# A Simulation Study on Bed Capacity Management in a Public Hospital

**Doha Makarem, Farah Sarraj, Fatemah AlKandarie, Shouq Thuwaini, Yara Tafesh, Dr.Ufuk Kula**
Industrial Engineering Department
American University of the Middle East
250 St, Eqaila, Kuwait
Dohamakarem4@hotmail.com, Farahsarraj@outlook.com, Fatemahalkandarei@hotmail.com, Shougthuwaini3@gmail.com, Yara.tafesh@outlook.com, Ufuk.Kula@aum.edu.kw

**Systems Simulation and Probability and Statistics in Engineering Applications**

## Abstract

It is important to effectively manage the allocation of limited resources such as beds in order to provide access to care in a timely manner. Bed capacity management is essential in delivering high-quality health care. The aim of this paper is to optimize the number of beds in the hospital, reduce length of stay, reduce discharge delays, and evaluate alternative solutions to bed management. This research mainly focuses on developing a discrete event simulation to help and support in decision making on scheduling staff and optimizing resources. Scenarios were tested to find out the effect of length of stay, queue length and waiting times of patients. Data required to build the model such as patients' length of stay, available resources, and processing times were collected from a public hospital. The results were found to be that the bottlenecks in the system is resulting from the over occupancy in wards (especially surgical wards) that is affecting the patient flow and overcrowding in the Emergency Department. OptQuest was used to optimize the number of beds in order to have bed utilization no less than 70% and no more than 85% which will give the optimal solution. In addition, four what-if scenarios were constructed and tested as solutions to be recommended to improve the system.

## Keywords

Bed Capacity Management, Emergency Department, Discrete Event Simulation, Length of Stay, Bed Occupancy, Queue Length.

## 1. Introduction

For the past few decades, worldwide healthcare systems have been under tremendous stress for failing to plan effectively as hospitals cannot function at 100% bed occupancy (Kumar & Mo, 2010; Hospital Bed Occupancy, 2018). High levels of bed occupancy can affect patient care since it is less likely possible to direct the most suitable bed for the patient care. In a health system, a wide spread of consequence may result in a lack of available beds causing an increased rate of infections, inappropriate clinic ward patient placing, and pressure on staff to clear up beds. In addition, overcrowding and over occupancy in hospitals are considered as a global crisis and is classified as a national catastrophe in many countries. One of the main factors of over occupancy rates is the poor capacity planning of beds required. According to The King's Fund in England (cited in the National Institute for Health and Care Excellence, March 2018). It is stated that hospitals with average bed occupancy rates higher than 85% have the risk to experience regular bed shortages, recurrent bed crisis, and increased numbers of healthcare attained contagions and infections (National Institute for Health and Care Excellence, 2018). Planning the bed capacity must tackle and take into consideration the reasons and causes that affect the load increase in hospitals. One important reason is the divergence between the patient flow through beds, bed supplements, and the demand. Whenever the demand of urgent care increases, the bed supply lessens thus flow of patients turn out to be weakened. Additionally, treatment delay due to lack of resources and the absence of medical staff without any reason will cause the increase load in hospitals. Throughout the year's other classifications appeared, such as level of care (medium or ICUs), LOS, or urgency (elective, urgent, and emergency care units) (Bruin, 2008). All the reasons mentioned above contribute to the effectiveness of managing the capacity of beds. The following fishbone diagram represented in figure 1, shows the possible reasons of overcrowding in a hospital.

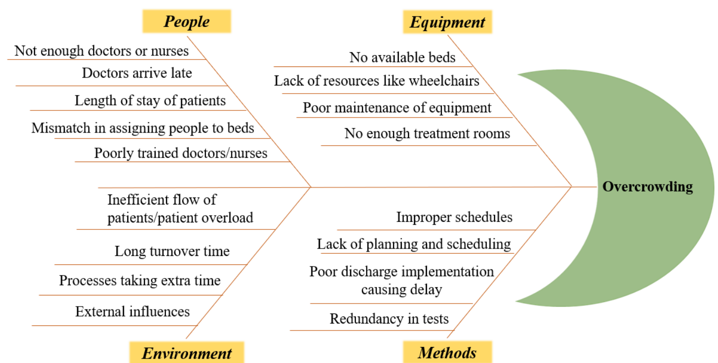


**Figure 1: Fishbone Diagram of Overcrowding**

## 1.1 Problem Statement

A Health care system seeks for finding better ways of operating and planning hospital bed capacity for delivering necessary care to patients and allocating beds to arriving patients. Reducing number of beds may have an impact on improving hospital performance, which will result in higher occupancy rates and tighter control of costs. Nevertheless, hospitals are facing major issues regarding its inappropriate number of beds in each department due to overcrowding and over occupancy. The factors such as infection rates, discharge delays, and admission of patients with incurable diseases make bed management a difficult task. Poor BCM leads to long LOS, excessive patient waiting times as well as lower quality of patient care. As a response to this problem, the project is going to propose a methodology that will improve the bed management process in a hospital in order to assign right patients to right beds, decrease bed investment costs, and increase patient satisfaction. Therefore, we will conduct a simulation study to examine and inspect the arrival patterns of different patient types, LOS, and flow of patients.

## 1.2 Causes and Results of Poor Bed Capacity Management

Ineffective Bed management is the bane of hospitals, causing myriads of problems for patients, administrators, doctors, and nurses. Ineffective management is caused due to the over-occupancy that is happening in hospitals. Variation in LOS, discharge delays, staffing volume, shortage in resources, and misallocation of patients all contributes to the inefficient planning of bed management. Nowadays, patients arrive to hospitals waiting long period of time for assigning a bed and get immediate treatment. In some cases, patients are forced to wait or transferred to another hospital due the lack of available beds in the ED. Despite waiting for long period of time, the patients are not well cured by doctors due to the over occupancy of beds that is causing improper scheduling of doctors and nurses. Although when a patient finally receives a bed, the hospital also faces a 'blocked transfer' situation. For example, patient's condition is marked by the movement from one bed to another and each hospital division is categorized with different treatment procedure. Meaning that, if one patient suffers from brain aneurysm or a stroke, the patient must be assigned to the right room and bed related to neurological procedure. Therefore, a bottleneck occurs due to lack of advance planning that affects patient movement and prevents them to be assigned to the right medical bed. In some events, there are occupied beds by patients that are ready to leave but are not discharged by their physicians. This is leading to over occupancy and give away chances for new patient's arrival to be treated. Radiology, incomplete discharge prescription, and incomplete referral paperwork are also considered as delays that are occurring in several hospitals leading to discharge delays. Leaving patients to stay longer than needed eventually causing patient's health to deteriorate due to acquired hospital infection. Occasionally, patients are forced to wait in the ED for the operation day because all time slots are occupied that increases their hospital LOS. In many hospitals, overcrowding is forcing nurses to transfer patients around, moving them to local hospitals, or accommodate them in halls. Unfortunately, the impacts of poor bed management problem end up patients to be treated in less safe settings. According to (Gossart, Guinet, and Meskens, 2010), EDs usually host patients of traumas and other type of injuries for a maximum of twenty-four hours. However, it does not always go as planned. Patients stay longer than a day due to the lack of available beds in each department and care unit. This can result, in poor hospitalization and over occupancy in the ED. In addition, the main causes and results of poor bed capacity management is illustrated in figure 2.

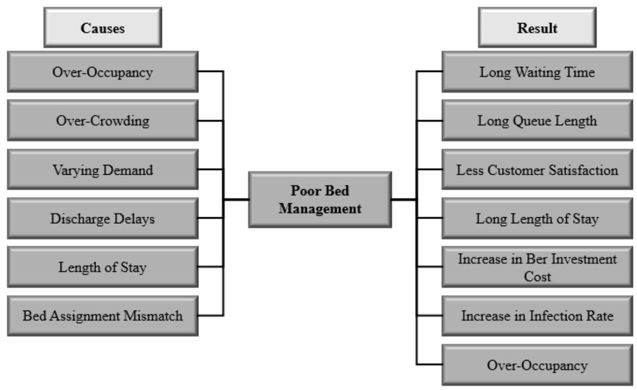


**Figure 2: Causes and Results of Poor BCM**

## 2. Literature Review

This paper will represent literature review about different papers. These papers discuss variety of topics related to BCM. They are sequenced based on the problem studied. Different problems were analyzed from different departments using different techniques and methodologies to suggest several solutions. In addition, a summary table is provided to clarify the problem presented in each article besides to the performance indicators and techniques used to study the mentioned problem. (Geisler, Schmit, and Spreckleser, 2013) conducted a study about hospital bed management in Germany using individual LOS estimations and shared resources. The aim of this study is to improve the efficiency and effectiveness of bed and case management process. They calculated the expected free ward capacity that is based on LOS estimates using mixed integer programming solver (SCIP) and heuristic strategies. The result showed that the optimization strategies leads to improved assignment. In a similar study, (Kobis and Kennedy, 2006) studied the financial effect that results from inefficient capacity management. They suggested many options that minimize this risk. As a result of these options, the organization was capable of improving the throughput outcome measure, reducing dependence on premium staffing, and efficiently planning for long term capacity. (Zeitz, Carter, and Robinson, 2012) performed a case study over a 4-year period to provide the variations in acute hospital bed delays. Capacity Audit process involving surveys were used. The study showed that overall bed stock usage has not changed significantly. In another study, (Bares et al., 2012) presented a case study for the transfer of neurosurgery services between two places where simulation package to analyze usage of bed was provided. The results showed that the bed capacity did not meet the demand on daily basis. Solutions to meet the demand were suggested by the software used to simulate the problem. Moreover, (Clarke, 1996) showed the variability in LOS while mentioning the significant factors that determines the LOS. He highlighted the most significant factors that causes variation in LOS which are supply and demand actors. Moreover, Clarke analyzed how different methods of historical trends and geographical variations can determine the LOS. Gynaecology and general surgery department were studied for post up surgical operation. The results showed that patients in Italy stayed in the hospital longer than the person who is in Norway.
(EL-Darzi et al., 1998) used simulation and flow model to evaluate the flow of patients through geriatric hospitals in UK taking into consideration occupancy, LOS, and bed blocking. They also carried out what if analysis to observe the sensitivity to any change in model parameters. Finally, their study showed that the flow model and simulation are equally viable tools to measure bed occupancy. In a similar study, (Bagust et al., 1999) simulated emergency admissions of all types in hypothetical hospital in England, to examine the daily bed requirements and quantify risk of insufficient capacity for patients. They used a discrete event simulation model and their results showed that if

average bed occupancy rises to 90% or more, the hospital will expect bed shortages and periodic bed crises. In the same way, (Beeknoo and Jones, 2010) studied the shortage of beds in the emergency department (ED) for a hospital in United Kingdom (UK). The data were collected for the patient arrival in the ED. They were used time-series and forecasting technique for one year. The results showed that the bed capacity in the ED have been improved by 6.3%. In addition, (Mawengkang, Husein, and Sitepu, 2017) pointed out an optimal model for capacity management. The study used a linear programming model to analyze multifield resources such as doctors, nurses, beds, and rooms in order to find the optimum requirements of resources. The goal of this study is to increase better service performance with less waiting time. The result showed that the LP model enhanced the allocation planning of beds. Likewise, (Kumar and Mo, 2010) studied overcrowding in a Singapore hospital bed shortage due to rising elderly pneumonia cases. They developed several models to predict bed occupancy rates. Furthermore, (Antelo, Calvo, and Santias, 2015) studied the waiting time for the elective surgery because of the shortage in the bed capacity. The data were collected for inpatient activity and surgery waiting list size. For this study they used simulation model for linear regression method and what if scenarios. The result of the study reducing the length queue of the elective surgery. (Lee, Shapoval, and Wang, 2017) proposed a two-stage framework approach consisting of cluster analysis, queueing theory, and utility functions to efficiently allocate impatient beds. They applied the frame work in a hospital in Asia. In a similar study, (Landa et al., 2014) analyzed the patient flow between the ED and the inpatient wards. They investigated the dynamic movement and flow between wards in a hospital in Genova city, and collected data related to the flow of emergency to inpatient wards. The technique that they used is the discrete-event simulation modelling. Performance metrics were chosen such as misallocation index, average number of patients waiting, bed utilization rates, and number of postponed patients. The results showed a better patient flow with high performance level due to the efficient management of beds. In addition, (Pinto et al., 2015) used queuing theory and simulation to develop two bed management models. The article showed an estimation through these two methods the number of beds required in a Brazilian city of Belo Horizonte. The study highlighted some important features required to conduct the two studies which are: age, illness severity, arrival rates, LOS, and seasonality. After conducting the two methods, they compared the results of their models and showed that simulation provides a more accurate estimation than the queuing theory. In another study, (Foster et al., 2003) investigates the effects of hospital occupancy on ED using data obtained from two different databases. They developed an Autoregressive Inductive Moving Average (ARIMA) model to predict admission rates, LOS, and consolation rates. The results showed that increasing bed occupancy is associated with LOS for admitted patients and ED overcrowding is reduced by increasing hospital bed availability. Correspondingly, (Beullens et al., 2007) also used queuing model which solved the problem which is the wrong allocation of beds in Zichuan Hospital in China. By the model they increased the performance of the entire hospital from 90.59% to 94,94%. Thus, it decreased the number of rejected patients. (Belciug and Gorunescu, 2015) used mix Operation Researches and Artificial Approaches to improve the bed management process in UK Hospital. It results with decreasing the postponed health care service of patients. Moreover, (Bessman et al., 2014) used active bed management including twice daily bed management round. It decreases the ambulance diversion hours and ED throughput times. By the same token, (Gorunesc, McClean, and Millard,2002) optimized the number of beds needed in George Hospital in London by Queuing model. In consequence, the number of rejected patients decreased. In a similar study, (kemba, Agada, and Owuna, 2014) used a queuing model to reduce the long patients waiting tine in a Rehabilitation Center in Nigeria. They used their model to find the optimal number of beds needed. In a similar way, (Forneas, 2018) considered in some of USA's hospitals that there were some surgeries being cancelled because of no available beds. They used a forecasting schedule to identify the number of needed resources during each week in order to not cancel any surgery. The results showed that this technique improved the bed capacity from 30% to 50 %. Table 2 below shows the summary of the literature review, and they are categorized into groups based on the similarity of the problem presented in each article.

## 3. Design

This section denotes a comprehensive information regarding the collected data needed for building the system in simulation ARENA Software. In addition, data analysis was preformed showing the number of patient's arrival and bottleneck of bed crises. Furthermore, patients' process flow chart was constructed to understand the flow of patients in the hospital.

### 3.1 Data Collection and Analysis

This section gives a comprehensive information regarding the collected data needed for building the system in simulation ARENA Software. Number of capacity beds in each ward along with the schedules of doctors and nurses are collected. Moreover, the types of beds in each department are also collected. Additionally, the departments that are studied in the hospital are the following;

1. Triage Rooms
2. Vital Signs Rooms
3. Check-up Rooms
4. Resuscitation Room
5. Intensive Care Units (Surgical and Medical)
6. Operation Rooms (Minor and Major)
7. Male and Female Observation Rooms
8. Male and Female Internal Wards
9. Male and Female Surgical Wards (General Surgery, Orthopedic, Urology, ENT, Ophthalmic, and Dental).

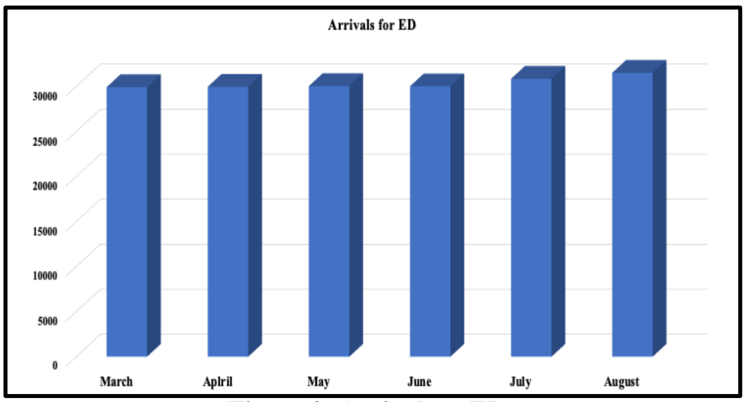


**Figure 3: Arrivals to ED**

Figure 3 demonstrate the arrival data of patients arriving to the emergency department showing the historical data from March 2019 – August 2019. Since the graph shows no seasonality for the arrival data in these six months. For that reason, the system will be focusing only on one month which is March-2019. Second, data were collected for patients inside the observation room based on the LOS, to understand where the problem is occurring exactly whether it is from ED or the Wards. One of the policies that the hospital must follow which is the patient shall stay for one day maximum. However, patients are staying more than one day in the observation room. The reason behind this case is that there is no available bed for the patient in the ward. Hence, the doctors must decide to keep the patient in the observation unit until one bed become available.

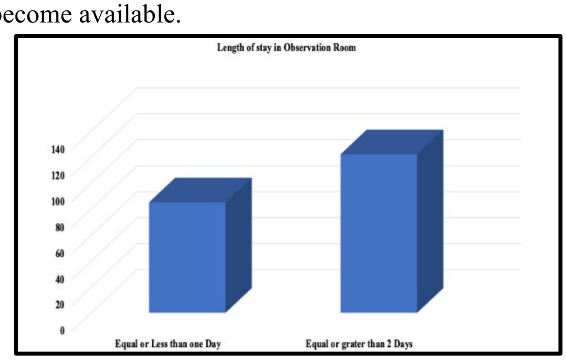


**Figure 4: LOS in Observation Room**

After analyzing the data for the LOS in the observation room, the data were classified into two groups as it shown in figure 4. First column shows the number of patients that stay one day or less, the second column shows the number of patients that stay more than two days. From this analysis, it has been considered that the number of patients who are staying two days or more are greater than the other patients, which means that the main problem of bed occupancy is originally from the ward. Therefore, the number of admission data for each ward was taken to observe which ward has the highest admission and then check which ward has the longest LOS.

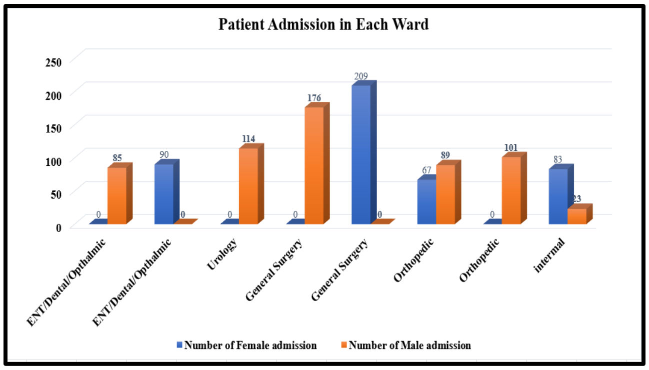


**Figure 5: Patients Admission in Each Ward**

Figure 5 shows the admission number of patients in each ward, from the chart above, it is noticed that the highest admission is in General Surgery ward for both sections female and male. However, this hospital used Orthopedic female ward for both female and male because the male admissions are higher than female in orthopedic ward and the LOS for this ward is high. After all the analysis that were constructed as shown in figures (3,4,5), a conclusion was made that the main problem is coming from the General surgery and Orthopedic wards which mean if we solved the problem in these wards the problem in the ED will be solved too. Simulation ARENA will be built in order to understand the problem specifically and create an effective bed management.

## 4. Methodology

This section describes the methodology of the hospital system. Patient flowchart was conducted showing the flow of patients in the hospital. Also, input and output of the simulation model have been identified to assess in building the simulation model. In addition, key performance indicators were identified to measure the system's performance. The following section include simulation model, replication parameter, warm-up period, replication length, validation and verification along with the current system performance.

### 4.1 Patient Process Flowchart

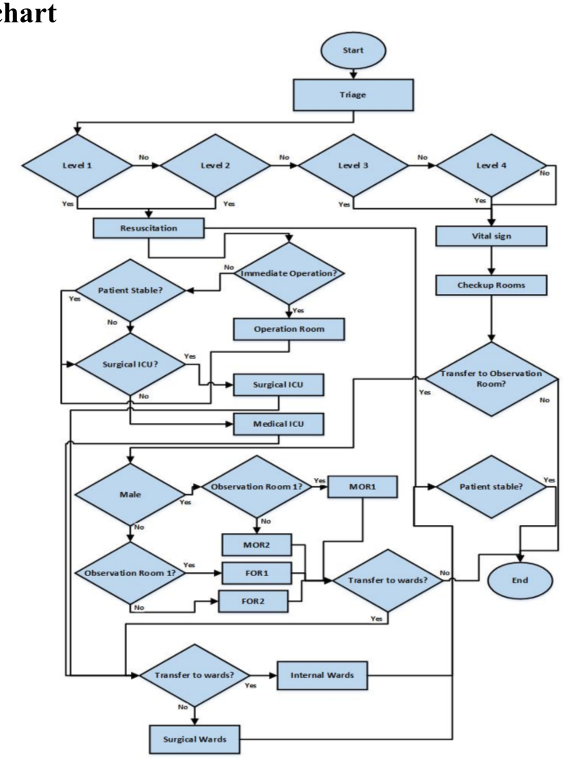


**Figure 6: Patient Flowchart**

As shown in figure 6, when patients arrive to the emergency department, they will be classified under one of the five levels according to the severity level that they have. Level 1 and level 2 are related with the resuscitation room. Level 1 is for the patients who are coming by their own and level 2 is for the patients who are coming by ambulance. After the resuscitation they will be either sent to the operation room (minor or major) or to the intensive care unit (medical or surgical). Patients who had major operation they will be sent from operation room to the ICU if their condition are not stable or to one of the wards (surgical/medical) if they are in a stable condition. Patients who had minor operation they will be sent from the operation room to the observation room. According to the other three levels which are related to the checkup rooms. First, they will be sent to the triage room after that to the checkup rooms. Level 3 patients should wait for maximum 30 minutes, level 4 patients should wait for maximum 2 hours, and level 5 patients can wait until their turns come. From the checkup rooms if the patients' condition is stable they will leave the hospital; if not, they will be sent to the observation room (male/female). From the observation room they will be sent to one of the wards (surgical/ internal) or leave the hospital.

## 4.2 Input and Output of the Model

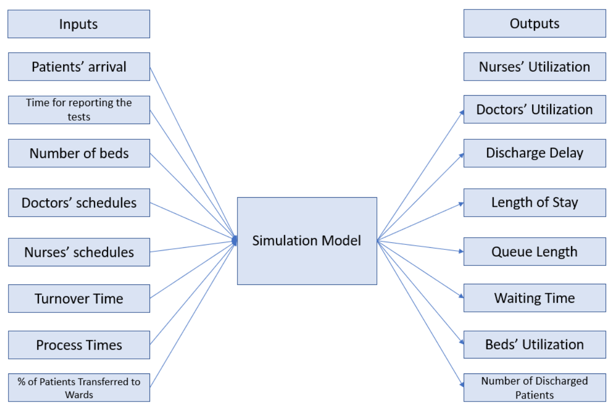


**Figure 7: Simulation Model's Inputs and Outputs**

Figure 7 displays the inputs and outputs that are needed to build the simulation model.

## 4.3 Performance Measure

After collecting and analyzing the data, there are four performance indicators that can be used to measure the system's performance.

1. LOS: The LOS of patients in the hospital should not be long, as the longer they stay without the need of it the more they are utilizing beds which is causing over occupancy.
2. Bed occupancy: The bed occupancy should not exceed 85%, in order to make sure that the efficiency in using beds is maximized. This ensures using beds optimally. It should not be less than that in order to cover the cost and it should not be more, so that new patients have a place.
3. Waiting time: Patients should not wait too long as it might affect their health negatively.
4. Resource utilization: Utilization of resources should not be more than 85%. Using resources efficiently will lead to increase in the whole system's efficiency and effectiveness. Moreover, overusing resources may cause many problems, losses and failures.
5. Number of patients discharged: The more discharged patients, the more it is better as they are giving the chance to waiting patients to occupy their place.

## 4.4 Simulation Model

The hospital has been simulated through ARENA Rockwell Software. A simplified version of the hospital was modeled taken into consideration the parts and wards of the hospital that need to be studied. Twelve wards were simulated that consist of six surgical wards and three internal wards. Moreover, input analyzer was used only for the internal ward, because patients' LOS per hour were provided.

**Table 1: Percentage of Patients Transferred**

| Patients Transferred From | Patients Transferred To | Percentage |
|---|---|---|
| Observation rooms | Surgical wards | 20% |
| Observation rooms | Internal Wards | 9% |
| Observation rooms | Discharge | 71% |
| Checkup Rooms | Observation Rooms | 40% |
| Checkup Rooms | Discharge | 60% |

Table 1 above shows the percentage of patients flow between observation rooms, ICUs, ORs, surgical and internal wards, and checkup rooms.

**Table 2: Patients Transferred from Observation rooms and ICUs**

| Patients Transferred from Observation rooms and ICUs to | Percentage |
|---|---|
| General Surgery Wards | 41% |
| Orthopedic Wards | 28% |
| Urology Wards | 12% |
| Dental Wards | 9% |
| Ophthalmic Wards | 6% |
| ENT Wards | 4% |

Table 2 above shows the percentage of patients transferred from observation rooms and ICUs to general surgery wards, orthopedic wards, urology wards, dental wards, ophthalmic wards, and ENT wards.

**Table 3: LOS Distributions in Wards**

| Ward | Male LOS Distribution | Female LOS Distribution |
|---|---|---|
| **Internal Ward** | WEIB (1e+003,0.496) | 5.44e+003* BETA(0.416,1.06) |
| **General Surgery Wards** | TRIA (72,240,720) | TRIA (72,240,720) |
| **Orthopedic Wards** | TRIA(120,360,720) | TRIA(120,360,720) |
| **Urology Wards** | TRIA(24,96,168) | - |
| **Dental Wards** | TRIA(24,48,72) | TRIA(24,48,72) |
| **Ophthalmic Wards** | TRIA(24,72,96) | TRIA(24,72,96) |
| **ENT Wards** | TRIA(24,72,120) | TRIA(24,72,120) |

Table 3 above represents the male LOS distribution and female LOS distribution in each ward. Regarding the surgical wards, the LOS data was provided by the doctors and nurses in the wards

**Table 4: Types of Processes and Their Times**

| Type of Processes | Process Time |
|---|---|
| **Triage** | EXPO (3) mins |
| **Vital Signs** | UNI (1,2) mins |
| **Register Room** | UNI (1,2) mins |
| **Clinic Checkup** | UNI (2,7) mins |
| **Observation Doctor Examination** | UNI(5,15) mins |
| **Surgical Wards Doctor Examination** | UNI(10,15) mins |

| | |
|---|---|
| **Internal Wards Doctor Examination** | UNI(5,15) mins |
| **ICU doctor Examination** | TRIA(3,5,7) mins |
| **OT Casualty Operation** | EXPO (10) mins |
| **Major Operation** | TRIA (1,3,6) hours |

Table 4 above represents the types of processes and time taken to complete them.

### 4.5 Replication Parameters

The replication parameters specify how long the simulation will run. Based on the data analysis in section, the data showed that there was no variability in the months and the selected month to be studied is March. Therefore, the replication length is set to be 31 days and base time units in hours.

### 4.6 Warm-up Period

The hospital operates for 24 hours a day, 7 days a week, therefore the warm up period is important to be considered because the model will be in an initially empty idle-state. This means that the model has idle resources and no patient entities in the model. Therefore, by using output analyzer, the warm up period were decided based on the plot to chick on which hour the system reaches steady-state condition. The plot shown in figure 8 displays that after 50 hours the system starts reaching steady-state condition.

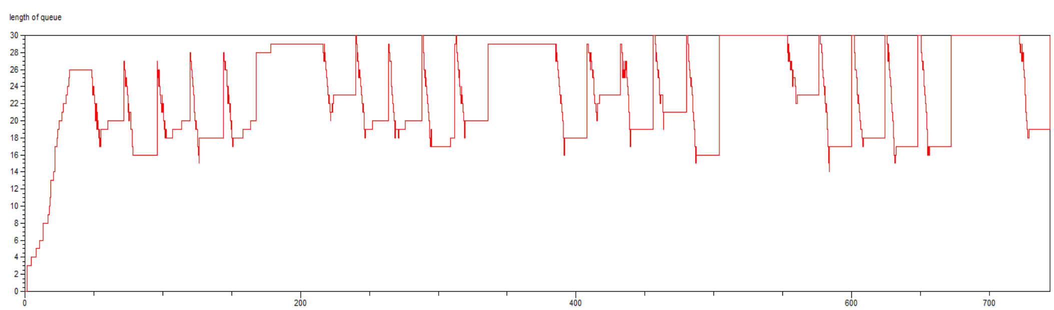


**Figure 8: Steady State of Patient Arrival**

### 4.7 Replication Length

The number of Replication in Arena is first inserted as 5 replications and then tested using the formula below to check if the P-value is less than 0.05. Based on the chosen KPI (total discharged patients from wards), the value that is obtained from the formula is 0.04 that is less than 0.05. Therefore, setting the replication number as 5 is valid.

$$Ratio = \frac{Half\ Width}{Total\ Discharged\ Patients}$$

### 4.8 Validation and Verification

Verification of the model was made to ensure that the assumptions made in the model behaves in the intended way. Therefore, the model execution was controlled by using the step button to step the patient entity through the system. An assign model was used to determine the entity gender and the entities were observed to check the system behavior. Validation of the model is performed to ensure that the model behaves as the real system. Therefore, the KPI is compared from the results of our model to the results of the real hospital system. The chosen KPI is the total number of discharged patients from wards as the data is collected from the hospital, and the total discharged patients from the model is counted using a record model. Table 5 below shows the number of discharged patients from the real system. The number of replications that is calculated from the previous section 4.7 is used to find the half width of the total discharged patients. The confidence interval is calculated by subtracting and adding the half width to the total discharged patients from wards. As shown in table 6, the real-life data falls in the confidence internal, therefore the data is applied to the real-life situation.

**Table 5: Number of Discharged Patients in Real**

| Ward Type | Number of Discharged Patients (Real System) |
|---|---|
| General Surgery | 226 |
| Orthopedic | 215 |
| Urology | 120 |
| ENT | 47 |
| Ophthalmic | 28 |
| Dental | 13 |
| Internal | 321 |
| Total | 970 |

**Table 6: Number of Discharged Patients in Real and in Model**

| Key Performance Indicator | Real-life Data | Model Data | Half Width | Confidence Interval |
|---|---|---|---|---|
| **Total Discharged Patients from Wards** | 970 | 993.8 | 38.72 | (955.08,1032.52) |

## 4.9 Current System Performance

The following table 7 represent the current utilization of beds in each department in the hospital along with the average patient waiting times.

**Table 7: Current Utilization of Bed and Waiting Times**

| Departments | Utilization of Beds | Average Patient Waiting Times (Hours) |
|---|---|---|
| Male Observation Room | 100% | 114.4 |
| Female Observation Room | 100% | 167.0 |
| Male General Surgery Ward | 99.75% | 236.5 |
| Female General Surgery Ward | 99.72% | 226.7 |
| Female Dental | 95.38% | 43.90 |
| Female Orthopedic | 95.38% | 70.20 |
| Male Ophthalmic | 19.23% | 0.003 |
| Female Ophthalmic | 37.14% | 0.002 |
| Male Internal Wards | 27.65% | 0.145 |
| Female Internal Wards | 29.51% | 0.203 |
| Male ENT | 30.61% | 0.196 |
| Female ENT | 35.41% | 0.004 |

**High Utilization and Long Waiting Time**

**Low Utilization And Less Waiting Time**

## 5. Results and Analysis

In section 5.1, the OptQuest for Arena™ will be exemplified. In section 5.2, the what-if scenarios and results of output analyzer will be discussed.

## 5.1 OptQuest for Arena™

OptQuest for Arena™ is used to make sure that hospital beds in wards are used appropriately. (National Institute for Health and Care Excellence, March 2018) stated that average bed occupancy rates greater than 85% have the risk to experience regular bed shortages and increased infection rates. However, average bed occupancy rates below 70% leads to excess capacity and high unemployment of resources (nurses, doctors). Therefore, the objective of OptQuest is to setup an optimization model to maximize the utilization of beds subject to the utilization of beds to be above

below 85% and above 70%. The controls and responses are defined as bed resource and bed utilization. In OptQuest for Arena™, the optimization model is conducted for all type of wards to examine the optimal number of beds that should be used to satisfy the constraints. However, some of the wards' optimization model solutions were infeasible because they did not satisfy the given constraints. Yet, the best infeasible solutions that are close to 70% utilization were chosen because it is better to have capacity than bed shortages. Moreover, male Dental ward and male orthopedic ward beds were not optimized since they have optimal utilization rate that satisfies the constraints.
Table 8 shows the actual number of beds and utilization rate in each ward besides the OptQuest results of optimized number of beds that should be used in each ward and its utilization rate.

**Table 8: OptQuest Results**

| Wards / Beds | Actual Number of Beds | Actual Utilization % | Optimized Number of Beds | Optimized Utilization % |
|---|---|---|---|---|
| **Internal (Male)** | 105 | 27.65% | 36 | 83.1% |
| **Internal (Female)** | 105 | 29.51% | 37 | 83.3% |
| **General Surgery (Male)** | 26 | 99.75% | 112 | 84.9% |
| **General surgery (Female)** | 26 | 99.72% | 49 | 83.3% |
| **Urology (Male)** | 30 | 62.36% | 22 | 81.9% |
| **Ophthalmic (Male)** | 13 | 19.23% | 4 | 64% |
| **Ophthalmic (female)** | 7 | 37.14% | 3 | 57.8% |
| **ENT (Male)** | 15 | 30.61% | 4 | 67.5% |
| **ENT (Female)** | 11 | 35.41 | 4 | 71.5% |
| **Dental (Male)** | 2 | 81.41% | - | - |
| **Dental (Female)** | 2 | 94.54% | 3 | 77.3% |
| **Orthopedic (Male)** | 36 | 84.08% | - | - |
| **Orthopedic (Female)** | 23 | 95.38% | 35 | 84% |

## 5.2 What-If Scenarios and Output Analyzer Results

What-If scenarios were generated in order to find solutions related to poor bed management. The following scenarios are listed below:
1- Allowing to discharge patients on weekend and having the discharge policy to be from 7:00 am – 7:00 pm instead from 7:00 am – 1:30 pm.
2- Adding mobile beds in Male and Female Observation Rooms.
3- Using two internal wards for general surgery wards
4- Reducing the turnover time which is the cleaning time that is considered as the time between a discharged patients and admitted patient to be 15 minutes instead of 30 minutes.

Output Analyzer is one of the tools that can be used in arena simulation in order to decide if there is any statistical difference between two scenarios. Therefore, the output analyzer was applied for the four scenarios that were mentioned above based on the number of discharged patients. Table 9 represents the comparison of each scenario with the base model along with the findings and the effectiveness of each scenario.

**Table 9: Comparison between Scenarios**

| Comparisons | Output Analyzer Findings | Effectiveness |
|---|---|---|
| Base model and scenario 1 | Zero is out of the Interval and interval >0 | Has a significant effect |
| Base model and scenario 3 | Zero is out of the Interval and interval >0 | Has a significant effect |
| Base model and scenario 2 | Zero is inside the Interval | Has no sigficant effect |
| Base model and scenario 4 | Zero is out of the Interval and interval >0 | Has a significant effect |
| Scenario 3 and scenario 1 | Zero is out of the Interval and interval >0 | Has a significant effect |

Each of the following Figures (9, 10, 11, and 12) denotes the change in utilization of beds, waiting time, length of queue and discharged patients in each ward for each gender after applying the scenarios in the system.

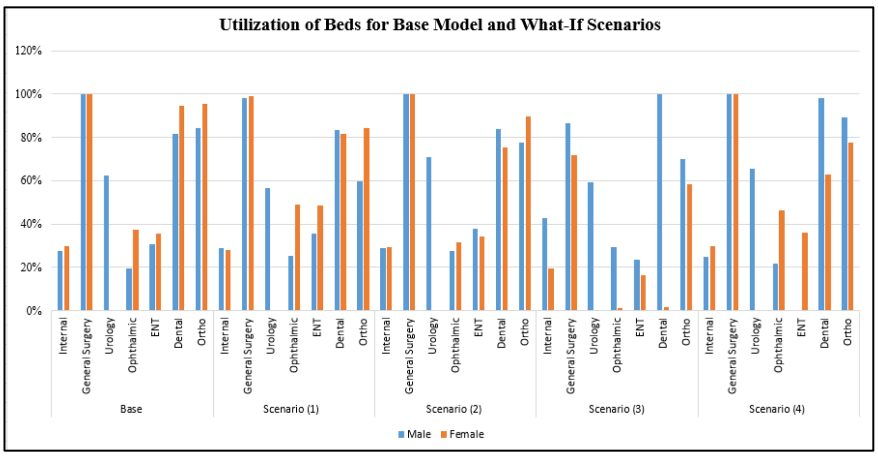


**Figure 9: Utilization of Beds**

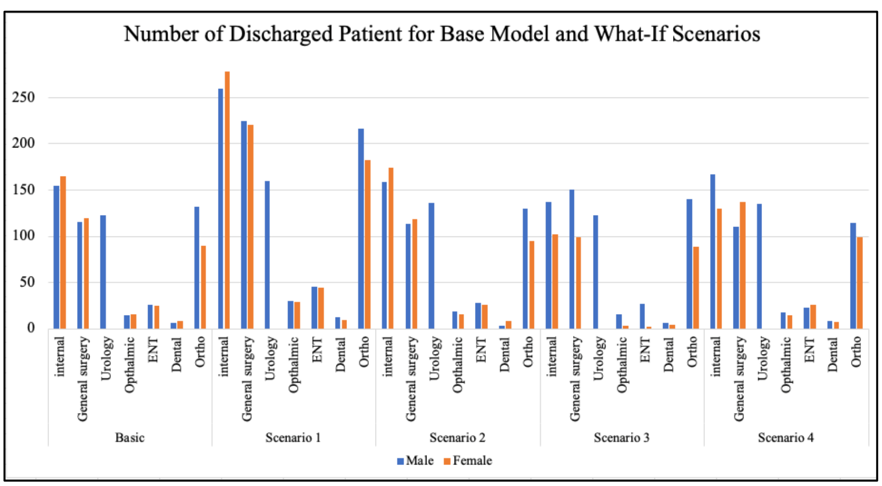


**Figure 10: Number of Discharged Patients**

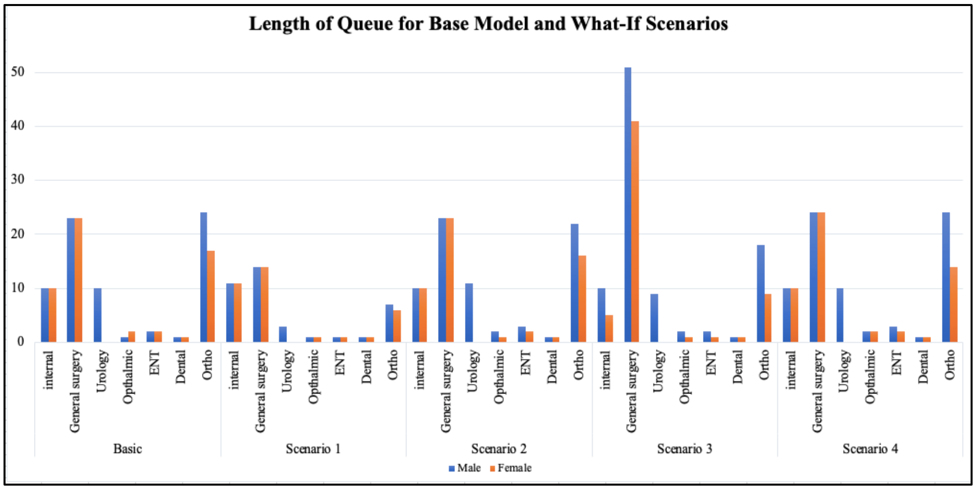


**Figure 11: Length of Queue**

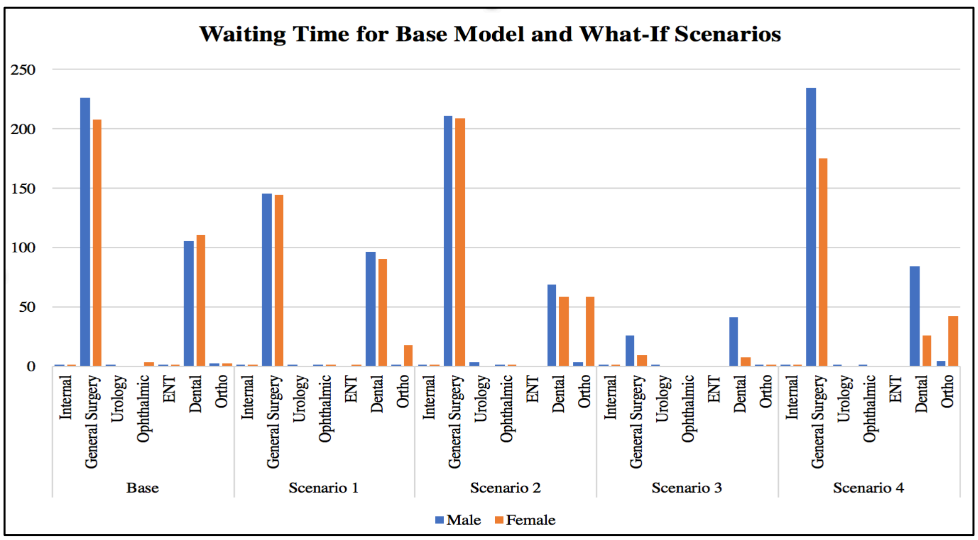


**Figure 12: Patient's Waiting Time**

## 6. Recommendations

Suggested solutions were provided to enhance the hospital performance showing the possible effective solutions for the hospital representatives.

1) Patients that are ready to be discharged, must be signed by doctors' approval. Hence, transferring patients who are just waiting for the doctors' signature to be discharged to a specialized room called a discharge room or lounge for males and females. This will minimize the waiting times of new patients' comers to the wards.
2) Adding a new general surgery ward in the unused basement floor of the layout to reach the targeted utilization rate and reduce the waiting time of patients in the observation room waiting to be admitted to wards.

3) Add extra cleaners on Sunday to free up rooms earlier for patients waiting to be admitted. This will minimize the queue length of patients waiting time.
4) After finding the total optimal number of beds in the hospital, a suggestion can be made by expanding the observation rooms for both females and males through using the extra beds that were non-occupied in some wards. This will reduce the waiting time for patients entering the observation rooms and decrease the utilization of beds.
5) Adding a doctor who is responsible for female wards and a doctor for male wards to prevent shared resources between genders. The goal is to increase the number of discharged patients and increase the opportunity for other patients to occupy the bed.
6) Reduce the turnover time between admissions by assigning two cleaners at the same time to clean the beds.
7) Increase the number of male general surgery beds by 86 and female general surgery beds by 23 to reduce the high occupancy rates and infection rates.
8) Reduce the number of internal male beds by 69 and female internal beds by 68 to minimize the underutilized resources.
9) Combine wards with very low utilization of beds (such as internal, ophthalmic, and ENT wards) and use the beds in these wards for wards with high utilization of beds (such as general surgery wards).
10) Extend the working hours of doctors that are responsible in patients' rounds to improve the discharge policy. This will permit patients that are ready to be discharged to be discharged earlier in the day and will reduce the overlap time to accommodate both patients awaiting discharge and new patients' admission to wards.
11) Transferring patients with acute and long-lasting medical conditions to residential care centers in order to reduce the occupancy rates in the wards.
12) Adding a waiting time system in the hospital's website that shows the current waiting time in assigning the triage level. This will allow people with non-emergent conditions in deciding of when to arrive to the hospital. The goal is to minimize the number in queue and the high congestion rates in the ED.

### 7. Conclusion

To sum up, management of bed capacity and availability will have a decisive impact on the hospital, meaning that improvement related to bed management will impact the availability of beds therefore improving patient flow. The objective of this project is to optimizing the appropriate number of beds in a public hospital to decrease the high occupancy rates and prolonged patients waiting time. By achieving this objective, the system will be improved in different aspects related to BC such as: reach a better utilization rates of beds that are between 70% and 85%, decrease the length of queues for beds, reduce patients waiting time, and increase the number of patients recovered. All the data that have been collected from the hospital were applied in Arena Simulation Software to understand the current system behavior. After running the base model, the outputs showed the bottle neck department that causes the congestion in the ED. The department with the highest utilization rate, queue length, and long waiting times are the male and female general surgery wards. Therefore, OptQuest for Arena™ have been used to provide the appropriate number of beds in each department to decrease the utilization rate and increase the number of discharged patients. Furthermore, four scenarios have been suggested for the base model to improve the performance of doctors and decrease the queue length of patients .The first one is changing the schedule of the doctors; second, adding mobile beds in MOR2 and FOR2; third, using two of the internal wards to be occupied by the general surgery ward; finally, reducing the bed cleaning procedure time by hiring extra cleaners for the wards. By using the output analyzer, the first scenario was shown that is the best to apply.

## References

Agada, P., Kembe, M., & Owuana, D. (2014). A Queuing MOdel for Hospital Bed Occupancy Management. *International Jornal of Computational and Theoretical Statistics*, 13-28. Retrieved March 12, 2019

Bessman, E., Howell, E., Kravet, S., Kolodner, K., Marshall, R., & Wright, S. (2014, June). Active Bed Management by Hospitalists and Emergency Department Throughput. *Annals of Internal Medicine, 149*. doi:10.7326/0003/4819/149/11/200812020/00006

Beullens, P., Jones, D., Tamiz, M., & Li, X. (2007). An Integrated Queuing and Multi-Objective Bed Allocation Model with Aplication to a Hospital in China. *Jornal of the Operation Research Society*, 1-9. doi:10.1057/palgrave.jors.2602565

Clarke, A. (1996, June 13). Why Are We Trying to Reduce Length of Stay? *Quality in Health Care, 5*, 172-179.

Gorunescu, F., McClean, S., & Millard, P. (2002). A Queuing for Bed-Occupancy Management and Planning of Hospitals. *Jornal of the Oparetion Research Society, 53*, 19-24. doi:10.1057/palgrave/jors/2601244

Landa , P., Sonnessa, M., Tanfani, E., & Testi, A. (2014). A Discrete Event Simulation Model to Support Bed Management. *4th International Conference on Simulation and Modelling Methodologies, Technologies and Applications*, 901-912. doi:10.5220/0005161809010912

Pinto, L., Perpetuo, I., Campos, F., & Ribeiro, Y. (2015, January). Analysis of Hospital Bed Capacity Via Queuing Theory and Simulation. *Winter Simulation Conference*, 1-13. doi:10.1109/WSC.2014.7019984

Sitepu, S., Mawengkang, H., & Husein, I. (2017). Optimization Model for Capacity Management and Bed Scheduling for Hospital. *4th International Conference on Operational Research*. doi:10.1088/1757-899X/300/1/012016

Antelo, M., Calvo, A., & Santias, F. (2015). Bed capacity and surgical waiting lists: a simulation analysis. *European Journal of Government and Economics*, 2.

Beeknoo, N., & Jones, R. (2016). A Simple Method to Forcast Future Bed Requirements: A Pragmatic Alternative to Queuing Theory. *British Journal of Medicine &Medical Research*.

Demeulemester, E., & Ma, G. (n.d.). A Multilevel integrative approach to hospital case mix and capacity planning. *Faculty of Business and Economics*.

Bares, R., Baboolal, K., Griffiths, J., Knight, V., Nelson, A., & Williams, J. (2012). Simulating Bed Capacity: Evaluating the Impact of Healthcare Service Transfers. 358 - 362 .

Carter, L., Robinson, C., & Zeitz, K. (2012 ). The ebbs and flows of changing acute bed capacity delays.

Kennedy, K., & Kobis, D. (2006, October). Capacity management and patient throughput putting this problem to bed. 88-94.

Lee, S., Shapoval, A., & Wang, Z. (2017). Inpatient Bed Management to Improve Care Delivery. 1033 - 1039.

El-Darzi , E., Chaussalet , T., Vasilakis, C., & Millard, P. (1998). A simulation modelling approach to evaluating length of stay, occupancy, emptiness and bed blocking in a hospital geriatric department. *Health Care Management Science*, 143-149.

Bagust , A., Place , M., & Posnett, J. W. (1999, July 17). Dynamics of bed use in accommodating emergency admissions: Stochastic simulation model. *York Health Economics Consortium, 319*, 158.

Forneas, N. (2019). *Improving hospital bed management with AI - Client Success Field Notes*. Client Success Field Notes. Available at: https://www.ibm.com/blogs/client-voices/improving-hospital-bed-management-ai/ [Accessed 1 Apr. 2019].

Foster, A. J., Wells, G., Lee, A. J., & Walraven, C. V. (2003, February). The Effect of Hospital Occupancy on EmergencyDepartment Length of Stay and Patient Disposition. *Academic Emergency Medicine, 10*(2), 127-133. Retrieved from https://onlinelibrary.wiley.com/doi/epdf/10.1197/aemj.10.2.127

Geisler, S., Schmit, R., & Spreckleser, C. (2013, January 7). Decision support for hospital bed management using adaptable individual length of stay estimations and shared resources. *BMC Medical Informatics and Decision Making*.

Kumar, A., & Mo, J. (2010, January 9-10). Models for Bed Occupancy Management of a Hospital in Singapore. *International Conference on Industrial Engineering and Operations Management* .

Bruin, A. d. (2008, September 18). *Dimensioning hospital wards using the Erlang loss model*. Retrieved February 25, 2019, from math : https://www.math.vu.nl/~koole/publications/2010aor/art.pdf

*Hospital Bed Occupancy*. (2018, September 13). Retrieved February 28, 2019, from Nuffield Trust: https://www.nuffieldtrust.org.uk/resource/hospital-bed-occupancy

*Management Study HQ*. (n.d.). What is Management?. Retrieved March 1, 2019, from: https://www.managementstudyhq.com/what-is-management.html

National Institute for Health and Care Excellence. (2018, March). *Chapter 39 Bed Occupancy.* Retrieved February 25, 2019, from nice: http://www.nice.org.uk/guidance/ng94/evidence/39.bed-occupancy-pdf-172397464704

Gossart, D., Guinet, A., & Meskens, N. (2010, October). Strategic and Tactical Hospital Bed Management in Belgium and in France. *HAL*. Retrieved April 6, 2019, from https://link.springer.com/content/pdf/10.1007%2F978-3-642-15961-9_29.pdf

Hendy, P., Patel, J., Kordbacheh, T., Laskar, N., & Harbord, M. (2012). In-depth analysis of delays to patient discharge: a metropolitan teaching hospital experience. *Clinical Medicine, 12*(4), 320-323.

Kobis, D. A., & Kennedy, K. M. (2006, October). capacity management and patient throughput putting this problem to bed. *Helathcare Financial Management*, 88 - 94.