OBSTETRIC UNIT CAPACITY OPTIMIZATION AND CONSOLIDATION
ANALYSIS USING SIMULATION MODELING AND USING ANALYTICAL
HIERARCHY PROCESS

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Revanth Kumar Reddy Gandhari

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OBSTETRIC UNIT CAPACITY OPTIMIZATION AND CONSOLIDATION
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Thesis

Approved: ________________________________  Accepted: ________________________________

Advisor  Committee Member  Department Chair
Dr. Shengyong Wang  Dr. Celal Batur  Dr. Sergio Felicelli

Department Chair  Committee Member  Dean of the College
Dr. Shengyong Wang  Dr. Celal Batur  Dr. George K. Haritos

Dean of the College  Committee Member  Interim Dean of the Graduate School
Dr. Sergio Felicelli  Dr. Chen Ling  Dr. Rex D. Ramsier

Interim Dean of the Graduate School  Date
Dr. Rex D. Ramsier  ________________________________
ABSTRACT

Healthcare costs are exponentially increasing in the world and especially in the US. In such an expensive field, it is important to eliminate all the waste from the system. Waste can be found in many forms like excess resources, staffing, unnecessary process steps, rework etc. Hospitals experience high variation in the incoming patient volume throughout the year. Unlike manufacturing industry, it is impossible to control variation in healthcare. As the years go by, the patient volume varies which could be an upward trend or a downward trend. As the patient volume changes, it is important to stay updated on the number of beds required to accommodate the patients. Many techniques have been used by the hospitals to estimate the bed requirements. Most hospitals use the occupancy method in which the management estimates the bed requirement to reach 80% occupancy. Due to the variation in incoming patient volume, such method would lead to excess delays in patient care. In today’s competitive world, patient satisfaction is extremely important to generate revenue. The task is to minimize delays while keeping the operating costs at minimum. More advanced methods are required to estimate the required amount of resources considering the variation in the patient arrival rate. In case if the hospital management decides to consolidate their facilities, how much capacity do they need? How many patients are they about to see? After literature review, research in such area has not been found. This research concentrates on exploring such scenarios in effort to add to the body of knowledge in the area. In this research, a simulation model is built to study the current operating conditions of the system followed by optimizing the
capacity of an Obstetric unit. Patient volume projections in case of consolidation have been estimated followed by estimating the resources required if consolidated. Finally analytical hierarchy process is used to assist in decision making considering numerous decision criteria and alternatives available.
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CHAPTER I

INTRODUCTION

1.1. Research Motivation

Cost of healthcare in the US is a burning platform. Per capita, the US spends at least 50\% more than any other nation on patient care and yet in quality, it is not ranked at the top of the list.\cite{87,88} Government’s efforts to control the exponentially growing expenses place many regulations on hospitals, suggesting them to control their costs. Care providers are posed with a challenge to reduce costs while providing exceptional care to their patients. Many hospital systems started implementing process improvement methods like lean and Six Sigma to eliminate waste and enhance efficiency. Due to continuously changing trends of patient volumes seen by hospitals over the years, optimization of resources like staffing and bed capacity is important in order to avoid underutilization or unavailability of resources during a volume spike. Maintaining optimal resources is vital in being cost effective while providing quality patient care, which is the initiative and motive behind this research.

Experimentation has been conducted at two Obstetric units at Location 1 (L1) and Location 2 (L2) owned and operated by a medium size community hospital system in northeast Ohio. This research concentrates on estimating optimum bed requirements for two Obstetrics (OB) units from now until 2017 and analyzes possible consolidation of
both facilities based on projected demands. Complexity and randomness in system utilization requires advanced Systems Engineering tools to assess performance and analyze alternative scenarios. This study uses a simulation approach to evaluate performance, followed by capturing results of numerous settings. To estimate the patient volume in case of consolidation, a linear mathematical model embedded with a loyalty element has been used, considering the driving distance and influence of competitors as factors. These numbers are then used to calculate projected revenue using payer mix. At that point, we introduce Analytical Hierarchy Process (AHP), a multi criteria decision making tool to rank various scenarios in finding the best option in logistics perspective for the hospital system.

1.2. Birth Trends

According to the data from Ohio department of health [89], number of births in the state has been declining for the past few years. Birthrate in regions from which most of the patient volume seen by the studied facilities appears to be more steady compared to state.
1.3. Research Objectives

The overall objective of this research is to propose and validate a general methodology to aid the decision making process of hospital OB unit consolidation. The specific aims are described below:-
1) Determine optimal resource requirements for both facilities.

2) Estimate the number of patients each unit would see if consolidated.

3) Determine the best scenario using AHP.

1.4. Thesis Overview

Chapter 1 provides the motive behind research and how the challenges in healthcare lead to application of engineering tools in the industry. Chapter 2 presents the background and literature review in the related field. A solution approach in order to solve the problem, in-depth analysis of data, and defining decision criteria for AHP will be presented in Chapter 3. All the data analyzed is used in building a simulation model to replicate multiple scenarios and find the optimal resource requirements which have been incorporated in Chapter 4. Results of the research have been presented and discussed in Chapter 5 followed by conclusions and future research in Chapter 6.

AHP has been mentioned in Chapter 3 and Chapter 5. Simulation is explained in chapter 4. Originally, during the research, AHP was introduced after simulation but in this thesis, AHP is mentioned in an earlier chapter than simulation modelling. During the research, after data analysis, the simulation models were built and validated. After model validation, consolidation scenario was analyzed starting with estimation of patient volumes if consolidated and then building simulation models for consolidation scenario. At this point, AHP was introduced, and more simulation experiments were done due to the requirement of some quantitative factor values for AHP ranking. To avoid the complex back and forth flow between simulation and AHP, the factors used in AHP are explained in chapter 3 followed by simulation and finally the ranking of decision criteria.
has been explained in the results and discussion section. Though simulation modelling is a part of methodology used, since simulation modelling is a major concentration in this thesis, a separate chapter was dedicated to it.
CHAPTER II

BACKGROUND AND LITERATURE REVIEW

2.1. Introduction to Process Improvement in Healthcare

It is a known fact that healthcare expenditures in the US are higher than any other country, despite the fact that it is at bottom of the list in quality rankings. These expenses are projected to continue rising in the years to come. 60 to 65% of the US population is insured through various government programs like Medicare, Medicaid, Children’s Health Insurance Program, etc. The rest of the insured population is privately insured. 16.3% of the population remains uninsured in 2010. In order to control these costs while making sure patients receive quality care, the government continues placing numerous regulations on hospitals, which lead to added burden on hospitals and cuts in reimbursement. This translates to more work required to be done with comparatively lower budget.

In pursuit of quality control, reducing medical errors, and cost, hospitals began using tools from process improvement methods like lean and Six-Sigma, as these tools have been successful in revolutionizing quality and reducing operating costs in manufacturing. Six-sigma is a set of techniques and tools for process improvement developed by Motorola. Lean and Six Sigma are related improvement concepts. Both concepts focus on eliminating waste and making processes more efficient. Lean focuses
on eliminating non-value added steps in order to reduce overall cost, while preserving the quality of the product or service provided to customers. Six Sigma states that waste is a result of variation within the process. Lean Six Sigma, which is a combination of tools from both methods, is being widely used today by every industry. In process improvement, we look for eight types of wastes, namely waiting, inventory, transportation, unused human potential, overproduction, defects, excess motion, and over processing.

The basic process starts with identifying an area that requires improvement followed by mapping out the processes, identifying waste and defects. Current state metrics are measured and documented. Goals will be established and progress is tracked. Some believe that in many processes, 90% of steps are non-value added. All wasteful steps from the current state are eliminated, a future state is mapped out, and standard work is written and implemented. This is done by the frontline staff rather than the management. In a traditional way, the management dictates standard work but lean enforces a philosophy where the frontline staff defines standard work as they have the best knowledge of what works and what does not. The quest for a better process never ends. Standard work needs to keep changing, improvements will have to continue.

2.2. Introduction to Obstetrics (OB)

OB is an inpatient unit which provides care to pregnant women, especially during child birth, and various complications during that period. Resources available in this unit are Operating Rooms, Labor & Delivery, and Postpartum Rooms. Different types of patients go through different procedures and use various resources within the unit for
varied length of time. Patient appointments are partially scheduled, some patients call-in for urgent need of care and a few patients come in with no prior notice.

There is high fluctuation in demands from time to time, which leads to scarcity of resources at times and underutilization during low demand periods. Assuring that patients are provided care whenever required is a high priority in this case. In order to achieve that, the unit needs to have overabundant resources at all times. Enormous operating costs are associated with having inventory of resources that are not being used to the fullest extent which increases cost per service provided. The hospital’s facilities need to operate at optimal levels at all times and reduce waste as there has been a substantial rise in healthcare costs in the nation. If the resources are optimized to balance between operating costs and demand, cases where patients cannot be accommodated will be encountered. Alternative plans need to be made for patient accommodation if demand exceeds capacity.

Unlike an Emergency Room, length of stay for an OB patient is typically around 2 to 3 days or more depending on factors like procedure, complications in delivery etc. Patients like to stay longer than necessary, which is one of the factors influencing length of stay. Reducing patient length of stay and improving flow will help in utilizing the limited resources in the best possible way.

2.3. Research in Facility Consolidation

Hospitals have been merging and forming conglomerates in the United States leading to a near monopoly. There are five major transactions happening between hospitals namely affiliations, joint ventures, joint operating agreements, mergers, and
acquisitions. In affiliation, one hospital helps provide services in which they excel, at another hospital. Joint venture is where a new facility is created with shared profit and risk. Coordinated services are established in Joint Operating Agreement. Two hospitals combine to form a merger. One organization purchases another making the transaction an acquisition.

In many cases, hospitals affiliate to provide a broad range of services to the community. There has been an enormous amount of research in the area of mergers. The research concentrates on different aspects of mergers. Studies have been conducted on how a merger affects the price rise in healthcare, changes in efficiency, savings seen due to economies of scale, effects on quality of care, etc[3-15]. L. Baker et al. analyzes variation in demand/occupancy of hospitals and the costs of operation and concludes that difference in cost of operations due to change demand is not significant [16].

In a case of consolidation, if a facility is shut down, the other facilities in the area are expected to see higher volume of patients. Percentage of patients choosing a certain hospital over the rest of the competition depends on a multitude of factors. The choice of patients also depends on the purpose of their visit. In some scenarios, patients tend to follow their physician if the physician stays in the same locality. In other situations such as, if a patient happens to need surgery, they will have to find a surgeon. Generally, the patient’s current physician refers that person to a physician and/or a facility.

From a managerial perspective, if a facility is closed locally, an opportunity opens up for more business. Adequate resources need to be allocated to serve the additional volume. Surge in volume could impact quality of service. When demand exceeds supply,
a number of issues or flaws may be found in the processes which haven’t been noticed in the past, which opens up an opportunity for improvement. High demand results in increased patient waiting times. Frontline workers start experiencing burden and pressure. This can lead to many mistakes in the process resulting in redundant work in some occasions, like tests being done on the wrong patient. Every so often the mistakes could be as dangerous as wrong surgeries performed. Capital spent on redundant work is a substantial loss. Most of the patients may choose to not return to the hospital resulting in loss of any further business with those patients. To ensure safe operation of the facilities and provide the best care to customers, capacity planning is paramount for every hospital. A best practice for customer service is defined as providing customers exactly what they need, when they need the product or services. Costs associated within the healthcare system places many constraints. Assuring that services are provided to patients with minimal to no wait is the goal of any healthcare organization.

Most traditional ways followed by the hospitals to determine level of resources needed is by making sure the occupancy levels are 85%. To control spiking costs in healthcare, government placed a regulation in late 20th century that every hospital has to justify the number of beds it requires in terms of occupancy levels. The ratio methods are still being used by many service providers to determine the capacity. Linda V. Green et al. have done research on the relation between the number of hospital beds and quality of service. The authors stated that the traditional method used by hospitals to determine number of beds required (based on occupancy) is not accurate. It has also been asserted that though queueing theory has been successful in determination of capacity for service industries, there is a need for a more accurate method [17-19].
To bridge the research gap, this thesis particularly concentrates on finding the optimal amount of resources required for the current volume in the studied OB units in two sister hospitals in medium sized community health care system in Northeast Ohio, followed by estimating the patient volume either facility will experience in case of consolidation. When merged, the unit that continues to operate will see more patients. This study also provides the optimal amount of resources required to accommodate new estimated patient volumes. No literature has been found on estimating resultant patient volume after a facility has been consolidated. A substantial amount of research has been found on how consolidation affects costs, quality of care, etc. As this research does not focus on those aspects, literature referenced here is limited. More in-depth literature review on estimating optimal bed capacity required in hospital inpatient units will be presented in the literature review section.

2.4. Literature Review

In this section we explore all the literature related to hospital bed capacity optimization, OB unit capacity optimization, estimating patient volume in case of a consolidation and use of multi-criteria decision making tool AHP in healthcare.

2.4.1. Hospital Bed Capacity Optimization

Nguyen, J. M., et al developed a simple method to estimate the required bed capacity considering the following parameters: number of transfers due to lack of space, number of days with no possibility for $S$ (unscheduled admissions) and number of days with at least a threshold of $U$ (unoccupied beds).[20] E. Akcali et al uses a network flow model to find the optimal bed requirements while accounting for constraints like...
maximum allowed wait time and budget. [21] A. Kokangul uses a combination of simulation model and nonlinear mathematical models to optimize bed capacity. [22] Y. Tütüncü et al uses integer programming model, queuing theory and an algorithm to estimate the required bed capacity using both monthly patient volumes and projections throughout the year. [23] Various mathematical models have been developed and used to estimate the required bed capacity. [24, 25] Simply matching capacity to demand may be insufficient. Certain amount of “excess” capacity, or slack, is required to allow for the appropriate achievement of reasonable wait time benchmarks. [26] Ratio methods have been used to determine the required bed capacity. [28-30]

L. V. Green develops some modifications and extensions to use queuing theory in healthcare. [31] Queuing theory has been widely used to estimate bed capacity required for hospitals. [32-36] It has also been widely used to find bottleneck stations, solve staffing concerns, etc. in healthcare. [37-45]

Simulation modelling is a powerful tool used to simulate any real-time business process before actually building and implementing the process. It enables identification of bottlenecks and assesses the performance factors like waiting times, number in systems etc. Lowery, Julie C. presents basic guiding steps to build a simulation model in a healthcare setting. [46] Computer simulation modelling has been used in healthcare for decades. Extensive research has been done on using computer simulation in healthcare. Simulation modelling is a powerful method for modelling both small and large populations to inform policy makers in the provision of health care. It has been applied to a wide variety of health care problems. [47] T. Eldabi et al have published research on the future of computer simulation modelling in healthcare. [48] Discrete event simulation
has become a popular and effective decision making tool for optimal allocation of scarce healthcare resources and improved patient flow. [49] Simulation modelling has been widely used in healthcare to solve numerous logistic issues. [50-62] Queueing theory is capable of calculating system performance and factors like time in queue, number in the system etc. The complexity in using queueing theory increases with the complexity of the system. In addition to that, a computer simulation program provides many additional features making it easy to embed complex conditions into the model. S. G. Elkhuizen et al use simulation in their research to account for demand variation. [60] P. T. VanBerkel et al used a simulation model to estimate the number of beds required in a general surgery division. After building the model, a bottleneck was identified and redistribution of available beds was done to address the issue. [63] A. Bagust uses simulation approach to determine how care for critical patients may be delayed on the days when the emergency department experiences a surge of volume. [64] T. R. Rohleder uses simulation to solve the issues of waiting time at an outpatient orthopedic clinic. The authors state that building a simulation model provided insights into improvement opportunities. The model has assisted the researchers in optimization and scheduling of staffing thus solving the concern. [65] M. B. Dumas, in his research to find the optimal bed reallocation based on occupancy by bed type and sex, uses computer simulation modelling. [66] J.K. Cochran et al used queueing network and discrete event simulation modelling to balance beds in an Obstetric hospital. Goals of the research are to minimize bed blocking and to redistribute resources so that the utilization of all the resources is optimal. [67] Z. Zhu et al developed a simulation model to determine the number of ICU beds required. [68] In order to increase the occupancy of the OB unit, some hospitals accommodate non-
obstetric patients in the unit. There are many restrictions due to laws enforced by state. J. O. McClain analyzes the effects of accommodation following the regulations and also predicts the volume of non-obstetric patients that can use the unit using simulation model. [69] F. Dexter uses statistical methods to determine the optimal staffing for an OB unit using daily census data. [70] H. Takagi et al analyzed patient flow in the OB unit and proposed a network flow model to study the system and the authors also state that, the proposed model can be used to estimate required number of beds in the unit. [71] C. Pehlivan et al use queueing theory in determining bed capacity required for maternity facility. This research considers multiple service providers in the area while estimating the bed capacity. [72]

Simulation modelling has been used to solve many issues in healthcare. To study the OB unit, a detailed analysis of patient flows within the system need to be assessed. Arrival rate has to be more accurate rather than saying it is Poisson, Exponential etc. Length of stay depends on the type of patient. Building probability distributions for length of stay by patient type is necessary to increase the accuracy of modelling the system. Multiple conditions have to be built into the system. For example, no patients are discharged during 3rd shift. Thus, if any patient’s length of stay ends during such hours, the discharge is either advanced or delayed based on remainder of the patient length of stay at the start of 3rd shift. These conditions are relatively easy to embed into a simulation model compared to any other statistical methods.

2.5. Analytical Hierarchy Process
AHP is a multi-criteria decision making tool which can use both qualitative and quantitative factors to find the best option. This method simplifies the complications associated with choosing the best alternative from available options. The process starts with defining the objective followed by listing out the decision criteria. Decision criteria means, the important factors under consideration while opting to choose the alternative. At this point, the criteria have to be ranked against each other in a tabular form shown below. 1 being neutral, and 9 being strongly preferred.

Table 1: Attribute prioritization matrix

<table>
<thead>
<tr>
<th></th>
<th>Attribute 1</th>
<th>Attribute 2</th>
<th>Attribute 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Attribute 1</td>
<td>1</td>
<td>3</td>
<td>1/9</td>
</tr>
<tr>
<td>Attribute 2</td>
<td>1/3</td>
<td>1</td>
<td>6</td>
</tr>
<tr>
<td>Attribute 3</td>
<td>9</td>
<td>1/6</td>
<td>1</td>
</tr>
</tbody>
</table>

A number greater than 1 indicates that the alternative in the row is preferred over the alternative in the column. The columns are normalized by its sum followed by averaging the rows. For the above example, we end up with numbers as such:

Table 2: Attribute priority or ranks

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Attribute 1</td>
<td>0.277</td>
</tr>
<tr>
<td>Attribute 2</td>
<td>0.372</td>
</tr>
<tr>
<td>Attribute 3</td>
<td>0.35</td>
</tr>
</tbody>
</table>
Let us consider that we have three alternative choices. The alternatives will be ranked for their performance separately in all three attributes under consideration. This is followed by normalization of columns by its sum and averaging the rows for all tables. The following three tables portray an example.

Table 3: Alternative ranking for Attribute 1

<table>
<thead>
<tr>
<th>Attribute 1</th>
<th>Alternative 1</th>
<th>Alternative 2</th>
<th>Alternative 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alternative 1</td>
<td>1</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>Alternative 2</td>
<td>1/2</td>
<td>1</td>
<td>1/7</td>
</tr>
<tr>
<td>Alternative 3</td>
<td>1/8</td>
<td>7</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 4: Alternative ranking for Attribute 2

<table>
<thead>
<tr>
<th>Attribute 2</th>
<th>Alternative 1</th>
<th>Alternative 2</th>
<th>Alternative 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alternative 1</td>
<td>1</td>
<td>3</td>
<td>1/4</td>
</tr>
<tr>
<td>Alternative 2</td>
<td>1/3</td>
<td>1</td>
<td>1/7</td>
</tr>
<tr>
<td>Alternative 3</td>
<td>4</td>
<td>7</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 5: Alternative ranking for Attribute 3

<table>
<thead>
<tr>
<th>Attribute 3</th>
<th>Alternative 1</th>
<th>Alternative 2</th>
<th>Alternative 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alternative 1</td>
<td>1</td>
<td>9</td>
<td>1/4</td>
</tr>
<tr>
<td>Alternative 2</td>
<td>1/9</td>
<td>1</td>
<td>1/3</td>
</tr>
<tr>
<td>Alternative 3</td>
<td>4</td>
<td>3</td>
<td>1</td>
</tr>
</tbody>
</table>
The scores for the alternatives are:

Table 6: Priority scores of Alternatives for Attributes

<table>
<thead>
<tr>
<th></th>
<th>Attribute 1</th>
<th>Attribute 2</th>
<th>Attribute 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alternative 1</td>
<td>0.57</td>
<td>0.213</td>
<td>0.348</td>
</tr>
<tr>
<td>Alternative 2</td>
<td>0.1448</td>
<td>0.2564</td>
<td>0.1023</td>
</tr>
<tr>
<td>Alternative 3</td>
<td>0.321</td>
<td>0.7013</td>
<td>0.548</td>
</tr>
</tbody>
</table>

Table 6 will be multiplied by Table 2 to get the final AHP rankings. The results are shown below in table 7.

Table 7: Final priority or ranking

<table>
<thead>
<tr>
<th></th>
<th>Alternative 1</th>
<th>Alternative 2</th>
<th>Alternative 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.36</td>
<td>0.17</td>
<td>0.54</td>
</tr>
</tbody>
</table>

Arranging them in descending order, the conclusion would be, alternative 3 is better than alternative 1 followed by alternative 2.

AHP has been used in many areas of research. [73-78] R. Baltussen et al state the importance and need of multi-criteria decision making tools in healthcare decision making. [79] AHP has been proposed to be used and has been used to make healthcare decisions. [80-86] AHP is a reliable method and accurately considers all the elements while making a decision. Accuracy of results depends on the understanding of ranking system by the management. This process simplifies the variables involved in decision making.
There was no research found where simulation is used to analyze and optimize the capacity of an inpatient unit with various patient types that have different flows within the unit. No analysis studying the consolidation scenario was found in the research. In the US, many hospital mergers have been happening. Sometimes, the facilities are consolidated or shut down due to various reasons. If a facility shuts down, other facilities in the neighborhood will receive more patients where there is a requirement of expansion. In smaller markets, there may only be two to three facilities in the area. If one of them is shut down, the remaining hospitals will experience a significant spike in patient volume. In this research, analysis has been done on the estimated patient volume if a facility in the area is shut down followed by estimating the capacity required to accommodate such additional patient volume.

This research also explores the complexity associated with decision making on facility consolidation involving multiple attributes and alternatives. AHP is used to solve such perplexing task of decision making by using robust systems engineering tool.
CHAPTER III

METHODOLOGY

Determining the optimal resources required to operate an inpatient facility is challenging. Demand for the facility on a certain day is almost impossible to determine. Enormous variation in the utilization of the available capacity makes the task difficult. There is a requirement to determine a capacity where all the patients that arrive at the facility are accommodated. As the number of beds increases, the utilization decreases. Though patient access increases, costs associated with the maintenance of additional resources is high. The point where the cost of operating the next unit of resource is high compared to its utilization, that additional resource does not justify costs associated with its maintenance. To optimize the resources available, the management has to make a decision on the acceptable level of service. In this case, the service level is measured as the average waiting time. Waiting time is the difference between the time when the bed is required to the time it is provided to the patient. The services are partially scheduled. In many cases facilities experience surge in volume of unscheduled patients. In that scenario, maximum occupancy of the facility is reached. At this point, the incoming volume needs to be either rerouted, or requested to wait at home. The patients waiting will be called back as soon as the next room becomes available. If multiple patients are waiting, priority will be given based on patient condition. Not all patients can be asked to wait at their residence until the facility is able to provide accommodation. If the patient
condition is critical and needs immediate attention, the staff either tries to make room for that patient or redirects the patient to the next location. As there are two facilities available, and the distance between them is a 20 minute drive, the transportation would not be an issue.

Data plays an important role in this research. Collecting adequate and accurate data is paramount. Prior to data collection, requirements have to be established on what statistics are required for research. To build an accurate simulation model, each detail within the process has to be captured. Process maps have been put together to capture the patient flow and understand resource utilization as various types of patients use different resources for statistically variable amount of time.

3.1. Process Observation and Mapping

To understand process and flow of patients through the OB unit, 80 hours of process observation has been done at both facilities. In that time, we tracked the movement of different types of patients within the unit. The OB unit is not associated with any other inpatient unit in the hospital. There is no patient flow into or out of this facility to any other inpatient facilities. Frontline staffs on the floor were surveyed about the processes in the unit. Multiple insights were captured from different people.

At this point, process maps were built capturing the flow of patients in the unit. These process maps were evaluated by nurse managers at both locations (L1 & L2) to make sure all the steps were captured. Figure 3 shows the basic process map capturing all the important steps involved that are related to patient flow.
A patient can walk in, come in from Emergency Room (ER), Physicians office or at their scheduled appointment time. Once the patients arrive to the unit, if the person belongs to either scheduled induction or C-Section, they are provided with a delivery room. If the patient does not belong to previously mentioned categories, and about to deliver, she is moved to a delivery room. One final category is, where patients come in because they feel that they are about to be in labor or the patients that experience various pregnancy related complications. These patients are monitored by the nurse, seen by the physician and put under observation. If any of those observation patients are about to go into labor, they will be moved to delivery room. The rest of the patients will be treated and discharged. A quick registration will be done for all patients as soon as they enter the unit. Additional documentation for triaged patients will be done after they are moved to triage. For patients in labor or C-Section, it will be done earliest of patient’s convenience.

After child birth, the patients are moved to a recovery room or stay in the same room based on how the facility is setup. Location 1 has Labor, delivery (LD) and Postpartum/Recovery setup and Location 2 has Labor, delivery and Postpartum (LDRP) setup. In LD and Postpartum setup, room where the patient delivers the baby and the room where the patient stays after the baby is born are different. In LDRP setup, the patient is not moved after delivery. This will be explained in more detail later in the chapter.
**Process map - Obstetrics**

- **Patient Walk-in**
- **Patient from ER**
- **Appointment Scheduled Induction C-Section**
- **Doctors Office**

**Figure 3: OB Process map**

**Process Map - GYN Patient**

- **GYN patient has surgery**
- **Patient transferred from PACU**
- **GYN patient admitted**
- **Admit patient to inpatient floor**

**Figure 4: GYN patient process map**
Figure 4 describes the process map for the Gynecology (GYN) patients. Surgery for GYN patients can happen in the OR room within the OB unit or in the OR located on the surgical floor. After surgery, the patients are transferred to Post Anesthetic Care Unit (PACU) for a few hours. After the patient recovers from anesthesia, they will be transferred to one of the recovery rooms in the OB unit. The terms AP room, LD room etc. in the process map will be explained in detail later in the chapter. GYN patients can either be accommodated in OB unit or other Inpatient units in the hospital based on bed availability in the OB unit. GYN patients are usually discharged the same day of surgery.

3.2. Data Collection

Statistically significant amount of data has to be collected and analyzed. Poor and or insufficient data can result in misleading interpretation of the operation of the system.

3.2.1. Electronic Data

Three years worth of electronic data has been acquired from the hospital management. The following table explains the information available in the obtained electronic data.

Table 8: Electronic data of patients

<table>
<thead>
<tr>
<th>Column Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pt. Name</td>
<td>Patient name.</td>
</tr>
<tr>
<td>Med Rec #</td>
<td>Medical Record number. This is unique for each patient even if their name changes. This allows us to differentiate patients.</td>
</tr>
<tr>
<td>AR# patient</td>
<td>Accounts receivable number. This is unique for every visit to the hospital. AR# and Med Rec # together allow us to find repeated patient visits, and distinguish each visit.</td>
</tr>
<tr>
<td>Adm Date</td>
<td>Admit Date of patient to the unit.</td>
</tr>
<tr>
<td>Field</td>
<td>Description</td>
</tr>
<tr>
<td>------------------</td>
<td>-----------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Disch Date</td>
<td>Discharge date of patient from the facility.</td>
</tr>
<tr>
<td>LOS</td>
<td>Patient length of stay in days (Integer).</td>
</tr>
<tr>
<td>Pt Type</td>
<td>Patient Type. This helps in determining if the patient has been inpatient or outpatient with or without surgery.</td>
</tr>
<tr>
<td>DRG</td>
<td>Diagnosis related group. This explains patient diagnosis.</td>
</tr>
<tr>
<td>ICD-9</td>
<td>Stands for International Classification of Diseases and Related Health Problems. ICD 9 and DRG codes have been used in patient classification.</td>
</tr>
</tbody>
</table>

The file also contains other information like attending physician, attending physician group, surgeon etc. This information is not relevant to the research. Thus, the additional information has been ignored.

3.2.2. Data from Log Sheets

There is some required data missing in the electronic data, for example arrival, discharge times, and in case of LD and Recovery setup, time when the patient has been moved from LD to recovery. These statics are necessary while analyzing the system performance. In order to capture that data, patient log sheets from both locations have been collected. 6 months’ worth of data from the log sheets was put into an excel spreadsheet, followed by cross referencing the information in from log sheets to electronic data using medical record number in coordination with date of arrival. Log sheets are a paper document used by OB unit staff to capture various patient information. A patient may come in for different reasons within the time frame in the log sheets. So, both date of arrival and medical record number were used to match the patient information. It is of rare occurrence that a patient visits the OB unit more than once on
the same day. This has happened seldom in the data of our interest. In such cases, more information from both data sources has been matched to capture the statistics accurately.

Table 9 describes the data captured in the log sheets. These log sheets are called Patient Activity Records.

Table 9: Patient log sheets

<table>
<thead>
<tr>
<th>Column Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pt. Name</td>
<td>Patient’s Name.</td>
</tr>
<tr>
<td>Med Rec#</td>
<td>Patient medical record number</td>
</tr>
<tr>
<td>Admit Dx.</td>
<td>Defines why the patient is there (Ex: induction, C-Section etc.).</td>
</tr>
<tr>
<td>Nurse</td>
<td>Nurse assigned to the patient.</td>
</tr>
<tr>
<td>Birth Suite</td>
<td>Suite or room assigned to patient.</td>
</tr>
<tr>
<td>Time in</td>
<td>Arrival time of patient to the facility.</td>
</tr>
<tr>
<td>Time D/C home</td>
<td>Patient discharge time.</td>
</tr>
<tr>
<td>Delivery time, Sex</td>
<td>Time at which the baby was born and gender of the baby.</td>
</tr>
<tr>
<td>Transfers, Complications setup, complications.</td>
<td>In case of Labor delivery (LD) and Postpartum (PP) Patient is transferred to a PP room after delivery. This captures that information in addition to any complications.</td>
</tr>
</tbody>
</table>

These patient activity log sheets provide more in-depth information about patient flow. Comprehensive statistical analysis on patient arrival, discharge patterns, length of stay (LOS) etc. will be presented later in the chapter. The information about when the patient is being transferred from LD to postpartum room is missing in these sheets. From the observations made and after speaking with staff on the floor, we captured the information on how long after the patient delivery time will the patient be transferred to
postpartum room. This data is used to address the missing information from the available data.

3.3. Data Analysis

Vast amount of data is collected in hospital systems. A detailed data analysis reveals every minute detail in regards to the current operating conditions of the system. It provides an ample knowledge about the system performance and previous assumptions will now be backed by data.

3.3.1 Patient Classification

The raw data obtained from the hospital had Diagnosis Related Group (DRG) codes and International Classification of Diseases (ICD). Using DRG and ICD 9 codes, patient classification has been done. Patients have been classified into four categories namely, OB Outpatients, Regular Delivery, C-Section and GYN patients. OB Outpatients are the patients that come in due to complications during delivery. These patients get treated and discharged within 24 hours, thus the name Outpatients. Regular delivery patients do not require a surgery during childbirth. Significant number of regular deliveries are scheduled inductions. C-Section patients go through a scheduled surgery during childbirth. GYN patients are placed in the unit for recovery after surgery.

3.3.2 Available Resources and Utilization

As previously stated, this research is being done on two OB units located approximately 17 miles apart. Basically an OB unit can be setup in two different ways namely, LDRP and LD and Postpartum (PP). In this research, L1 has LD and PP setup and Facility L2 has an LDRP setup. LDRP is a comparatively newer model to that of LD
and PP. It was designed with the idea that patient has to never move from their room, which is supposed to help in the betterment of patient experience and also be more efficient. During this research, many staff members on the floor were surveyed which kind of design they like better; LDRP or LD and PP. Staff working in an LDRP set up think that LDRP is better than LD and PP. Crew from LD and PP argue that LD and PP setup is better than LDRP.

3.3.2.1. Location 1

This facility has a LD and PP model. The kinds of rooms available in this facility are

1. Labor and Delivery (LD) Rooms
2. Postpartum (PP) Rooms
3. Operating Rooms (OR)

Any non GYN patient that walks into the unit will first be given a LD room. The types of patients include OB outpatients, regular delivery patients, C-Section patients and false labor. False labor patients are later categorized to be an internal part of OB outpatients. Operating rooms are used by C-Section patients. GYN patients only use PP rooms in the facility. After delivery, patients in LD room are moved to PP rooms for recovery. After safe recovery, patients are discharged home.

3.3.2.2. Location 2

This unit has an LDRP model. In this facility there is less movement of patients compared to that of LD and PP model. In LD and PP model, every patient is moved to a recovery room after delivery. But in LDRP model, patients recover in the same room that
they deliver which results in less patient movement. The types of resources available in this facility are:

1. Labor, delivery and postpartum rooms
2. Operating rooms
3. Antepartum (AP) rooms
4. Triage rooms

LDRP rooms are used by delivery patients and also by GYN patients. Basically, GYN patients are placed in AP rooms. If all the available AP rooms are occupied, GYN patient is given an LDRP room. For a GYN patient to be placed in LDRP bed, the delivery patient volume seen should be low and there should be at least 2 LDRP rooms open with no patients scheduled to come-in for the next 4 hours. If the facility is full of OB patients, GYN patients will be redirected to inpatient units. In case the unit has all its LDRP beds occupied and still expecting patients to walk in, the staff transfers patients in recovery to AP rooms to make space for more patients. When a patient walks in, if it is obvious that the patient is going to deliver a baby or a patient is scheduled for delivery, the patients are given a LDRP room. In any other case, an OB patient is first placed in triage. In case all the LDRP rooms are occupied, patients are boarded in the triage until the next bed is made available. The operating rooms are used by C-Section patients.

3.3.3. Patient arrival and Discharge patterns

Methods like queuing theory uses arrival rates like poison, deterministic, Erlang etc. Capturing arrival rate into the system accurately is important in building a simulation model. Errors in data collection or analysis, compromises the robustness of the model. The arrival process has a pattern which include seasonal, weekly, and hourly. In this
scenario, few months in a year had higher volume of patients than the rest. But no specific seasonal trends were observed.

3.3.3.1. Arrival Pattern

The following figures show the analysis by day of week done in JMP.

![Figure 5: Arrival rate of OB outpatients by day of week to L1](image)

![Figure 6: Arrival rate of OB outpatients by day of week to L2](image)
Figure 5 and Figure 6 represent the arrival rate of OB Outpatients by day of the week for L1 and L2 consecutively. The average arrival rate for L1 is slightly higher than 1 and L2 has an average arrival rate of 2. No significant difference in arrival rate between the days of the week has been found.

Figure 7 shows the arrival rate of OB Outpatients by hour of the day. The arrival rate by hour has been assumed to be similar for both locations. Each bar represents the percentage of patients arriving for the next two hours from the time specified below the bar in the graph.
Figure 8 and Figure 9 represent the arrival rates of Regular delivery patients by day of the week for L1 and L2 consecutively. Though there is variation between arrival rates on some days of week greater than others, no significant difference between the arrival rates has been found between days of weeks from the data.
Figure 10: Arrival rate of regular delivery patients by hour at both L1 and L2

Figure 10 displays the hourly arrival rate for Regular delivery patients at both locations. Highest arrival rate is between 8 AM to 10 AM.

Figure 11: Arrival rate of C-section patients by day of week at L1

Figure 11 shows the arrival rate for C-Section patients by day of the week at L1. Significant difference in arrival rate was found in different days of the week. So, the days of the week with similar arrival rate have been grouped together and more analysis has
been done on the arrival rate. Saturday and Sunday were grouped together followed by Friday as a separate group and finally the rest of days of week were grouped together.

Figure 12: Further analysis on arrival rate of C-section patients to L1

Figures 12 depicts the analysis done on different days of the weeks grouped together for arrival rates at L1. The figures also display various statistical elements of the analysis. The initials of days of week grouped together can be found on x-axis. In this picture, the order is Friday being the first group followed by Monday, Tuesday, Wednesday, Thursday and finally the third group is Saturday and Sunday. The graphs pictured are to be referred from right to left followed by top to bottom.
Figure 13: Arrival rate for C-section patients by day of week at L2

Figure 13 represents the arrival rate by day of the week for C-Section patients at L2. As the arrival rate between different days of the week is not statistically similar, the days in the week with similar arrival rate have been grouped together and analyzed. Saturday and Sunday had slightly lower arrival rate and Tuesday and Thursday had slightly higher arrival rate compared to the other days of week. Days with statistically similar arrival rate have been grouped together for further analysis. Saturday and Sunday were grouped together for further analysis followed by Tuesday and Thursday and finally the rest of the days in the week.
Figure 14: Further analysis on arrival rate of C-section patients to L2

Figure 14 is set of the box plots for Monday, Wednesday and Friday followed by Saturday and Sunday and lastly Tuesday and Thursday consecutively. The graphs pictured are to be referred from right to left followed by top to bottom.
Figure 15: Arrival rate of C-section Patients by hour of day at L1 & L2

Figure 15 shows the arrival rate by hour of day for C-Section patients to both L1 and L2. The incoming volume is high from 6 AM to 12 PM and stays low for rest of the day.

Figure 16: Arrival rate of GYN patients by day of week at L1

Figure 16 shows the arrival rate of GYN patients by day of the week Saturday, Sunday and Monday have similar arrival rate which is also lowest of the other days that
have been grouped together and analyzed further. Wednesday and Friday have seen the highest arrival rate followed by Tuesday and Thursday.

Figure 17: Detailed analysis on arrival rate by day of week to L1

Figure 17 displays further statistics of the groups Saturday, Sunday, and Monday followed by Tuesday, Thursday and lastly Friday and Wednesday consecutively. From Tuesday through Friday, the unit experiences significantly higher volumes due to OR schedules.
Figure 18: Arrival rate of GYN patients by day of week to L2

Figure 18 depicts the box plot for the arrival rate of GYN patients by day of the week at L2. Tuesday and Thursday have been seeing significantly high patient volume compared to the other days of the week due to scheduling in OR.

Figure 19: Further analysis on arrival rate by day of week of GYN patients at L2
Arrival data is divided into 3 groups and analyzed further as shown in figure 19 which have Monday, Wednesday and Friday grouped together followed by Saturday, Sunday and finally Tuesday and Thursday. Length of stay for GYN patients is usually few hours. These patients are mostly discharged the same day.

Figure 20: Arrival rate by hour of day for GYN patients at L1 & L2

Figure 20 depicts the arrival rate of GYN patients to both facilities. Most of the patients arrive between 6 AM and 6 PM. This is due to the OR schedule.

3.3.3.2. Discharge Pattern

OB Outpatients will always spend the regular length of stay and get discharged. In general none of the delivery patients will be discharged during late evening hours. In this research it has been assumed that no patients will be discharged between 6 PM and 8 AM.
3.4 Analytic Hierarchy Process (AHP)

In order to explore and evaluate the consolidation scenario, various decision criteria need to be considered. Numerous performance factors have been considered in this study. It is vital to consider all the factors that influence the overall performance. The hospital management have shortlisted all the important elements in restructuring the facilities. After the decision criteria have been decided, the quantitative and qualitative data has to be obtained. Different methods have to be used to obtain such data. After acquiring all the data of decision criteria, AHP is used to find the best possible alternative that satisfies all the requirements. After careful review, the management finalized the decision criteria as such:

1) Projected payments after consolidation
2) Service level
3) Cost of construction
4) Care model (LDRP vs LD & Recovery)

3.4.1 Projected payments after consolidation

Estimation of revenue generated after consolidation requires a lot of ground work. First step in the process will be to estimate the patient volume at both facilities if consolidated followed by analyzing the payer mix. Given the operating costs of the unit are steep and continue to escalate every year, ensuring the facility generates sufficient revenue is of greatest importance. The first step in the process is to estimate the average payments for areas from which patients come in to the unit by zip code, from the historic data. It is followed by estimating patient volume for future based on the historical trends by zip code. Multiplying the average payments with projected patient volumes will give
us the revenue generated in the best case scenario. Best case scenario is assuming if one of the locations is closed, all patients that would go to that facility if it was open, will go to the new consolidated location. Which means, after consolidation, the hospital will retrieve 100% patient volume. Planning for the best case scenario is not optimal, as the assumption may be unrealistic. In this research, we develop a worst case scenario and a middle case scenario, where we project the lowest patient volumes the consolidated facility will experience considering various factors. Capacity needed if moved to either location has been estimated followed by estimation of capacity for various other scenarios. A 3’×4’ sheet containing results of the capacity required at different patient volumes. A total of 370 different scenarios were simulated and results have been presented in the charts for both locations combined.

3.4.1.1 Payer mix

Charges v/s payments received have been analyzed for each zip code. Some insurance companies reimburse more than others. For example, Medicare and Medicaid have lower reimbursement rate compared to many other private insurance. Average payer mix for every zip code has been calculated.

Figure 21 represents the percentage reimbursement by different insurance companies which are named A1, A2 so on. The graph covers the overall data from 2009 to 2013 for insurance reimbursement.

Figure 22 illustrates the charges vs payments by insurance groups for 244 patients from one zip code area. Depending on the type of insurance the patient has, the payment to the hospital varies.
3.4.1.2 Patient Volume Projections

Three different scenarios have been considered in patient volume projections. Those are best case scenario, intermediate scenario and worst case scenario. To project the patient volume for the future in the best case scenario, statistical software has been
used. The patient volume projections have been done by zip code. A linear time series model was used in estimating the patient volume.

Figure 23 illustrates the patient volume projections of which 2010 to 2012 is the historical data, followed by projected patient volumes until 2017. These volume projections are in case of the best case scenario. Projected revenue generated from 2013 to 2017 is also presented in the graph.

3.4.1.2.1 Intermediate Scenario

In this scenario, three factors that affect patient’s choice have been considered. The first factor is repeating patients. If a patient has been to the facility for the previous delivery, that patient will come back to the same hospital system in the future, if she is in need of OB services, which is called patient loyalty factor. One element that lowers the loyalty factor is if the patients OB physician moves to another hospital but the doctor’s office stays in close proximity, the patient may go back to the same physician and also go
to a different hospital system if the physician suggests. From the historical data, on an average, 30% of patients have been to the facility in past for their previous delivery. Assumption in this scenario is for instance if facility L1 is shut down and L2 has been chosen as a consolidation site, L2 will continue pulling all the patient volume that it used to before consolidation and in addition to that, 30% of volume of patients projected for L1 in best case scenario will go to L2. The rest 70% of patient volume will choose their preferred OB unit based on the distance from their home to the facility. Probability of choice is inversely proportional to the distance. Reputation and capacity of the hospital also affects patient’s choice. This element is also embedded into the calculations. Reputation and capacity factor of the hospital is directly proportional to the patient volume it captures. Distance from the patient’s residence to the hospital has been calculated in two ways which are driving time and driving distance. Based on the connectivity of the hospital to freeways, the driving time varies. Not much difference has been found in patient volumes estimated between driving time method and driving distance. Fastest driving time and shortest driving distance from each zip code from where the either facilities have had patients from, were gathered from google maps.

Thus the formula for calculating estimated patient volume is as such: Projected patient volume of the facility to which the services are being consolidated + 30% of projected patient volume of the location that will be shut down + $\sum((0.7\times\text{expected patient volume from each zip code}) \times (\text{expected patient volume moving to the consolidated location using distance method}))$

To calculate the percentage of volume that will choose to go to the existing location we use quality adjusted weight for all the hospitals that are in 25 mile radius to
that zip code area, expected patient volume to the unit that will no longer provide services after consolidation, and shortest driving distance or fastest driving time.

The formula for % of patients from a certain zip code area choosing any new facility in the area as is as such:

\[ P_s = \frac{\left( \frac{1}{\text{Driving time to location}} \right) \times \text{quality adjusted weight of that facility}}{\sum \left( \frac{1}{\text{Driving time to all other hospitals in that area}} \times \text{quality adjusted weights} \right)} \]

Example:

For zip code 12345, let us say that there are 3 other competitive hospitals within the 25 mile radius to that zip code. Current projections are 109 patients go to L1 and 109 patients go to L2 from that zip code area. Both locations get equal patient volume from that area. If say L1 is closed, the amount of patient volume that would choose L2, who, if not closed, would have chosen to go to L1, is determined as such.

\[ P_s = \frac{\left( \frac{1}{6.7} \right) \times 1}{\left( \frac{1}{6.7} \right) + \left( \frac{1}{16.3} \times 0.9 \right) + \left( \frac{1}{16.5} \times 1.1 \right) + \left( \frac{1}{22.9} \times 1.1 \right) } = 0.465 \]

Highlighted numbers in the above formula are the quality adjusted weight for hospitals.

The table below shows the driving distance in miles and probability for a patient to choose that hospital. C1, C2 and C3 represent the competitor hospitals in the area.
Table 10: Probability of patient choosing a hospital

<table>
<thead>
<tr>
<th>Hospital</th>
<th>Shortest driving distance in Miles</th>
<th>Probability of choice</th>
</tr>
</thead>
<tbody>
<tr>
<td>L2</td>
<td>6.7</td>
<td>0.465</td>
</tr>
<tr>
<td>C1</td>
<td>16.3</td>
<td>0.17</td>
</tr>
<tr>
<td>C2</td>
<td>16.5</td>
<td>0.21</td>
</tr>
<tr>
<td>C3</td>
<td>22.9</td>
<td>0.15</td>
</tr>
</tbody>
</table>

C1 is closer than C2 according to driving distance. But the quality adjusted weight has increased the probability of patient’s choice for C2.

So the total patient volume choosing L2 from that zip code area is:

\[109 \text{ (Projected to go to L2)} + (0.3 \times 109) + (0.465 \times 0.7 \times 109) = 177\]

This means the new location will have 177 patients from that zip code area according to shortest driving distance method will choose to go to L2 in the intermediate scenario.

The following graphs present the projected patient volume in the intermediate scenario based on driving distance method followed by driving time method. Patient volume is plotted in reference to the primary axis and projected payments for every year are plotted in reference to the secondary axis.
Figure 24: Patient volume and payment projections in intermediate scenario driving distance method

Both driving distance and time methods project similar volumes. Driving distance method estimates slightly higher volume compared to driving time method. In driving time method, L1 and L2 retain 73.8% and 79.2% of the patient volume from best case scenario consecutively. According to driving time method, L1 and L2 retain 72.8% and 79.8% of patient volume from best case scenario.
3.4.1.2.2 Worst case scenario

In this scenario the patient loyalty factor is eliminated from the volume projections. For instance, if L2 is closed, the patients that would have chosen to go to L2 will now solely base their choice of facility on the driving distance or driving time. So for the same zip code area mentioned above, in the worst case scenario, the following equation shows how the patient volume from every zip code to L1 is calculated:

Projected volume to L1 from that zip code+ (Ps × Projected volume that go to L1)

The calculation is made for every zip code and the results are summed up to get the total projected volume. The following graphs represent the projected patient volumes in worst case scenario.
Figure 26: Patient volume and payment projections in worst case scenario driving time method

Figure 27: Patient volume and payment projections in worst case scenario driving distance method
3.4.2 Service level

Average waiting time is intern used as service level. Since there is a high variation in the incoming patient volume, most patients do not wait for a bed.

Figure 28: Frequency of arrival for delivery patients per day at L1 & L2

Figure 28 shows the number of delivery patients (Regular delivery and C-section) experienced by both locations together on a day for the past 3 years. 73% of times they have 6 or less delivery patients. At times, after having very small patient volume, the units will have high patient volumes which lead to a comparatively smoother flow. Small percentages of patients wait for a room. There is always a tradeoff between acceptable wait times and cost of adding additional resources. Three different average wait time scenarios have been considered in AHP. 5, 15 and 30 minutes as average wait times of patients.
3.4.3 Cost of Construction/Renovation

Renovation is very expensive in healthcare considering the cost of building equipped rooms. Thus choosing the location that has lowest renovation cost is vital. The procedure is to simulate different scenarios and find the bed requirements at average waiting times of 5, 15 and 30 minutes at a patient volume picked by the management. After this is calculated, the quantitative data will be plugged into AHP.

3.4.4 Care Model

LDRP model is a newer model in which patient does not have to be transferred into a postpartum bed after delivery. In LD and postpartum setup, the patients will be moved to a postpartum bed after delivery. There are advantages and disadvantages in both care models. In LDRP setup, some people feel that there is no flow of patients. LD and postpartum (PP) model face bottleneck issues and some argue that patients do not like to be transferred after the delivery. Physicians and nurses at both locations have been interviewed to find out which care model is preferred by them and their patients. Staff at both locations preferred the care model they work in as a better choice. The hospital management has provided the qualitative ranking for this factor.

Using the data analyzed in this chapter and the results from the AHP, simulation models are built and multiple scenarios were simulated and results were captured. Detailed analysis on how the simulation models have been built is explained in the following chapter.
CHAPTER IV

SIMULATION MODELLING

Simulation modelling provides an opportunity to build and visualize multiple scenarios before making a decision. Building a simulation model needs robust data, the right conditions in routing the patient flow and expertise in using simulation software. The software makers are working on making the interface more user-friendly.

To build a basic simulation model the only requirements are to know arrival rate, processing time and capacity of server. The real-time operation of the OB unit is much more complex compared to a simple simulation model. From the available data, the arrival rate for different patients to both units has been calculated. The average arrival rate by day of the week is split into hourly arrival rate for every day of the week and has been fed into the model. Average arrival by day is split into 24 parts using the hourly arrival data. Adding up the arrival rates for an entire day will add up to the average arrival rate for that particular day of week. Variation in arrival rate will be created by the simulation model itself. If the number of entities created by the model per day is always equal to the average arrival of that day, this does not represent the actual scenario and these results are both worthless and misleading. Such an experiment is entirely flawed and does not satisfy the purposes of the research. To validate the variation in arrival rate created by the model, logic code has been embedded such that the number of entities created every day will be captured in an excel sheet along with the date. These numbers
have been compared to the actual historic data to make sure that the frequency of arrival generated by the model is similar to the actual arrival rate identified from the data.

Resources utilized by the patients will be associated to the patient type. The next step in the process will be writing the patient routing logic. Before writing the model logic, patient flow at both locations was studied and patient flow observations were made to comprehend the patient movement within the facility. Since the OB unit is an independent facility and not associated with any other inpatient unit, the patient flow is confined to the OB unit. This eliminates the complex job of embedding any other unit into the model to be able to study the operational statistics of the OB unit.

Patient length of stay depends on the patient type. After data analysis, the available data is exported to statistical software to generate a best possible statistical distribution with lowest square error. Since different patient types have used similar resources, the processing times have to be picked based on the patient type. These probability distributions are set at servers using some condition statements to make sure that each patient type is assigned with appropriate processing times.

After the recovery, patients depart the system. In case of delivery patients, due to some constraints, and requirement of signoffs from many specialists some restrictions have been placed on the time of their discharge. According the data provided, no patients have been discharged between 6 PM and 8 AM. If any delivery patient, due to the length of stay probability distributions assigned, is being discharged at such times by the model, a conditional statement has been assigned to prevent such occurrence.
4.1. Facility L1

This facility has LD and postpartum setup, which means more flow of patients compared to LDRP model. When a patient walks in, if the patient is either OB outpatient, or a delivery patient, she is routed to one of the LD rooms. If a GYN patient walks into the unit, she will be placed in a postpartum bed. OB outpatients are routed to leave the system directly from LD room and delivery patients will be routed to postpartum room and then leave the system after recovery.

Figure 29: Sources creating different entities

Figure 29 displays the arrival process of patients to the facility. The rectangular boxes before the patients are sources which create entities or patients according to the arrival process assigned. The blue square dots are called nodes and have many functions associated with routing, writing conditional statements and so on. The gray lines routing from the nodes are paths followed by patients or entities and the green lines are output
queues for source. Every element in this software possesses multiple functions which could be helpful in embedding complex conditions of real time into the model.

Figure 30 shows the entire layout of L1 which matches the actual layout in the facility with some minor exceptions of room size ratios, equipment, etc. The blue arrow marks in the picture represent the direction of flow on that individual path.

LD1 through LD6 represent the LD rooms, OR1 and OR2 depict the operating rooms and finally R1 through R17 present the postpartum or recovery rooms. Every room is connected with one path that routes the patients in and other that routs them out. These paths have been overlapped so that the model is unblemished for viewing purposes.

All OB outpatients and delivery patients walking in to the unit are routed to a node which leads the patients to one of the LD rooms. The following are the conditions specified at the node:
1) If a bed or server is available, the next patient in line will be sent in based on first in first out (FIFO) method.

2) List of servers are specified from which the node will pick one server to route the patients.

3) To capture the number of patients in the LD rooms, a logic has been written at this node which iterates and returns the value which is later exported to an excel file for viewing and analysis.

When a C-section patients walks in, the patient simultaneously occupies an LD room and operating room. At the input nodes of every LD room, a condition is specified which triggers when a patient enters the room. The condition is, if the patient entering the room is having a C-section, a duplicate entity is created and transferred to the input node of operating rooms, so that, the process in the model is similar to what actually happens. At the input node of OR, the entity will be transferred to one among the two available rooms or it is forced to wait until a room is available. After entering OR, the entity occupies the room according to specified length of time, which is decided by a probability distribution and then exits the system. The original entity occupies the LD room for a specified length of time according to the probability distribution and is then routed to postpartum room.

At the server, before the processing starts, a process is triggered which assigns the LOS to the entity based on the entity type. At this point for delivery patients, LOS probability distributions in days will be assigned followed by LOS in LD rooms. Later when the patient reaches the postpartum room, the LOS in LD room is subtracted from
the total LOS followed by adjustments being made to LOS to avoid any patient being discharged from 6 PM to 8 AM.

When a patient exits the LD area, a decrement function is triggered so that the statics for the number of patients present in the LD rooms every hour can be captured. After leaving the LD room, patients are directed to a node where the OB outpatients will be routed out of the system and delivery patients will be routed through a path to a node that directs the delivery patients to PP rooms. Both GYN and delivery patients wait at this node before they are directed to a PP room. If both Delivery patient and GYN patient are waiting for a bed, delivery patient will be given a bed even if the GYN entity has been waiting for longer duration. Priority values are assigned to all the entities and a condition has been used at the node such that, preference is given to delivery patients while assigning the rooms.

The input buffer for all the servers is set to zero so that the entities would not enter the processor and wait in the input buffer through the node while the server is still occupied. After the entity enters the processor, the length of stay in the PP room is assigned. Firstly, the LOS in PP room will be equal to total LOS – time spent in LD room. At this point, the discharge time is estimated based on the available parameters (LOS and current time). If the discharge time falls during the no discharge hours, the processing time is adjusted such that all the discharges happen during intended hours. After are recovered in the postpartum room, they are routed out of the system.
4.1.1. Model Validation (L1)

The simulation has been run for 365 days and 10 replication and the results were collected. The average waiting time of patients in this model was negligible proving the abundant and possibly excess capacity of the facility compared to the actual required capacity for the current patient volume. An inpatient unit like regular nursing floor does not have a high fluctuation of patient volume like the OB unit does. Due to the variation in the patient demands throughout the year, the utilization of this unit is significantly lower compared to the other inpatient units. Even in scenarios with lower available resources, the utilization is lower than normal. Thus considering utilization as a unique factor in allocation of resources is rather misleading. The goal of the management of the facility and this study is more patient centric. Minimizing patient wait times, while optimizing the resource level is motive of the simulation modelling. The following tables present the validation of simulation model.

Table 11: Simulation model validation for OB outpatients at L1

<table>
<thead>
<tr>
<th>Performance Metrics</th>
<th>Historical Data</th>
<th>Simulation Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of patients</td>
<td>512/542/378</td>
<td>497 - 537</td>
</tr>
<tr>
<td></td>
<td>10’/11’/12’ till Oct.</td>
<td></td>
</tr>
<tr>
<td>Average length of stay</td>
<td>N/A</td>
<td>3.8 to 4 hours</td>
</tr>
<tr>
<td>Maximum length of stay</td>
<td>2 to 3 days</td>
<td>2.8 to 3.2 days</td>
</tr>
<tr>
<td>Maximum number of patients waiting</td>
<td>N/A</td>
<td>1</td>
</tr>
<tr>
<td>Average patient waiting time</td>
<td>N/A</td>
<td>0</td>
</tr>
</tbody>
</table>
Table 12: Simulation model validation for regular delivery patients at L1

<table>
<thead>
<tr>
<th>Performance Metrics</th>
<th>Historical Data</th>
<th>Simulation Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of patients</td>
<td>685/660/491</td>
<td>657-696</td>
</tr>
<tr>
<td></td>
<td>10’/11’/12’ till Oct.</td>
<td></td>
</tr>
<tr>
<td>Average length of stay</td>
<td>2.4 days</td>
<td>2.6 days</td>
</tr>
<tr>
<td>Maximum length of stay</td>
<td>7 days</td>
<td>7.2 days</td>
</tr>
<tr>
<td>Maximum number of patients waiting</td>
<td>N/A</td>
<td>0</td>
</tr>
<tr>
<td>Average patient waiting time</td>
<td>N/A</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 13: Simulation model validation for regular delivery patients at L1

<table>
<thead>
<tr>
<th>Performance Metrics</th>
<th>Historical Data</th>
<th>Simulation Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of patients</td>
<td>259/286/187</td>
<td>258 - 282</td>
</tr>
<tr>
<td></td>
<td>10’/11’/12’ till Oct.</td>
<td></td>
</tr>
<tr>
<td>Average length of stay</td>
<td>3.5 days</td>
<td>3.5 Days</td>
</tr>
<tr>
<td>Maximum length of stay</td>
<td>7 days</td>
<td>6.9 to 7.4 days</td>
</tr>
<tr>
<td>Maximum number of patients waiting</td>
<td>N/A</td>
<td>0</td>
</tr>
<tr>
<td>Average patient waiting time</td>
<td>N/A</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 14: Simulation model validation for GYN patients at L1

<table>
<thead>
<tr>
<th>Performance Metrics</th>
<th>Historical Data</th>
<th>Simulation Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of patients</td>
<td>752/732/658</td>
<td>757-802</td>
</tr>
<tr>
<td></td>
<td>10’/11’/12’ till Oct</td>
<td></td>
</tr>
<tr>
<td>Average length of stay</td>
<td>8.6 Hours</td>
<td>8.3 hours</td>
</tr>
<tr>
<td>------------------------</td>
<td>-----------</td>
<td>-----------</td>
</tr>
<tr>
<td>Maximum length of stay</td>
<td>7 days</td>
<td>6.7 to 7.2 days</td>
</tr>
<tr>
<td>Maximum number of patients waiting</td>
<td>N/A</td>
<td>0</td>
</tr>
<tr>
<td>Average patient waiting time</td>
<td>N/A</td>
<td>0</td>
</tr>
</tbody>
</table>

The data provided was only until October 2012 and hence the patient volume is lower in 2012 compared to the other years. The inputs fed into the model had the average arrival rate by hour of day and by day of week for one whole week. Based on that input the model has created appropriate number of patients matching the historic data. Due to the unavailability of possibly rarely occurred patient waiting at the OB facility, it was made impossible to compare the average waiting time and maximum number of patients waiting, to any actual data.

After model validation multiple scenarios have been simulated and the results for the above listed performance metrics were exported and saved. If consolidation does not end up being a choice, a best scenario could be selected by the management. In this case, there is a tradeoff between patient waiting and the cost of allocating the next allocated resource and also the utilization associated with that particular resource. Considering those factors, a decision can be made on the reallocation of resources.

4.2 Facility L2

This facility has LDRP setup, due to which there is less movement of patients after they have been allocated a room. This facility has LDRP rooms, triage rooms, AP rooms and operating rooms. If the patient entering the facility is a GYN patient, she will
be sent to one among the two AP rooms. If the AP rooms are not available, and more than
2 LDRP rooms are available, the patient will be sent to an LDRP room. If the AP the
volumes are high and the unit can’t accommodate the GYN patient, they are redirected to
one of the inpatient unit. A scenario where estimation of resource requirements for GYN
patients has been simulated based on the fact that the GYN patients can be
accommodated in one of the inpatient units. This scenario was only considered in case of
a consolidation since the patient volume doubles and expansion is expensive. Since there
is no obligation that the GYN patients need stay in the OB unit, requirements for
accommodation of GYN patients has been analyzed.

If a patient entering the unit displays certain signs of childbirth, then she will be
directly sent to an LDRP room. If the signs of childbirth are not obvious, the patients are
sent to triage room and then either transferred to a LDRP room or discharged home based
on whether or not patient is about to deliver a baby. OB outpatients will be sent to triage
room, and in rare cases if the patient stays back in the unit for more than 6 hours, she will
be sent to one of the AP rooms.

Figure 31 shows the arrival process of different patient types to the facility. The
model has four types of patients and one source has been used to generate each patient
type. The arrival is set to time varying and average arrival rates for every hour of day for
an entire week are fed into the model. The model creates variation in the number of
entities it generates in a certain day, by itself. Since the nodes and paths have already
been explained while presenting L1, the next step would be to explain the logic and flow
of patients within the model.
The above picture depicts the OB unit at L2 which closely matches the facilities’ actual layout. The names LDRP1 through LDRP14 represent the labor, delivery and postpartum rooms. T1 to T3 are the triage rooms, OR1 and OR2 are the operating rooms.
and AP1 and AP2 are the antepartum rooms. After the entities are generated, all the delivery patients are routed to a node that connects all the LDRP rooms. The patients are allocated into beds according to FIFO method. List of input nodes which belong to server have been defined so that the node can pick one among those servers and direct the entity. If all the servers are full, patients will wait at this node until the next server is available. Every time an entity passes through the node, an increment function is processed providing chance to track the number of patients in LDRP rooms at any particular time during the simulation. When the entity enters the input node of processer, a conditional statement is triggered which creates a copy of the entity and transfers it to the input node of the OR, which further directs the duplicate entity to one among the two available ORs. When the duplicate entity enters the OR, before the processing starts, a process is triggered to assign processing time to the entity using a probability distribution. After processing, this entity is transferred out of the system.

If the entity entering LDRP room is not a C-section patient, there is no creation any duplicates. At this point the entity enters the LDRP processer and a processing time is assigned followed by the alteration of LOS if the patient is being discharged between 6 PM to 8 AM. After processing is done in LDRP room, entity exits the system. Input buffer for all processers is set to zero so that, entities don’t enter the input buffer of servers while the server is already occupied by other entity

After the entities representing OB outpatients are generated, those are redirected to one among the three available triage rooms through a node. As usual, a list of input nodes of processers is defined in a list so that the node can direct the entities to one among the available servers specified in the list. After the entity enters the server,
processing time using a probability distribution is assigned. The entity is routed out of the system after processing is done.

When a GYN patient enters the model, the entity is routed to a node which redirects the entities to one of the two servers. If both AP rooms are occupied, and more than two LDRP rooms open, the entity is directed to one of the available LDRP rooms. This condition is put in place to avoid bed blockage for delivery patients due to the presence of GYN patients. The processing time is assigned at the server, based on patient type, before processing starts.

4.2.1 Model Validation (L2)

After the model is built, the results of simulation should be compared to available data to validate the model. The model has been simulated for 365 days and 10 replications. The results from the model presented and compared to the historical data in the following tables.

Table 15: Simulation model validation for OB outpatients at L2

<table>
<thead>
<tr>
<th>Performance Metrics</th>
<th>Historical Data</th>
<th>Simulation Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of patients</td>
<td>816/728/634 10’/11’/12’ till Oct.</td>
<td>743 - 784</td>
</tr>
<tr>
<td>Average length of stay</td>
<td>280 mins</td>
<td>280 to 300 mins</td>
</tr>
<tr>
<td>Maximum length of stay</td>
<td>1080 mins</td>
<td>660 to 780 mins</td>
</tr>
<tr>
<td>Maximum number of patients waiting</td>
<td>N/A</td>
<td>0</td>
</tr>
<tr>
<td>Average patient waiting time</td>
<td>N/A</td>
<td>0</td>
</tr>
</tbody>
</table>
Table 16: Simulation model validation for regular delivery patients at L2

<table>
<thead>
<tr>
<th>Performance Metrics</th>
<th>Historical Data</th>
<th>Simulation Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of patients</td>
<td>712/706/579 10'/11'/12' till Oct.</td>
<td>689 - 725</td>
</tr>
<tr>
<td>Average length of stay</td>
<td>2.3 days</td>
<td>2.3 to 2.5 days</td>
</tr>
<tr>
<td>Maximum length of stay</td>
<td>7 days</td>
<td>5.9 to 7.45 days</td>
</tr>
<tr>
<td>Maximum number of patients waiting</td>
<td>N/A</td>
<td>0</td>
</tr>
<tr>
<td>Average patient waiting time</td>
<td>N/A</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 17: Simulation model validation for C-Section patients at L2

<table>
<thead>
<tr>
<th>Performance Metrics</th>
<th>Historical Data</th>
<th>Simulation Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of patients</td>
<td>270/285/240 10'/11'/12' till Oct.</td>
<td>276 – 292</td>
</tr>
<tr>
<td>Average length of stay</td>
<td>3.05 days</td>
<td>3.08 to 3.2 days</td>
</tr>
<tr>
<td>Maximum length of stay</td>
<td>7 days</td>
<td>6.45 to 7.45 days</td>
</tr>
<tr>
<td>Maximum number of patients waiting</td>
<td>N/A</td>
<td>1</td>
</tr>
<tr>
<td>Average patient waiting time</td>
<td>N/A</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 18: Simulation model validation for GYN patients at L2

<table>
<thead>
<tr>
<th>Performance Metrics</th>
<th>Historical Data</th>
<th>Simulation Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of patients</td>
<td>635/632/489 10'/11'/12' till Oct.</td>
<td>598 - 668</td>
</tr>
<tr>
<td>Average length of stay</td>
<td>8.6 Hours</td>
<td>8.3 hours</td>
</tr>
<tr>
<td>Maximum length of stay</td>
<td>7 days</td>
<td>7.2 to 7.3 days</td>
</tr>
</tbody>
</table>
This location has more delivery patients compared to L1 but lower GYN patient volume. The unavailability of data for average patient waiting time and maximum number of patients waiting makes it impossible to compare the outputs from model to actual occurrences in the past. A range is presented in the column of outputs from the simulation model since all the statics are varied in every single replication. Since the metrics from the model match the data provided, the model is validated and ready to be used for alternative scenarios.

Numerous scenarios have been simulated by changing the amount of resources in the model. After every scenario is simulated, the results have been exported and saved in an excel file which is later handed out to the management. All alternative scenarios are simulated for 365 days and 25 replications, making the simulation time for each alternative scenario as 25 years.

4.3 Facility Consolidation

After analysis of each facility with its current volume, in order to design the consolidation scenario, a part of or entire patient volume from the other facility is added the current volume. Different scenarios have been simulated by changing patient volumes. The paths and flow of patients depends on facility. If a patient is moved from L1 to L2, the patients follows the flow rules of L2.
Since GYN patients are not strictly an internal part of obstetrics, while amplifying the patient volume in consolidation scenario, only OB outpatients and Delivery patients are added. GYN patients are do not move to the consolidated facility but the GYN patients that already go to the consolidated facility will continue to go there. For example, if L2 is chosen to be the consolidated location, GYN patients from L1 don’t move to OB at L2. Only the GYN patients that are already at L2 will stay in the unit.

The increased volume at either location after consolidation will increase the waiting time of patients indicating the scarcity of resources. To solve this issue, the available resources are increased in the model and various scenarios are simulated and the results are captured for each experiment. A total of 370 different experiments have been simulated each for 365 days and 25 replications. The following are the different patient volumes considered for simulation:

- GYN patient volume using the facility after consolidation: 100%, 80%, 60%, 50%, 40%, 20% and 0%.
- OB patient volume moving to consolidated unit that would have chosen to go the other unit: 100%, 90%, 80%, 70%, 60%, 50%, 40%, 30%, 20%, 10% and 0%.

So it would be 154 (7×11×2(number of facilities)) different scenarios. Simulating 154 different scenarios at different combination of resources added up to 370 experiments.
For all OB patient types, one extra source is added to generate the extra patient volume that would choose this facility over all the other facilities in the area. The actual projected patient volume to the hypothetically closed facility is multiplied by the percentages mentioned in the above list of scenarios. This means if we are expecting a 20% drop in patient volume to the consolidated location, we assume that, such a drop will be constant on all the days of week. If the volume drop is 50%, the average patient volume by hour values fed into the model is reduced to half equally for every hour of day irrespective of the day of week.
The above shows the consolidated model of facility at L2. The unconsolidated version of the unit only has 14 LDRP beds. But the above figure, 21 LDRP beds can be identified. In consolidated version, additional capacity is needed to accommodate the patients with minimal wait times which lead to adding more resources. Available capacity of the facility is changed in every experiment and the above picture represents the setup for one among the multiple scenarios simulated.

There is a substantial amount of cost associated with expansion of the facility after consolidation. Higher the patient volume, higher the capacity required to accommodate them. To keep the patient volume to a minimum, a scenario where no GYN patients are allowed into OB unit is explored. A basic simulation model is built to find the requirements for accommodation of GYN patients outside the OB unit and the results were exported from the model. Since the arrival rate is very high on only a few days of
the week and almost no arrivals during many other days of the week, the number of beds required to accommodate GYN patients is high. Limitation to this analysis is that, it says that we need ‘x’ number of beds to accommodate ‘z’ number of patients. But the utilization for those beds is extremely low which does not justify the allocation of such resources. A more detailed analysis has to be done by including this patient volume in a regular nursing floor (RNF), which is an inpatient unit that meets the requirements for accommodation of such patients. Since RNF usually has very high volume, these patients would clearly fill into the few empty beds which would be otherwise probably be open for a few hours. Even if some beds are allocated in the hospital just for the GYN patients, it would make sense to share such beds with such an inpatient unit with high capacity which leads to increased utilization and reduce the inpatient waiting times for RNF as well.

Results from simulation model are used in AHP to quantitatively rank decision criteria namely cost of construction and service level. The number of additional rooms required is available from the simulation model which helps in estimating the cost of construction. The patient waiting time in interested scenarios is also obtained from simulation and used in ranking the service level.
CHAPTER V

RESULTS AND DISCUSSION

In this chapter, results from simulation model and AHP rankings are presented and discussed. With all the information needed to quantitatively rank the decision criteria, the next task is to gather the qualitative rankings. After acquiring the qualitative rankings, all the required input variables required for using AHP will have been made available to assist in decision making. In Delphi method, a set of survey or questionnaire will be sent out to selected group of experts in the area where decision making is necessary. Delphi method is said to be a forecasting method based on the answers to the questionnaire sent to the group of experts. In this method, the experts do not have any face to face interaction which avoids conflict. This group of experts need not be working for same organization. The collection of members can go to as far as selecting experts from across the world. The summary of answers and supporting statements will be sent back to the same experts encouraging them to revise their answers based on the summary. This is continued until the predefined stop conditions for the method is achieved.

Delphi method used in face to face meetings is called Mini-Delphi method. In this research, to assist in qualitative ranking for AHP, a panel of experts from executives within the organization assembled. In Mini-Delphi method, chance of conflict between experts is higher. In this case, since the group has been working together previously, as a
team, chance of conflict of opinions was eliminated making the method more efficient and smooth.

Here, it is assumed that 100% volume is retained after consolidation. AHP results for other scenarios are calculated and provided to the management for their reference. The following AHP calculations are presented only for best case scenario. The decision criteria and alternatives differ based on the circumstances of application.

5.1 Ranking decision criteria

Ranking the decision criteria accurately is necessary as these numbers can skew the decision making. AHP being a robust mathematical tool to assist in finding a best pick, it is necessary for the users to understand how this exactly works. Misinterpretation of the details in the methodology would lead to experts ranking the criteria inaccurately and would compromise the accuracy of results. Such flaws in using the method could cause loss of millions of dollars spent in making changes. Prior to ranking, it is vital to make sure the personal providing the numbers have through understanding of the method.

Four alternatives were selected for analysis by the management. In all the alternatives, it is assumed that consolidated location will retain 100% patient volume.

1) Moving to L2 at service level X (A1).
2) Moving to L1 at service level X (A2).
3) Moving to L2 at service level Y (A3).
4) Moving to L2 at service level Y (A4).

The letter X = acceptable average wait time of 5 minutes for Delivery patients.
The Letter Y = acceptable average wait time of 15 minutes for Delivery Patients.

Here the process would be, first ranking the decision criteria against each other, followed by ranking preference of alternatives over each other for each decision criterion.

Table 19: Ranking decision criteria

<table>
<thead>
<tr>
<th>Prioritization Matrix</th>
<th>Projected Payments</th>
<th>Service level</th>
<th>Construction cost</th>
<th>Care model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Projected Payments</td>
<td>1</td>
<td>3</td>
<td>7</td>
<td>4.5</td>
</tr>
<tr>
<td>Service level</td>
<td>1/3</td>
<td>1</td>
<td>7</td>
<td>2</td>
</tr>
<tr>
<td>Construction cost</td>
<td>1/7</td>
<td>1/7</td>
<td>1</td>
<td>1/6</td>
</tr>
<tr>
<td>Care model</td>
<td>1/4.5</td>
<td>1/2</td>
<td>6</td>
<td>1</td>
</tr>
</tbody>
</table>

The final scores of prioritization matrix are such:

Table 20: Final scores for decision criteria

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Priority score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Projected Payments</td>
<td>0.539</td>
</tr>
<tr>
<td>Service level</td>
<td>0.251</td>
</tr>
<tr>
<td>Construction cost</td>
<td>0.046</td>
</tr>
<tr>
<td>Care model</td>
<td>0.164</td>
</tr>
</tbody>
</table>

According to the rankings, projected payments is most preferred followed by service level, care model and construction cost consecutively.
5.1.1 Projected payments

In this case, the assumption is the consolidated facility retains all of the projected patient volume to the system. This criterion is qualitatively ranked and can be ignored in this case. Since both the facilities are expected to retain same patient volume, there is no difference in projected payments for either facility. If either the intermediate scenario, worst case scenario or any other scenario is considered, this criterion will affect the numbers. The priority for quantitative criteria is calculated by normalization.

<table>
<thead>
<tr>
<th>Projected payments</th>
<th>Quantitative values</th>
<th>Priority</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>1</td>
<td>=1/4 =0.25</td>
</tr>
<tr>
<td>A2</td>
<td>1</td>
<td>=1/4 =0.25</td>
</tr>
<tr>
<td>A3</td>
<td>1</td>
<td>=1/4 =0.25</td>
</tr>
<tr>
<td>A4</td>
<td>1</td>
<td>=1/4 =0.25</td>
</tr>
<tr>
<td>Sum</td>
<td>4</td>
<td>1</td>
</tr>
</tbody>
</table>

Since there is no difference in projected payments, priority for all the alternatives is equal.

5.1.2 Service level

Two service levels are considered for evaluation considering the tradeoff between cost associated with the additional resource and the revenue it generates. The tradeoff is qualitatively ranked in table 17. Ranking the alternatives according to service level is
quantitative. The resources in simulation model are set in such a way that the average waiting time is as close to intended (5 and 15) as possible. The value is not always equal to intended and the average waiting time are different in both models. So, the average waiting time values from the simulation model are used instead of 5 and 15. The additional resources required at both locations in both these would be used to calculated construction costs (quantitative).

Table 20 shows the resource requirement and priority calculated for each alternative. The order of priority according in service level is A1, A2, A4 and A3.

Table 22: Alternative ranking for service level

<table>
<thead>
<tr>
<th>Service level</th>
<th>A1</th>
<th>A2</th>
<th>A3</th>
<th>A4</th>
<th>Priority</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>1</td>
<td>1.0254</td>
<td>4.6284</td>
<td>3.1348</td>
<td>0.398</td>
</tr>
<tr>
<td>A2</td>
<td>0.9751</td>
<td>1</td>
<td>4.5136</td>
<td>3.0570</td>
<td>0.388</td>
</tr>
<tr>
<td>A3</td>
<td>0.2160</td>
<td>0.2215</td>
<td>1</td>
<td>0.6772</td>
<td>0.086</td>
</tr>
<tr>
<td>A4</td>
<td>0.3189</td>
<td>0.3271</td>
<td>1.4764</td>
<td>1</td>
<td>0.127</td>
</tr>
</tbody>
</table>

5.1.3 Cost of Construction

Due to the unavailability of data, the cost of construction is assumed to be the same in this case. It is possible to assume that cost would be proportional to the number of additional beds required at both locations. But such assumption would be wrong as the type of beds added are different at both locations which would affect the cost. So, we assume the cost of construction or renovation is same at both locations.
Table 23: Alternative ranking for cost of construction

<table>
<thead>
<tr>
<th>Cost of Construction</th>
<th>Quantitative values</th>
<th>Priority</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>1</td>
<td>=1/4 =0.25</td>
</tr>
<tr>
<td>A2</td>
<td>1</td>
<td>=1/4 =0.25</td>
</tr>
<tr>
<td>A3</td>
<td>1</td>
<td>=1/4 =0.25</td>
</tr>
<tr>
<td>A4</td>
<td>1</td>
<td>=1/4 =0.25</td>
</tr>
<tr>
<td>Sum</td>
<td>4</td>
<td>1</td>
</tr>
</tbody>
</table>

5.1.4 Care model

This is a qualitative attribute ranked by the management. The board preferred to have a LDRP model than a LD and postpartum model. According to the management, patients prefer LDRP model. Table 22 presents the priority and ranking for this attribute.

Table 24: Alternative ranking for care model

<table>
<thead>
<tr>
<th>Service level</th>
<th>A1</th>
<th>A2</th>
<th>A3</th>
<th>A4</th>
<th>Priority</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>1</td>
<td>4</td>
<td>1</td>
<td>4</td>
<td>0.4</td>
</tr>
<tr>
<td>A2</td>
<td>1/4</td>
<td>1</td>
<td>1/4</td>
<td>1</td>
<td>0.1</td>
</tr>
<tr>
<td>A3</td>
<td>1</td>
<td>4</td>
<td>1</td>
<td>4</td>
<td>0.4</td>
</tr>
<tr>
<td>A4</td>
<td>1/4</td>
<td>1</td>
<td>1/4</td>
<td>1</td>
<td>0.1</td>
</tr>
</tbody>
</table>
Summation of criteria weight multiplied by attribute priority score for each individual alternative will provide the final ranking score (Provided in Table 23). In this case A1 is the best option followed by A3, A2 and A4 consecutively.

Table 25: Final AHP score

<table>
<thead>
<tr>
<th>Summary</th>
<th>Projected payments</th>
<th>Service level</th>
<th>Cost of construction or renovation</th>
<th>Care model (LDRP versus LD &amp; Recovery)</th>
<th>Final Score</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Weight</td>
<td>Score</td>
<td>Weight</td>
<td>Score</td>
<td>Weight</td>
</tr>
<tr>
<td>A1</td>
<td>0.539</td>
<td>0.25</td>
<td>0.251</td>
<td>0.398</td>
<td>0.046</td>
</tr>
<tr>
<td>A2</td>
<td>0.539</td>
<td>0.25</td>
<td>0.251</td>
<td>0.388</td>
<td>0.046</td>
</tr>
<tr>
<td>A3</td>
<td>0.539</td>
<td>0.25</td>
<td>0.251</td>
<td>0.086</td>
<td>0.046</td>
</tr>
<tr>
<td>A4</td>
<td>0.539</td>
<td>0.25</td>
<td>0.251</td>
<td>0.127</td>
<td>0.046</td>
</tr>
</tbody>
</table>

As mentioned earlier, 72 different scenarios have been simulated and each scenario has a different patient volume. These results can be used as reference charts to plan the capacity of the unit for the years to come. The chart would be accurate as long as the length of stay is and patient flow remains unaltered. Length of stay for delivery patients in some countries is higher than in the US. Advancement of technology has been helping in reducing the LOS by making many procedures safer. Numerous procedures which formerly lead to patients being admitted into the hospital are now outpatient procedures. Currently C-section patients have longer LOS than regular delivery patients which might change due to the technology. In such case, inputs in the simulation model could be altered to match the desired conditions.
Due to the lower utilization of OB unit, the hospital started accommodating GYN patients in the OB unit. Since most GYN patient volume is outpatients, there is very less chance of a bed blocking. If patient length of stay is lower, the bed turn over time is lower making the beds available more often. If consolidated, to reduce the expansion costs, the GYN patients will be redirected to inpatient units. To explore the bed requirement for GYN patients, a basic model is developed and the results were captured.

The following table shows the accommodation requirements for GYN patients at L1. Accommodation requirements for different volumes of GYN patients are presented in the table below. Percentages considered are 100% to 20% with a decrement of 20% volume in each scenario. Multiple experiments have been simulated by changing the number of beds required, in order to reduce the average waiting time. The utilization of the beds decreases as the number of beds goes up. As the table shows, the utilization of beds even with high waiting times is less than 50%.

Table 26: Bed requirements for GYN patients

<table>
<thead>
<tr>
<th>% of GYN Patients Moving from OB Unit to Inpatient Units</th>
<th>Average Length of stay</th>
<th>Average Waiting time</th>
<th>Maximum Waiting Time</th>
<th>Average Number of patients waiting</th>
<th>Max number of patients waiting</th>
<th>Percentage Utilization</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Baseline</strong></td>
<td>12.079</td>
<td>0.007</td>
<td>0.0873</td>
<td>0.0006</td>
<td>1.72</td>
<td></td>
</tr>
<tr>
<td>100%, 5 beds</td>
<td>12.239</td>
<td>0.082</td>
<td>11.7108</td>
<td>0.006</td>
<td>2.95</td>
<td>17.7069</td>
</tr>
<tr>
<td>100%, 4 beds</td>
<td>12.541</td>
<td>0.33</td>
<td>27.3378</td>
<td>0.0243</td>
<td>4.35</td>
<td>22.2765</td>
</tr>
<tr>
<td>100%, 3 beds</td>
<td>14.993</td>
<td>2.909</td>
<td>71.8432</td>
<td>0.249</td>
<td>9.48</td>
<td>29.4717</td>
</tr>
<tr>
<td>100%, 2 beds</td>
<td>18.2</td>
<td>14.52</td>
<td>148.917</td>
<td>1.263</td>
<td>11.88</td>
<td>44.0103</td>
</tr>
<tr>
<td>80%, 4 beds</td>
<td>12.078</td>
<td>0.151</td>
<td>11.6995</td>
<td>0.0089</td>
<td>3.1</td>
<td>17.5147</td>
</tr>
<tr>
<td>80%, 3 beds</td>
<td>12.836</td>
<td>0.849</td>
<td>45.5257</td>
<td>0.0494</td>
<td>4.8</td>
<td>23.324</td>
</tr>
<tr>
<td>80%, 2 beds</td>
<td>17.657</td>
<td>5.827</td>
<td>107.268</td>
<td>0.3418</td>
<td>8.64</td>
<td>34.4896</td>
</tr>
<tr>
<td>60%, 4 beds</td>
<td>11.948</td>
<td>0.072</td>
<td>9.3004</td>
<td>0.0032</td>
<td>1.75</td>
<td>12.9444</td>
</tr>
<tr>
<td>60%, 3 beds</td>
<td>12.298</td>
<td>0.432</td>
<td>37.3436</td>
<td>0.019</td>
<td>3.05</td>
<td>17.2437</td>
</tr>
<tr>
<td>60%, 2 beds</td>
<td>15.41</td>
<td>3.171</td>
<td>89.6831</td>
<td>0.166</td>
<td>6.72</td>
<td>25.7003</td>
</tr>
<tr>
<td>40%, 3 beds</td>
<td>12.364</td>
<td>0.241</td>
<td>20.2001</td>
<td>0.0073</td>
<td>1.75</td>
<td>11.8902</td>
</tr>
<tr>
<td>40%, 2 beds</td>
<td>13.687</td>
<td>1.72</td>
<td>68.9612</td>
<td>0.0517</td>
<td>4.08</td>
<td>17.8348</td>
</tr>
<tr>
<td>20%, 2 beds</td>
<td>12.461</td>
<td>0.443</td>
<td>23.8688</td>
<td>0.0067</td>
<td>1.9</td>
<td>8.7631</td>
</tr>
<tr>
<td>20%, 1 bed</td>
<td>19.683</td>
<td>8.03</td>
<td>142.929</td>
<td>0.1226</td>
<td>4.2</td>
<td>17.5764</td>
</tr>
</tbody>
</table>
The highlighted rows in the results table shows the option with low waiting times for that particular scenario.

The results of all the experiments simulated during analysis of consolidation scenario are substantial. Thus, it is not feasible to present the results for such experiments in a paper of this size.
CHAPTER VI

CONCLUSION

Underutilization in of resources in healthcare is a critical issue as the resources are extremely expensive. Assessment of utilization, flow etc. should be done periodically to ensure that valuable capital is not being wasted on unnecessary resources. All facilities in healthcare have volume fluctuations, which is important to consider while planning resources. Facilities need to be prepared to take a risk of not being able to accommodate few patients during volume surge. If the volume fluctuation is extremely high, the number of beds required to accommodate patients goes up while the utilization is low. In this research, after looking at the data, when one unit had high volume of patients, the other unit is usually at its low utilization. If the capacity was combined and used, that would avoid scarcity of resources at one facility and underutilization at the other. The above case is not always true as there were situations where both facilities were operating at maximum capacity but that situation has seldom occurred. If the facilities are consolidated, based on the previously experienced patient volume, capacity required to accommodate the patient volume has to be estimated. In the consolidated scenario, the fluctuations in the patient volume seen are comparatively lower which enables handling more patients with fewer resources. Savings resulted from such action add up every year. The consolidated facility operates at higher utilization. There is also a chance of patient volume drop by a certain percentage due to the consolidation which needs to be
estimated. At this point, multiple choices, each with its own pros and cons will have to be dealt with. One well analyzed decision has to be made which could be cost a lot if any mistakes are made. All the methods used need to be proven to work in previously and perfect reasoning will have to be provided for using each method.

To find a solution for such a problem faced, literature review was started. No previous research has been found addressing such a problem. While various methods were used to estimate capacity in the literature, in this case where many input characteristics and logics are involved, simulation modelling proved to be the best option to address the issue. Simulation modelling is an advanced method of measuring system dynamics. Each and every statistic can be captured throughout the simulation period. Good knowledge of using simulation software is not good enough to build a model. Through analysis of process in the system followed by analysis of flow and accurate data are also required. As the amount of details increases, the complexity of simulation model increases. Multiple scenarios were analyzed for consideration including consolidation scenario.

Patient volumes after consolidation were estimated using driving distance, driving time methods and also including the patient loyalty factor to design an intermediate scenario. Using projected patient volume, and payer mix analysis, estimated payments after consolidation were predicted and used as a criterion in decision making.

Shortlisting the major decision criteria need to be done followed by listing out the alternative options available. Each alternative has its pros and cons which requires a robust method to study and solve such a puzzle. AHP is a tool widely used in solving
such problems in a robust mathematical fashion. AHP is used to analyze the alternatives and find the most preferred options considering all the criteria.

If consolidated, if GYN patients need to be accommodated in the OB unit, this increases the capacity required for the OB unit. Construction costs millions of dollars and there is no restriction for GYN patients to be placed in the OB unit. These patients can be accommodated in one among the inpatient beds. As there are many inpatient beds available and usually the number of patients coming in every day is low, it would be logical to find some space for these patients in other inpatient unit. Shorter length of stay of GYN patients ensures the faster bed turnaround time. As the beds are more frequently available, the patients waiting time in ED for inpatient bed is not majorly affected. Analysis of capacity in the inpatient unit to where GYN patients are being rerouted needs to be done. Many times human perception of the situation is wrong compared to what actually happens. Data analysis will show a clearer picture of the system dynamics. Many times, looking at data differently opens up many opportunities.

6.1 Future research

Expanding this research to the whole hospital will add to the available body of knowledge and help many healthcare organizations to make an informed decision.

Studying the impact of moving GYN patients to RNF is an opportunity created after this research. Since the number of beds available in RNF is many times higher than that of OB, the impact on the patient flow could be minimal due to such change.

In this research, patient volume was predicted using distance method by including the influence factor of competitors in the area. Search for a better method including
doctor’s influence in the area will be interesting to see. This would also help hospitals increase their patient volumes by allocating their doctors’ offices in the right locations and in the right field.

Research on finding a better method than AHP which is more suitable to healthcare setting will be interesting.
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