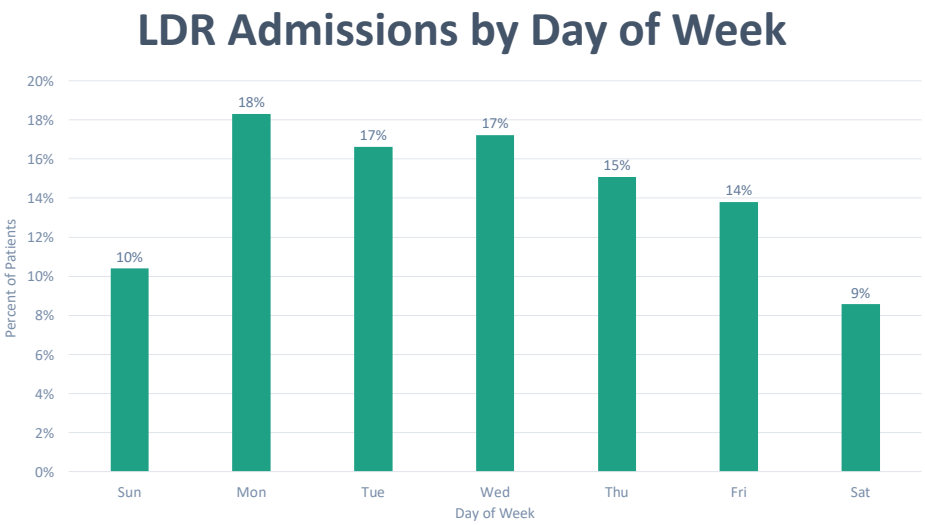

Figure 11: LDR Percentage of Patients Admitted by Day of Week

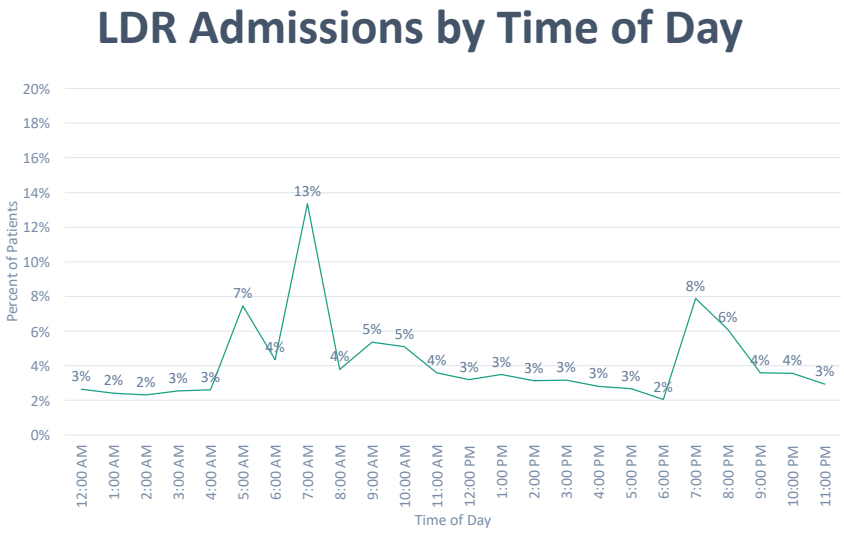

Figure 12: LDR Percentage of Patients Admitted by Time of Day

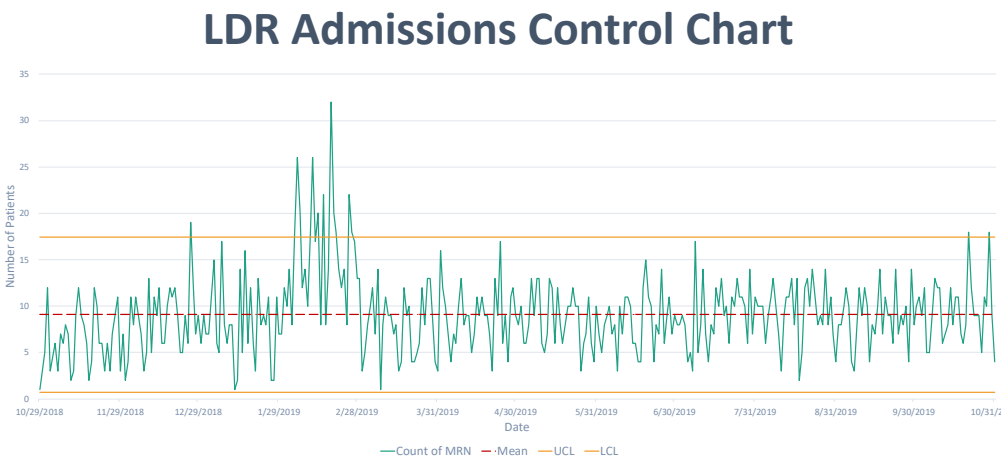

Figure 13: LDR Admissions Control Chart Depicting Possible Seasonality

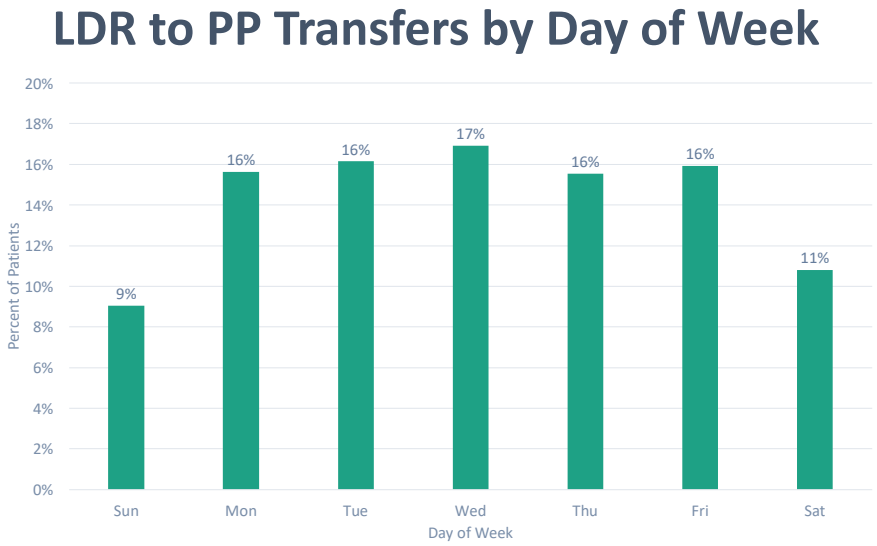

Figure 14: LDR to PP Percentage of Patients Transferred by Day of Week

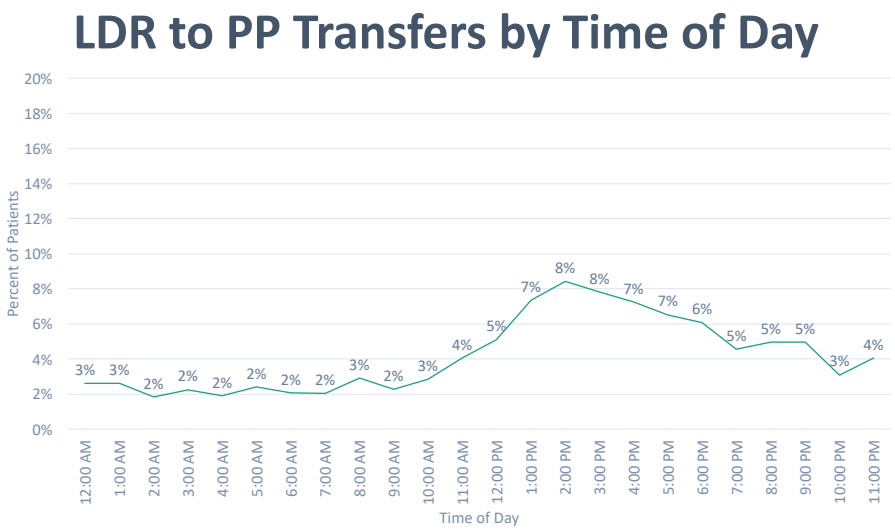

Figure 15: LDR and PP Percentage of Patients Transferred by Time of Day

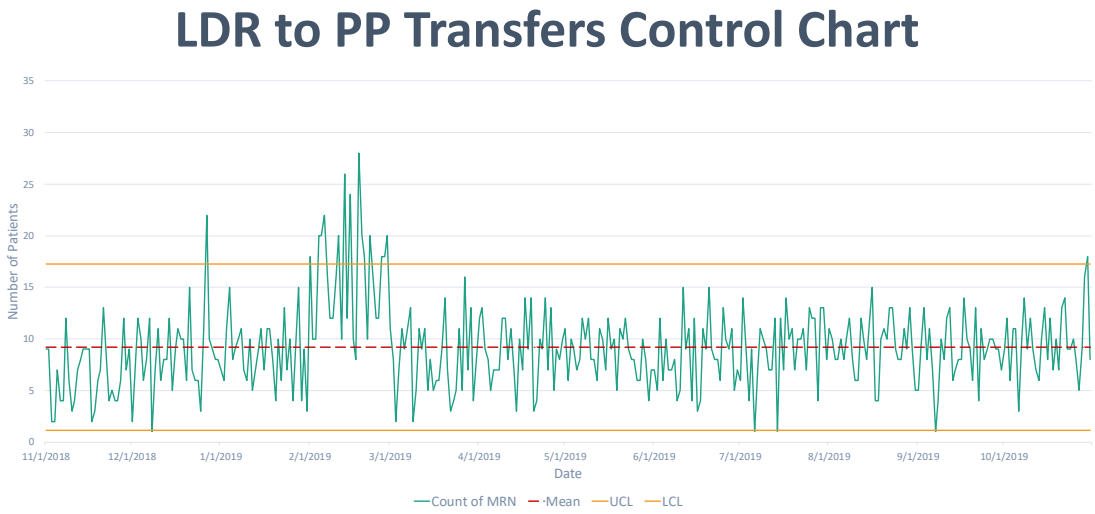

Figure 16: LDR to PP Transfers Control Chart Depicting Possible Seasonality

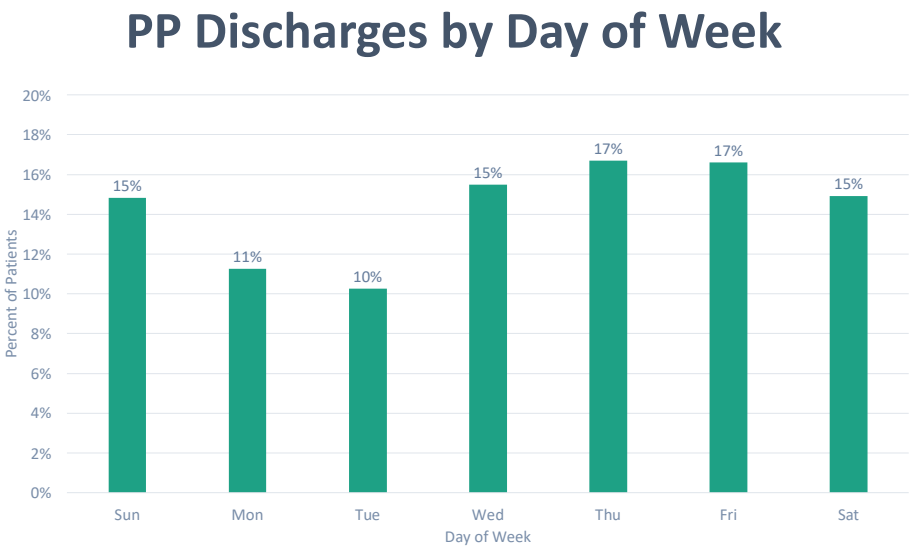

Figure 17: PP Percentage of Patients Discharged by Day of Week

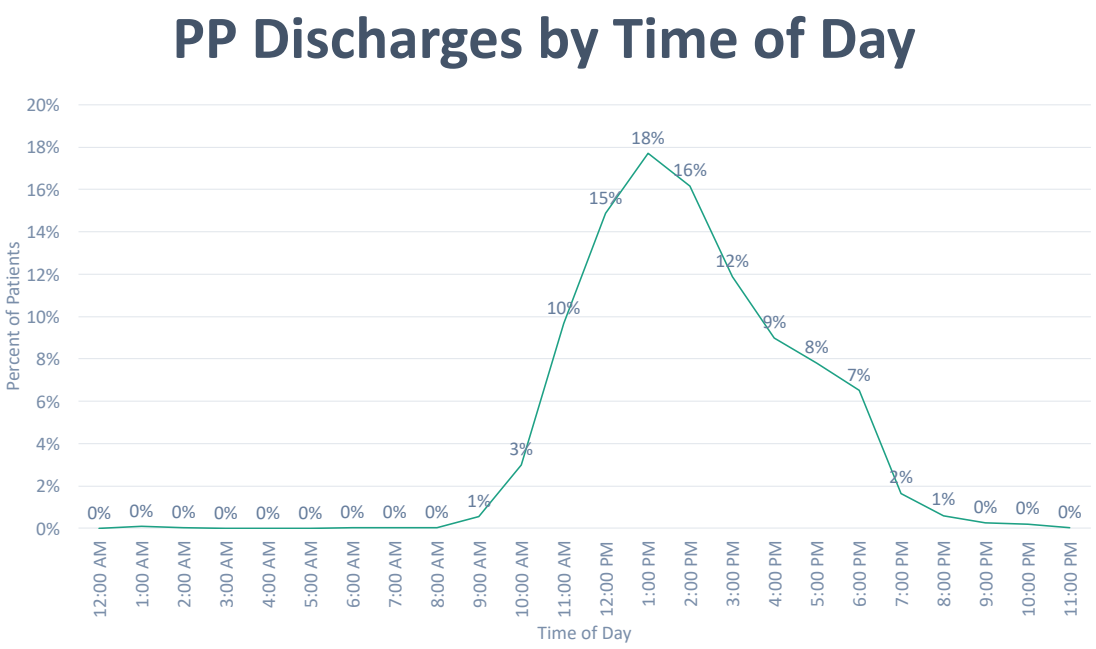

Figure 18: PP Percentage of Patients Discharged by Time of Day

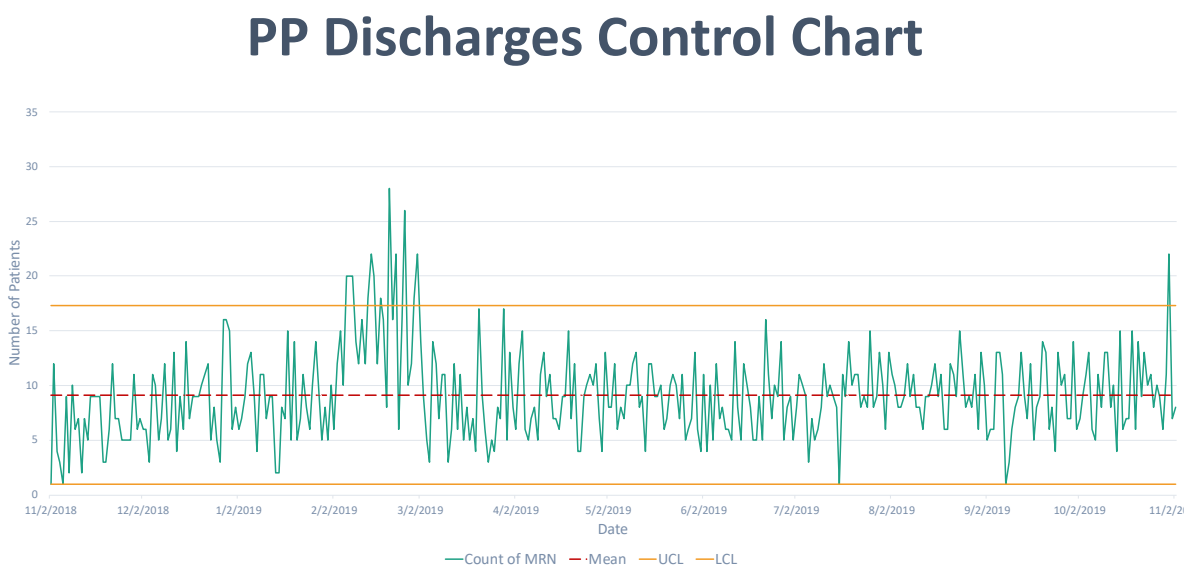

Figure 19: PP Discharges Control Chart Depicting Possible Seasonality

Appendix B: Length of Stay Data in Histogram

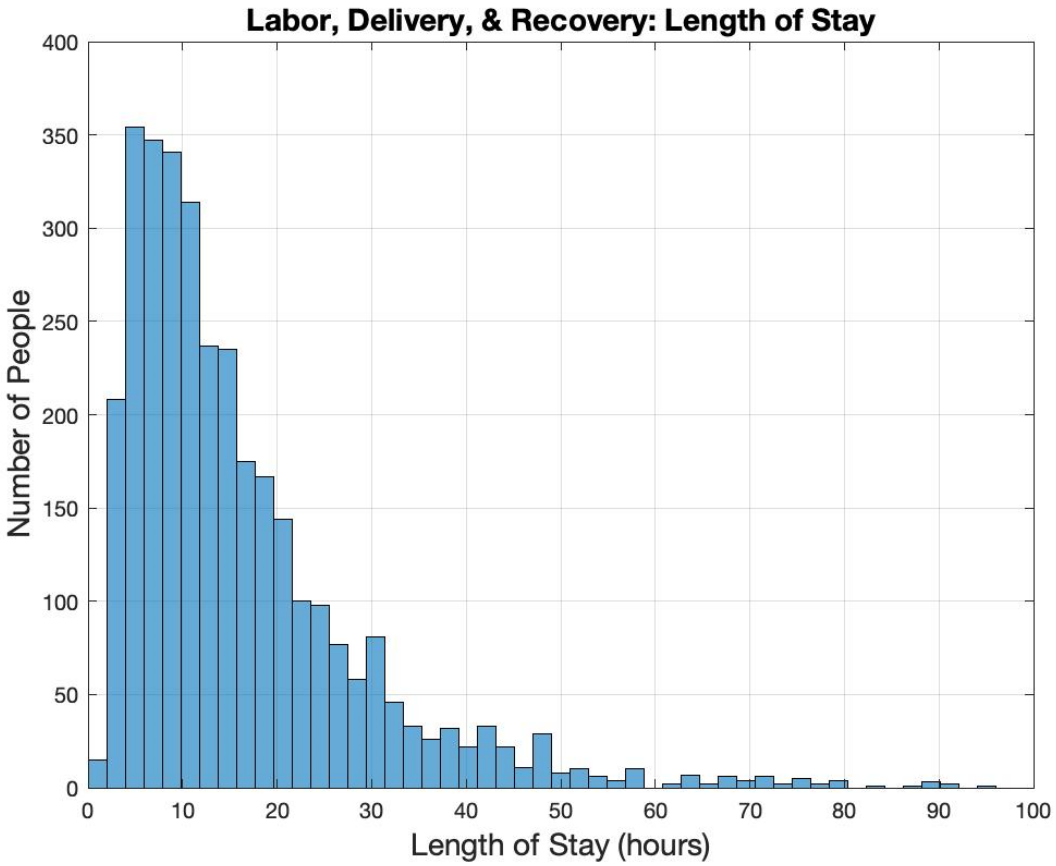

Figure 20: LDR Length of Stay Histogram of all Patients in 2019

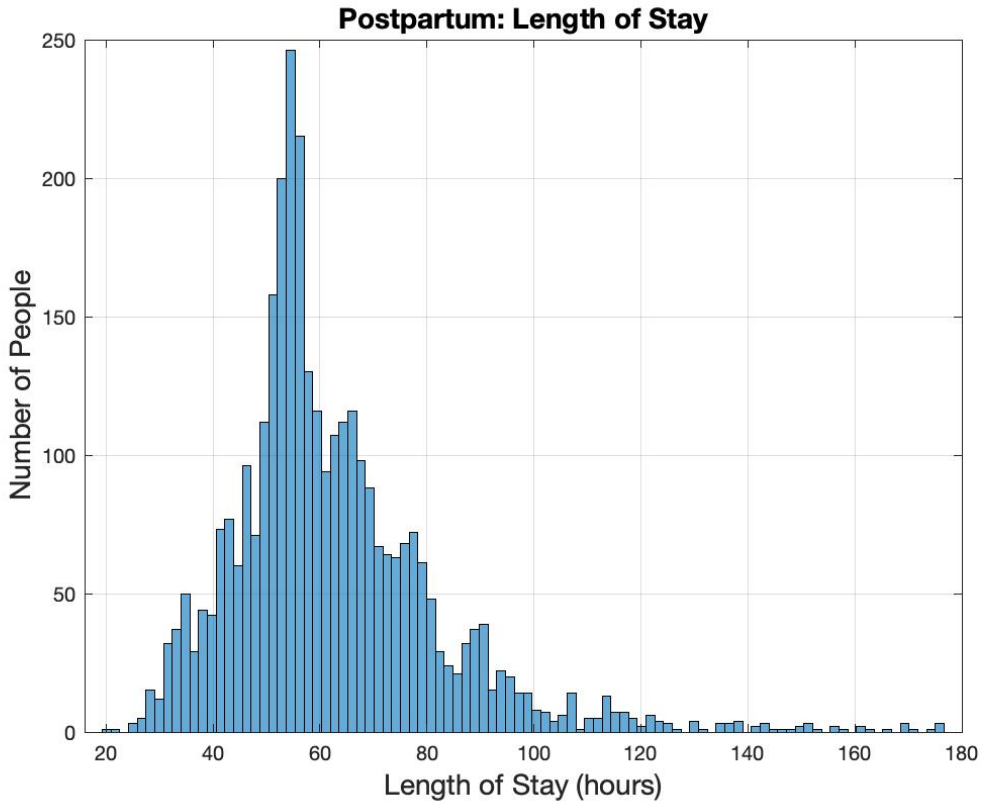

Figure 21: PP Length of Stay Histogram of all Patients in 2019

Appendix C: Current Sub-unit Capacity Data

Table 13: Capacity in LDR Sub-unit in 2019

Number of Patients at One Time	Percentage of Patients in 2019
0 - 7	25%
8 - 11	53%
12 - 14	16%
15 +	6%

Table 14: Capacity in PP Sub-unit in 2019

Number of Patients at One Time	Percentage of Patients in 2019
0 - 10	71%
11 - 17	24%
18 - 21	3%
22 +	2%

Table 15: Capacity in Triage Sub-unit in 2019

Number of Patients at One Time	Percentage of Patients in 2019
0	20
1	27
2	24
3	16
4	8
5	3
6 +	1

Appendix D: Probability Distributions Fits Based on Length of Stay

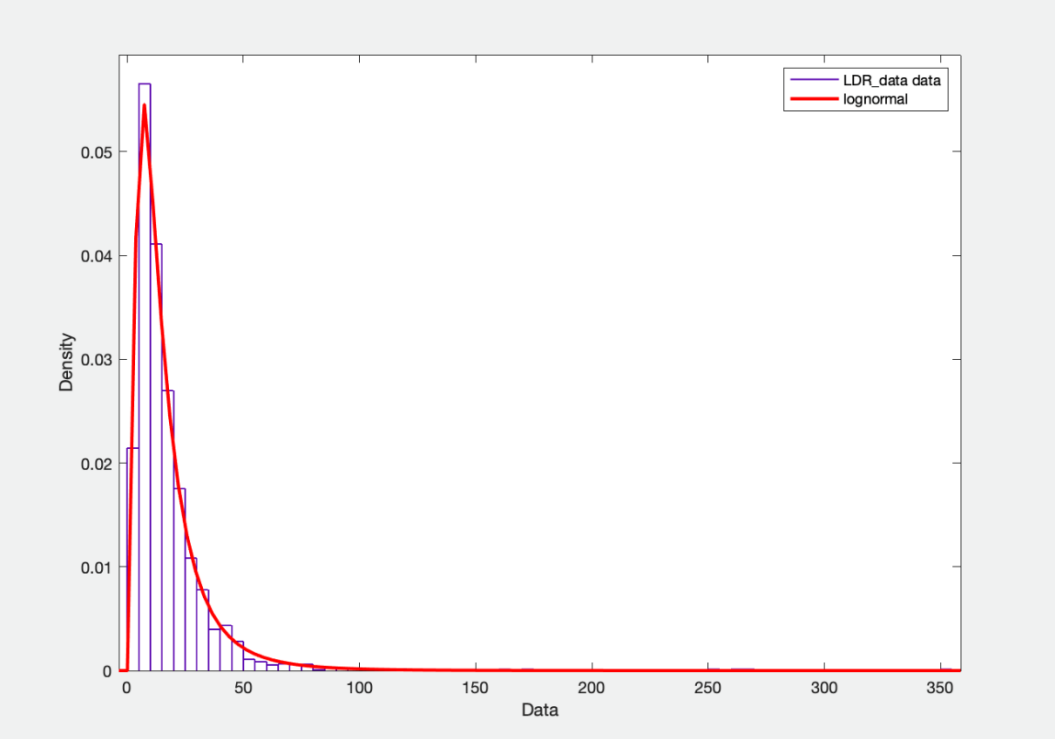

Figure 22: LDR Distribution Fit on Histogram

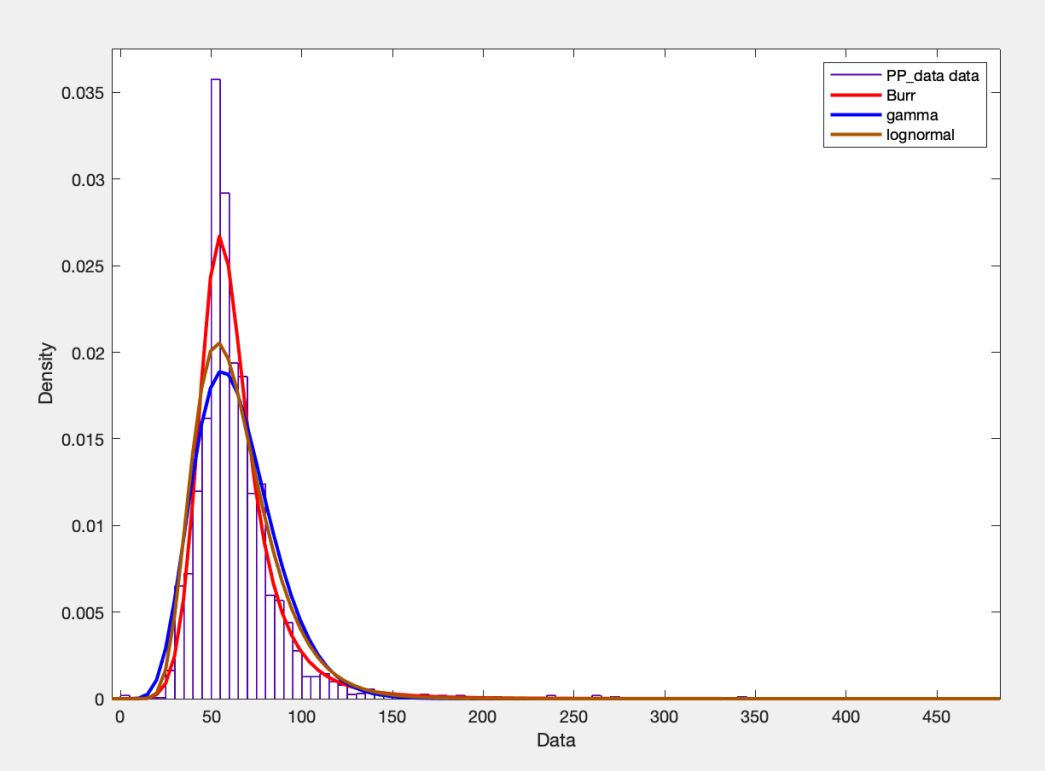

Figure 23: PP Distribution Fit on Histogram

Appendix E: Tables of Arrival Times

Table 16: Number of 2019 Patient Arrivals in Time Period

Time	Number of Outpatient Patient Arrivals in 2019	Number of Inpatient Patient Arrivals in 2019
00:00 – 01:00	102	88
01:00 – 02:00	78	81
02:00 – 03:00	70	77
03:00 – 04:00	60	68
04:00 – 05:00	58	87
05:00 – 06:00	70	249
06:00 – 07:00	62	145
07:00 – 08:00	133	446
08:00 – 09:00	176	127
09:00 – 10:00	224	179
10:00 – 11:00	288	170
11:00 – 12:00	288	120
12:00 – 13:00	283	107
13:00 – 14:00	261	117
14:00 – 15:00	290	105
15:00 – 16:00	297	106
16:00 – 17:00	269	94
17:00 – 18:00	224	89
18:00 – 19:00	197	69
19:00 – 20:00	181	263
20:00 – 21:00	205	203
21:00 – 22:00	175	120
22:00 – 23:00	148	119
23:00 – 24:00	97	98

Appendix F: Summary of Results from Each Alternative Run Simultaneously

Table 17: Summary of Results from Each Alternative Run Simultaneously in Simio

Alternative	Total No. of Patient Who Wait Before Care in Triage Sub-Unit	Average Wait Time Before Triage Sub-Unit (hours)	Total No. of Patients Who Wait for Care In-between Triage and LDR Sub-Units	Average Wait Time In-between Triage and LDR Sub-Units (hours)	Total No. Of Patients Not Transferred to Postpartum Sub-Unit
4-bed option LDR sub-unit: 15 beds Postpartum sub-unit: 33 beds	997 ± 6	0.77 ± 0.004	32 ± 2	4.50 ± 0.23	72 ± 2
5-bed option LDR sub-unit: 15 beds Postpartum sub-unit: 33 beds	348 ± 3	0.57 ± 0.004	31 ± 2	4.39 ± 0.22	71 ± 2
6-bed option LDR sub-unit: 15 beds Postpartum sub-unit: 33 beds	108 ± 2	0.46 ± 0.005	32 ± 2	4.65 ± 0.24	71 ± 2
4-bed option LDRP option: 37 beds	999 ± 6	0.77 ± 0.004	393 ± 8	8.45 ± 0.18	0
5-bed option LDRP option: 37 beds	346 ± 3	0.57 ± 0.004	397 ± 8	8.39 ± 0.16	0
6-bed option LDRP option: 37 beds	106 ± 2	0.46 ± 0.005	390 ± 8	8.27 ± 0.16	0
4-bed option LDRP option: 42 beds	997 ± 6	0.77 ± 0.004	72 ± 3	5.17 ± 0.15	0
5-bed option LDRP option: 42 beds	346 ± 3	0.57 ± 0.004	69 ± 3	5.15 ± 0.16	0
6-bed option LDRP option: 42 beds	106 ± 2	0.46 ± 0.005	71 ± 3	5.13 ± 0.16	0