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Emergency department design evaluation and optimization using discrete event simulation

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EMERGENCY DEPARTMENT DESIGN EVALUATION AND OPTIMIZATION USING DISCRETE EVENT SIMULATION

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Finally, I would like to thank all those who helped complete this milestone in my academic path. I believe there are many more that deserve to be acknowledged. I am blessed to be surrounded with such supporting mentors, family, and friends.

Abstract

The proposed research would help any architect/owner decide the number of rooms/ cubicles for each sub-department of the ED, as well as have an estimated price for the ED, in order to optimally serve patients entering the ED with a known arrival rate.

A thorough literature review was undertaken to collect data concerning the application of decision support tools for minimizing patient waiting times and maximizing the utilization rate in health care systems. Interviews were made with hospital managers in order to verify process flow, waiting times, activity durations, and resources. In addition, several floor plans of EDs have been studied in order to assure the logical flow of the process. Based on the data collected and the several verifications, a discrete event simulation model was developed using ARENA software. This simulation model was then verified by building a similar model on different software, which was AnyLogic. The results proved the accuracy of the model. Twenty additional simulation runs were performed to be used for the regression analysis. The equations resulted from the regression analysis were used for the optimization model. A genetic algorithm was used for the purpose of obtaining optimized resource allocation for different arrival rates within a constrained budget, area, and patient waiting time in the system.

This study will add to the body of knowledge in regards to architecture and construction management, as it will increase the efficiency of emergency departments' architectural design.

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Glossary

CDC: Centers for Disease Control

DES: Discrete Event Simulation

ED: Emergency Department

EM: Emergency Medicine

EMTALA: Emergency Medical Treatment and Active Labor Act

FT: Fast Track

ICU: Intensive Care Unit

LOS: Patients' Length of Stay

OR: Operation Room

PAC: Patients Acuity Class

- PAC 1 is for patients who are seriously injured or ill (car accidents, stroke) i.e. they need lifesaving treatment.
- PAC 2 and PAC 3 are related to accidents that occurred in workplace, food poisoning, bleeding injury, or broken bones. That makes the top three specialty areas are general medicine (in case of food poisoning), general surgery (in case of bleeding injury), and orthopedics (in case of broken bones).
- PAC 4 is for patients who have minor symptoms and could go to clinics instead of ED.

PDQ: Provider Directed Queuing

PNs: Petri-nets

Chapter One

Introduction

I. CHAPTER ONE: INTRODUCTION

A. Background

1. Emergency Department

An ED is a specialized medical facility that treats patients with emergency cases who come by themselves or via an ambulance with no preceding appointments. Such a facility is present either in a hospital or as a center for 'primary care'. Other terminology for the ED would be the accident & emergency (A&E), the emergency room (ER), the emergency ward (EW), and the casualty department. Preliminary treatments and protocols for various kinds of illness and injury should be present at all times because the nature of the patients' visitation is likely unplanned.

It is important to understand the journey the patient makes through the emergency department. Patients entering the ED are streamed into three categories some of which enter through the walk-in entrance and others through the ambulance entrance. These categories are as follows:

1. Simple injuries or illnesses most of whom arrive by their own means. They are called walk-in patients.
2. Further assessment of those with more serious or complex conditions, most of whom arrive through an ambulance.
3. Resuscitation most of whom enter the ED through the ambulance entrance.

Patients entering the ED from the walk-in entrance will arrive at the main entrance to the reception desk where they will be directed to an assessment room or asked to wait for a short time until the availability of an assessment room is provided. Some might be transferred to the resuscitation room or to the treatment room straight away. Once the patient is sent to the assessment room, examination and minor treatment will occur, and the majority of patients are discharged at that stage. Other patients will be asked to go to the treatment room where tests take place. Some of the patients may be taken to the observation room for a certain number of hours before being discharged from the ED. This can be seen in Figure 1

As for the patients entering the ED from the ambulance entrance, they will enter either the treatment room or the resuscitation room (NHS Estates, Road and Harrogate)

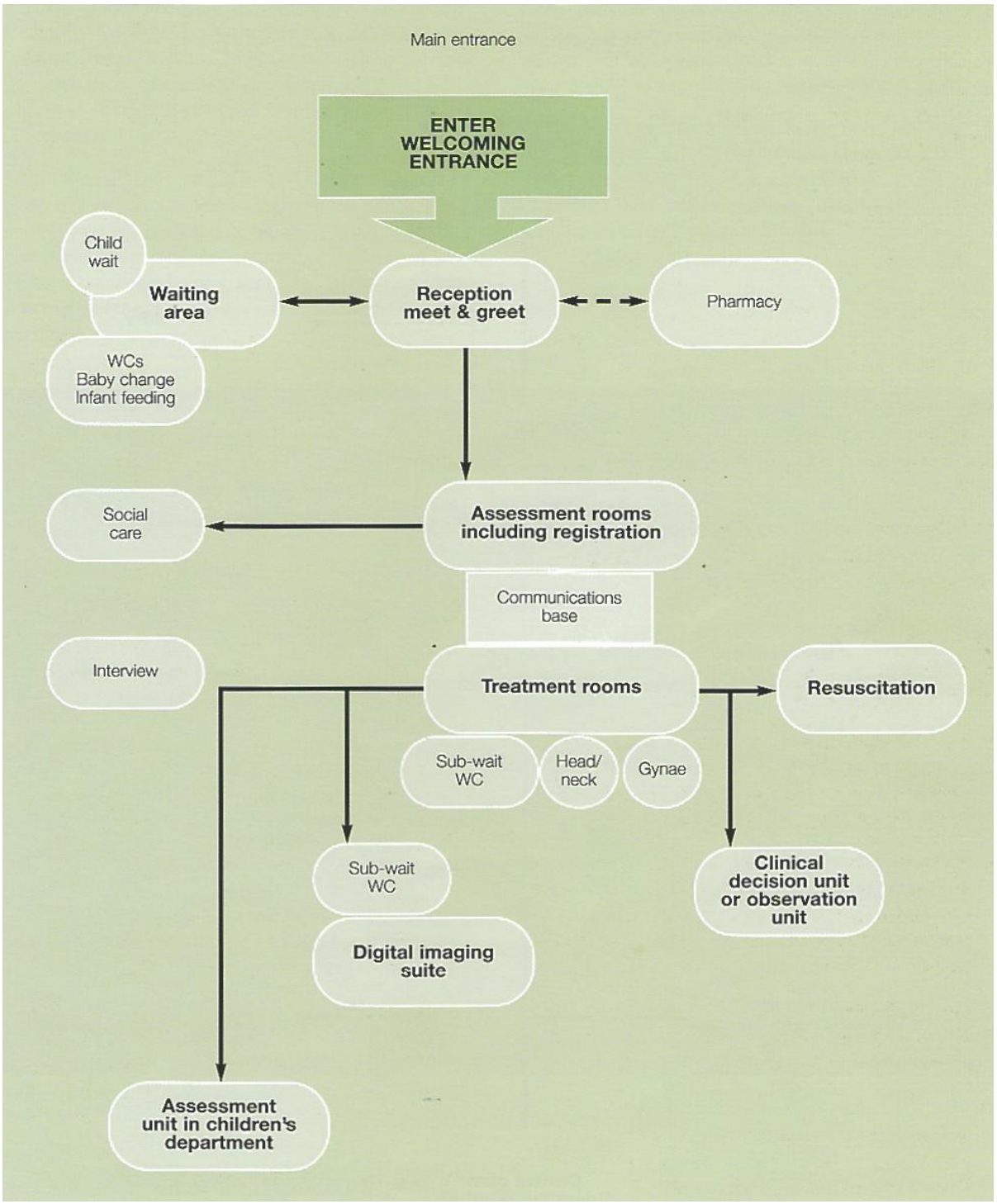


Figure 1: The flow of patients entering the ED through the walk-in entrance (NHS Estates, Road and Harrogate).

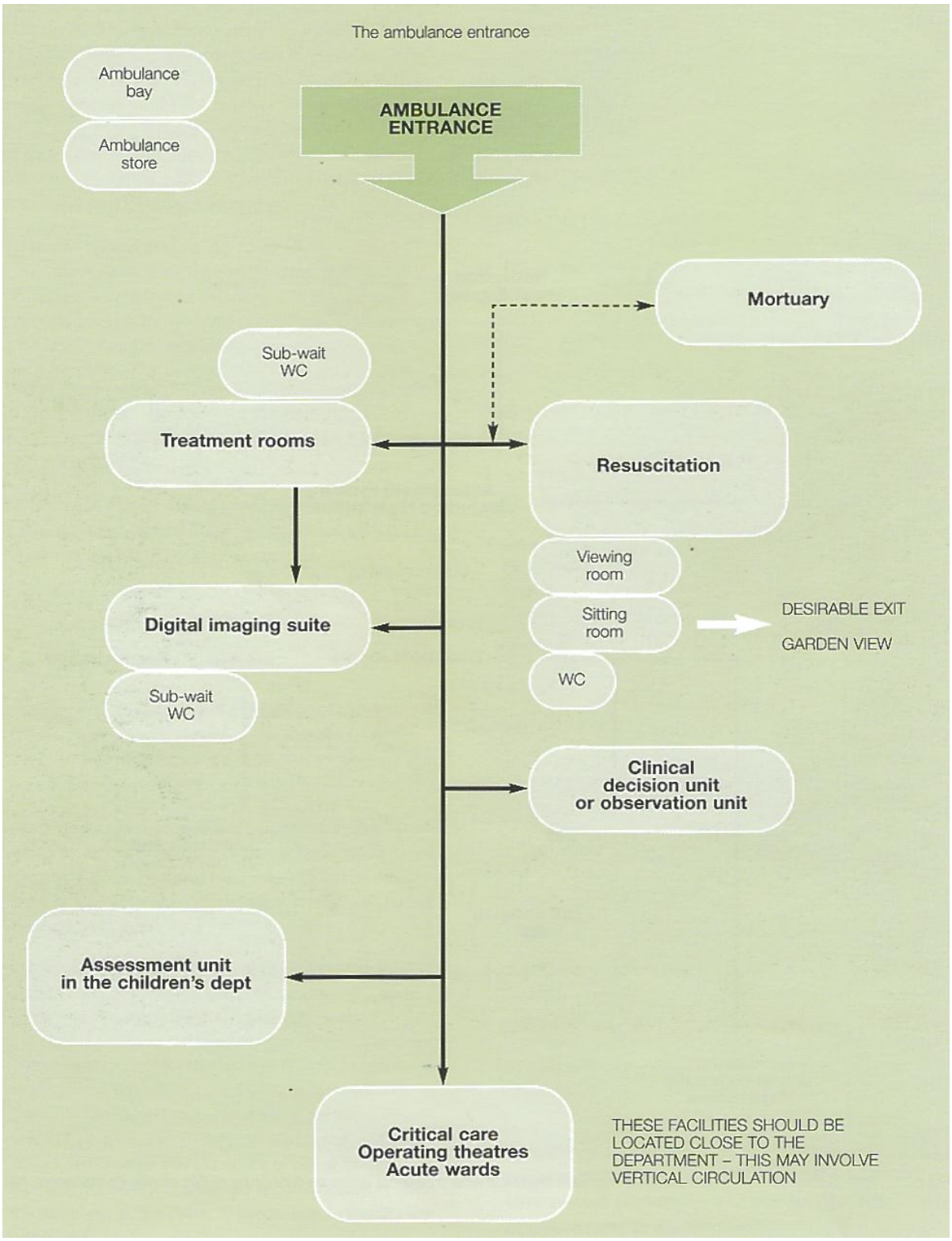


Figure 2: The flow of patients entering the ED through the ambulance entrance (NHS Estates, Road and Harrogate).

2. Design Guide-Lines for EDs

The ED is mainly divided into three major parts. These parts are; Hot case, intermediate, and cold case. The hot case contains the ambulance entrance and the resuscitation room. The cold case is from where walk-in patients enter the ED and go to gynecology, or examination and treatment. The intermediate space as referred to in its name is used by both users and contains the triage, a procedure room, the lab, the x-ray, the radiology and the observation room. This is illustrated in Figure 3.

The plan in Figure 4 is an example of the space distribution according to case. As one can see; the cold case is located on the top of the plan from where walk-in patients enter the ED. The examination and treatment room as well as the gynecology are located in the cold case also. Concerning the intermediate part in the plan, the intermediate activities are located there, which are; the triage (assessment), the mini-procedure/plaster room, the general tests (x-ray, laboratory), and the observation room. Last but not least, the hot case activities are located on the bottom of the plan, where one can find the ambulance entrance on the bottom right and the resuscitation room in the middle bottom.

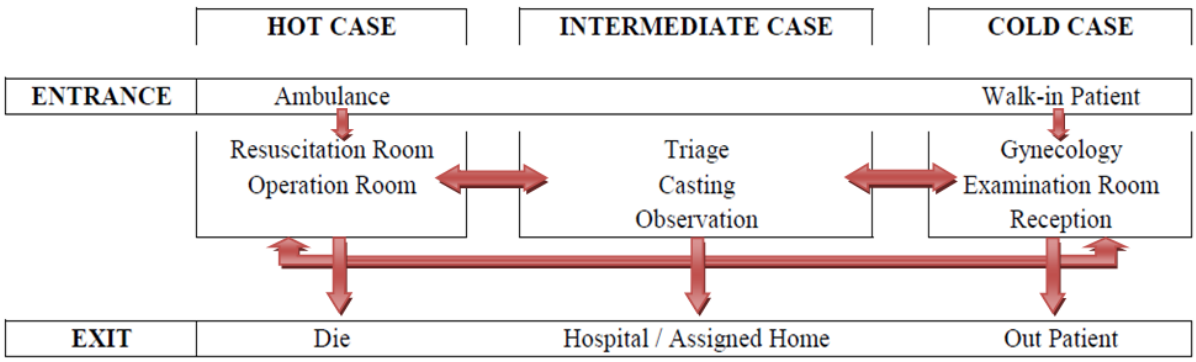
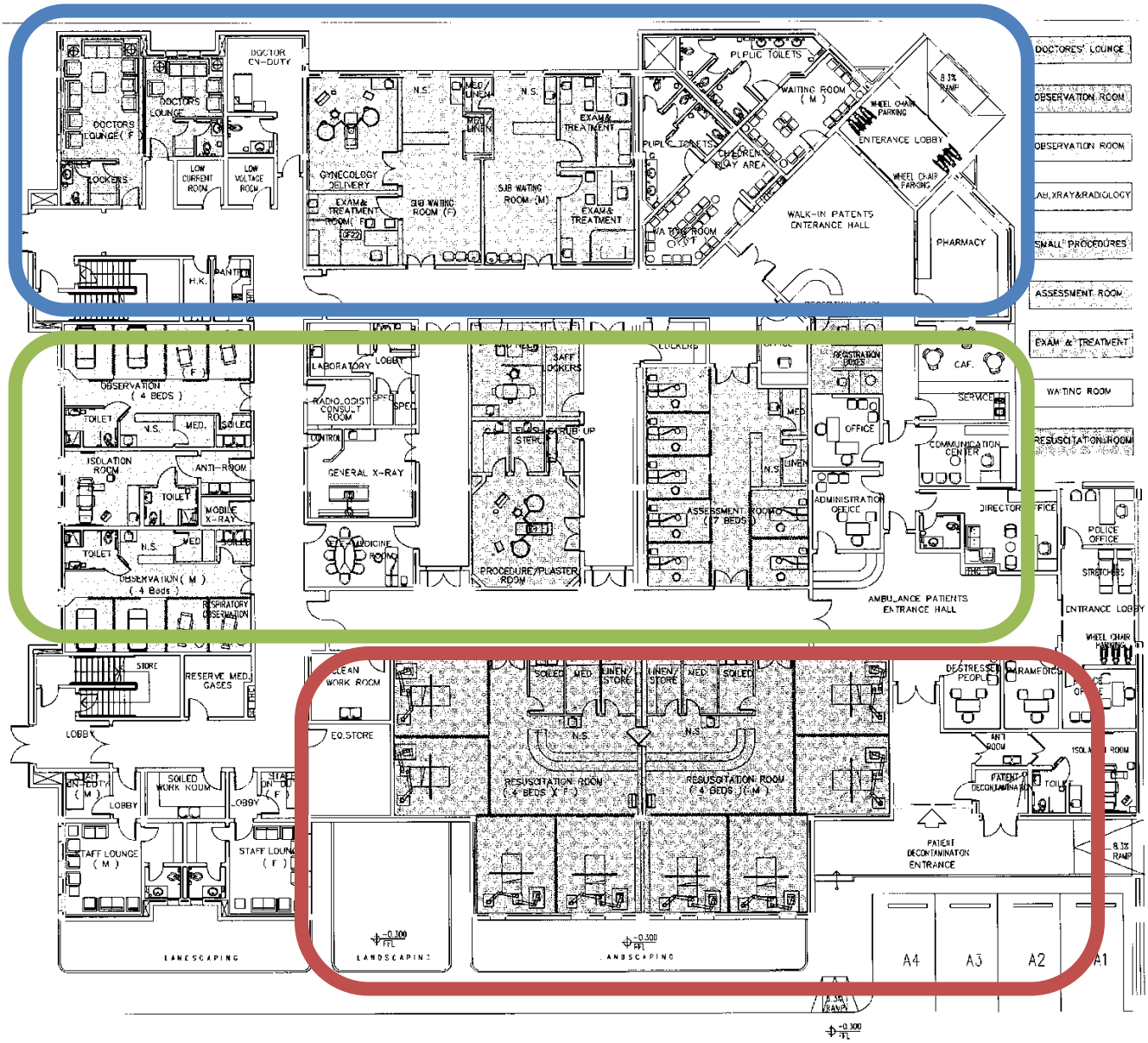


Figure 3: The Three Major Cases in an ED



Legend:

Cold Case	Intermediate Case	Hot Case

Figure 4: A Plan of an emergency department in Saudi Arabia

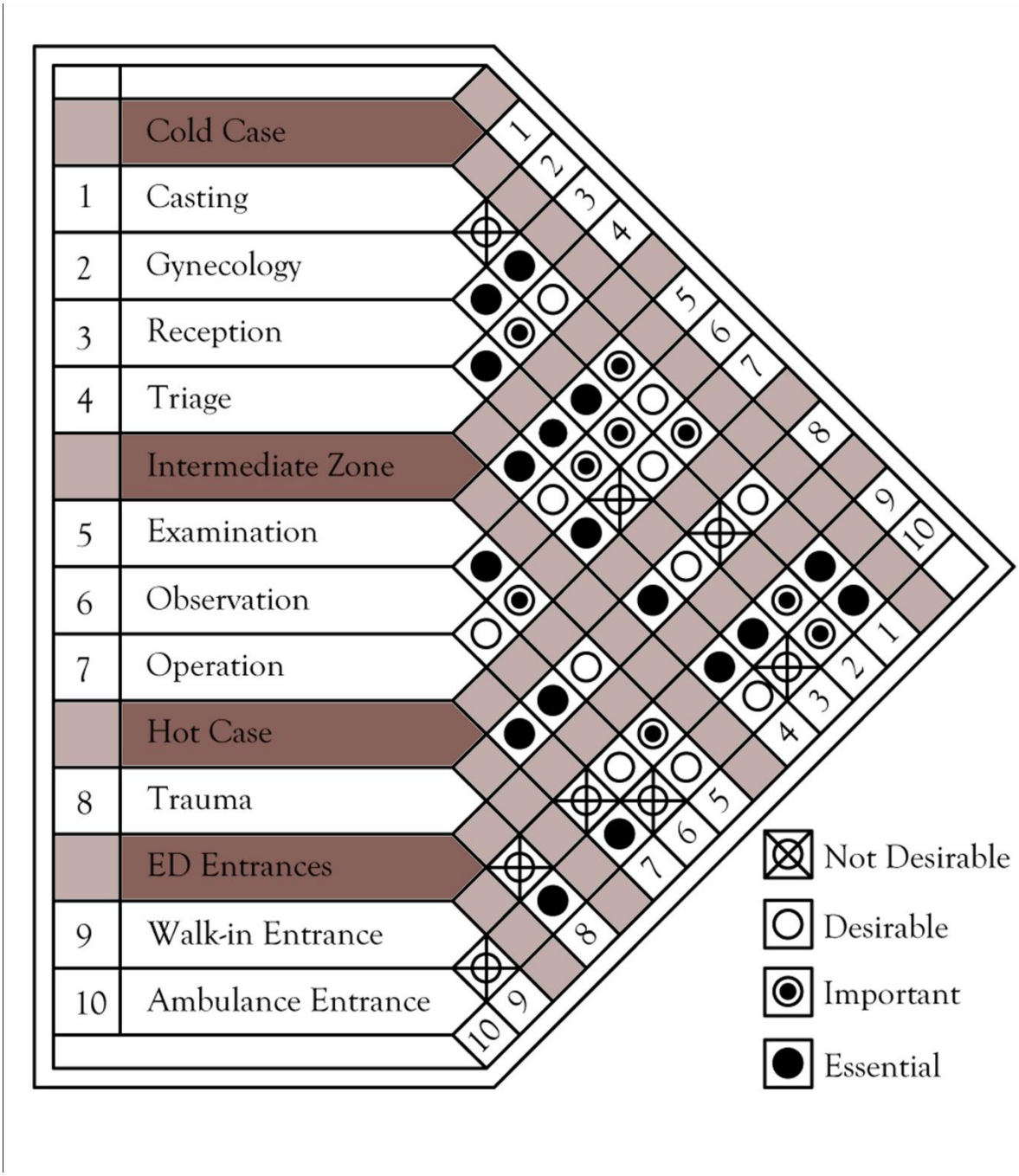


Figure 5: Interrelationship Matrix

B. Problem Statement

Architects face a challenge when it comes to designing Emergency departments (EDs). It should facilitate the process for patients so that they are satisfied while minimizing the cost so that clients are satisfied as well.

On the business front, architects practicing in the health care industry experience a rising demand on minimizing the cost on behalf of the clients. In order to respond to these demands, some architects may choose to achieve that goal while ignoring its effect on the main consumer, the patient. Therefore; due to the financing strategies and the increasing number of people with longer life expectancy, overcrowding in EDs takes place. (Kobus, Skaggs and Bobrow)

According to the Centers for Disease Control and Prevention (CDC), there has been an increase in the number of patients visiting the emergency department (ED) annually by 23% from 1992 to 2002. Another report by the Institute of Medicine in 2006 states that the number of ED visits has increased by 90.3 million (CDC, 2004 report). Such an increase in the no. of patients created overcrowding, which have lead to delayed treatment due to the long patient wait times, overstressed staff due to the overload and low throughput (the number of patients being dismissed from the ED in a certain unit of time). (Brenner, Zeng and Liu).

All of this should not take place because ED is the hospital's front door to the hospital, providing the first and most lasting impression of the quality of care service offered by the hospital even though ED is often underdeveloped and undervalued resource, costing the hospital in several ways (Jensen and Crane)

Patient flow improvement greatly affects the level of service for patients and the quality of life for staff. It may also increase the profitability rate of the ED. This improvement can be done through the improvement of the ED architectural plan by assigning the number of beds in each work station/ activity that would avoid the creation of bottle necks in the flow and accommodate the expected number of patient so as to decrease the patient length of stay. (Medeiros, Swenson and DeFlitch)

Therefore; there is a need for effective ED architectural design because better ED designs lead to better outcomes. ED design plays an important role in serving the functional needs of physicians, staff, patients, and their families. "If the physical facility can be either an enabler of high performance, or a barrier to effective performance, then appropriate design is vitally important. The best facility designs make it more likely that optimum performance can be achieved" (Hamilton and Shepley)

Architects can best support health care management through efficient solutions which pleases the client without disappointing the consumer, the patient. It is very important to evaluate the ED plan designed by architects, before falling in the trouble of having problems, trying to solve it. (Paul, Reddy and DeFlitch)

Architects are regarded as talented problem solvers. A successful emergency department is mainly measured by its capability of fulfilling and satisfying patients' needs. These needs can be defined as improving the level of services while minimizing the cost as much as possible. In order to increase the level of service, the time spent in the health care facility needs to be minimized and the staff should be friendly in order to make it easy for the patients to wait for their turn in a good mood. This could be achieved by the improvement of patient flow and the availability of resources. This is illustrated in Figure 6.

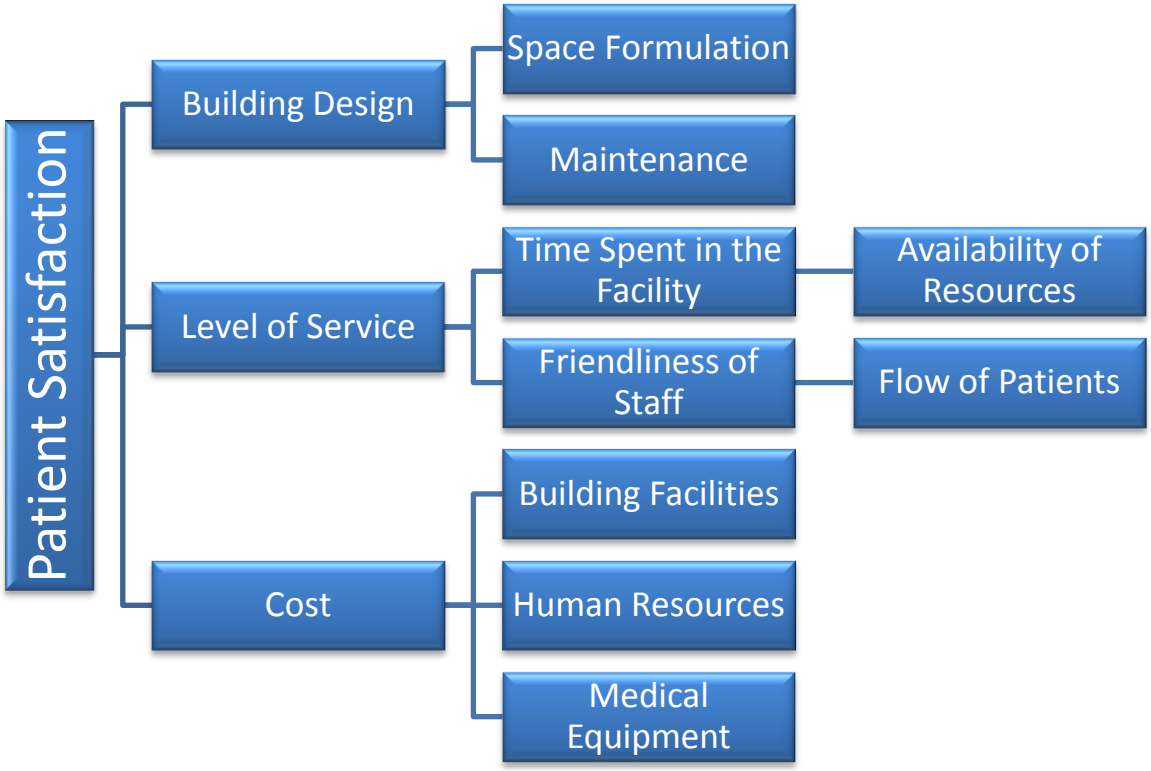


Figure 6: Factors affecting patient satisfaction (the level of service).

This can be done using simulation techniques that would provide guide lines in order to help architects while designing the EDs in order to come up with optimum solutions in terms of spatial areas and cost. (Paul, Reddy and DeFlitch)

C. Objective

The main objective of this research is to develop a tool that would evaluate and help improve the design of EDs and its capability of minimizing the time spent by patients in the facility through an optimization process. This can be done by varying the available design resources within the budget agreed upon by the owner in order not to increase the cost on the owner and respectively on the customers (patients).

D. Scope of Work

The research focuses on the evaluation of ED design and to guide the making of some changes and modifications in the plan according to the results from the proposed simulation model in order to minimize the time of patients in EDs without increasing the cost of the ED.

E. Plan of Work

First, a thorough literature review was conducted in which data was collected on issues related to ED wait times, overcrowding, patient flow, and health care simulations.

Second, a model flow chart was built based on the data collected from previous research and from interviews with hospital managers, doctors and professors.

Third, develop a discrete event simulation model using "AnyLogic Professional" software. Then evaluate and validate the model.

Finally, optimize the data taken from the model in order to maximize the utilization rates of resources and minimize the wait time of patients within the given area of the ED.

Chapter Two

Literature Review

II. CHAPTER TWO: LITERATURE REVIEW

The literature review is divided into two main categories according to the type of research done in this field. The first category is descriptive research (analytical research); where researchers analyze the problem, which is overcrowding and its effect on the length of stay in the facility and diversion, and come up with reasons for its causes. The second category is predictive research; where researchers try to predict when and where the problem will take place so that it could be avoided from happening in the first place. This is done through decision support research, where researchers create a model of what exactly happens in reality and apply different scenarios (what if scenarios) in order to upgrade the system. The scenarios applied are the change in the process of the emergency department or the modification of resources whether human resources like staff or equipment resources. This can be seen in Figure 7.

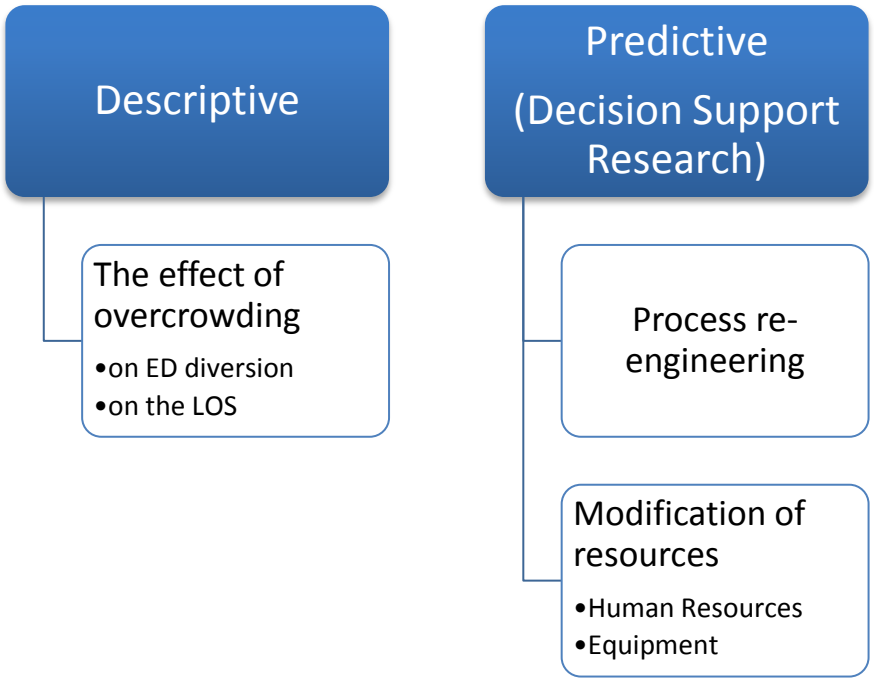


Figure 7: The categorization of published papers on the topic

The most commonly used decision support system is the simulation modeling techniques because simulation modeling helps in resolving problems found in various conditions via experimentation. It would be costly to build, destruct or change in what is real, therefore a simulation model, equivalent to what is real, is built and changes are applied upon it (Sterman). This is clearly illustrated in Figure 8.

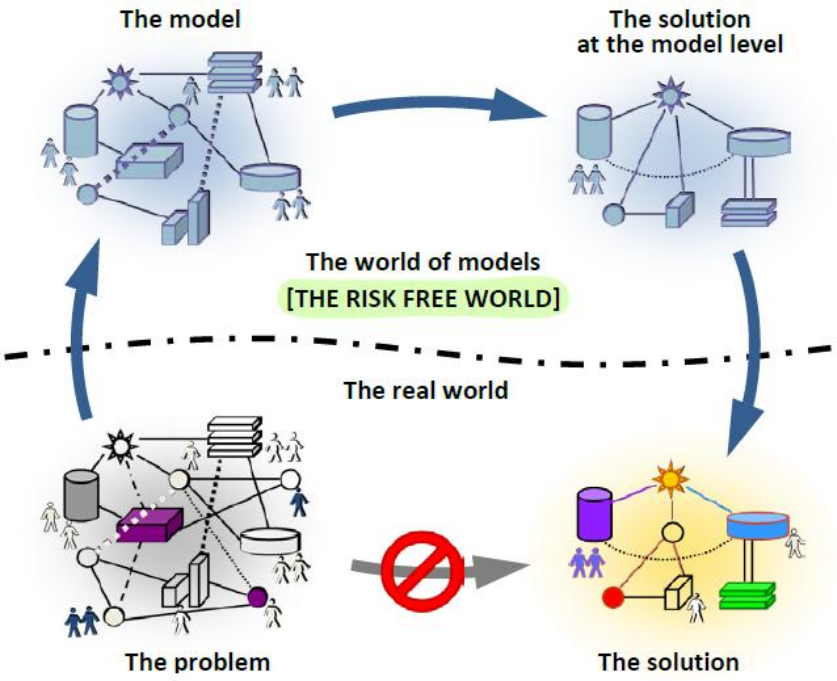


Figure 8: advantage of simulation modeling (Sterman, 2010)

Simulation is a very powerful tool when used to study complex systems, which is the case in emergency departments due to the complexity of interactions between different components and processes. It analyzes the behavior of existing systems that aids in decision-making which helps predict the system's performance via various scenarios structured by the person making these decisions and avoids failure as a result of the risk reduced. It also provides helpful performance measures in which cost analysis and organizational

performances for example, can be integrated in order to reach optimum solutions and better performances. (Shim and Kumar)

As a conclusion, simulation modeling is an important system analysis tool which provides flexibility in testing scenarios, hypotheses, policies, and re-engineering ideas in emergency department settings. It can be used as research tool, education device, decision-making tool and planning mode

> "Using such a tool, health care management can evaluate the efficiency of current practices, examine needed resources, carry out what-if analysis to compare various scenarios to predict the impact of operational changes, determine optimal system configurations, and investigate the relationships or trade-offs among system variables. Such efforts can lead to substantial improvement of system performance to achieve better quality of patient care service. For example, recent simulation studies have been used to help reduce patient waiting time and determine ED configuration and resource allocation like that of Kolker ()." (Brenner, Zeng and Liu).

It is very important to choose the suitable simulation model because they vary according to several aspects. Simulation applications are sorted in Figure 9 according to their level of abstraction. Those with the maximum details in the real world are represented having low abstraction levels. On the other hand, there are models that have high abstraction levels where "individual objects are typically replaced there by aggregates." It has been also

mentioned (Sterman) that there are models whose level of abstraction is considered to be of medium levels between the two mentioned extremes.

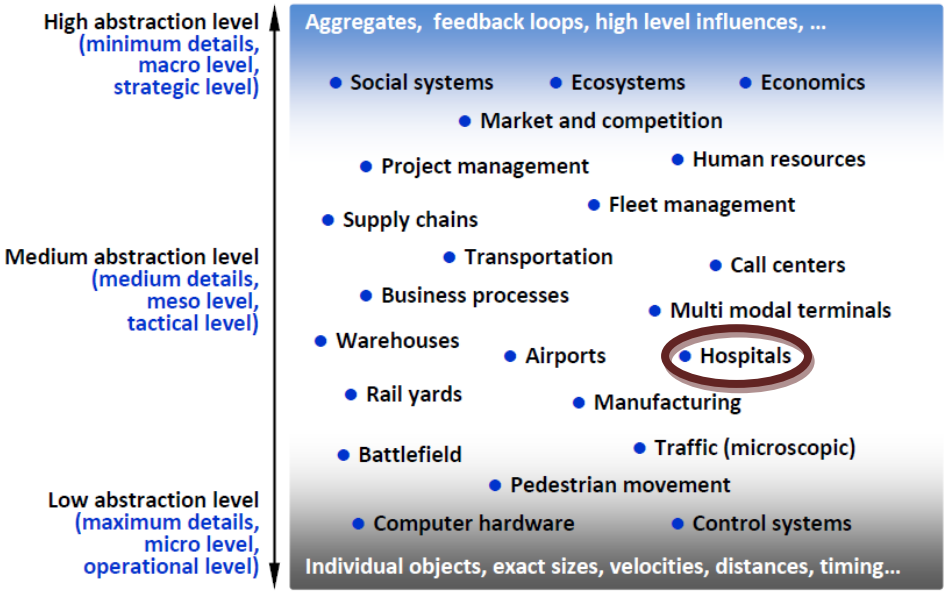


Figure 9: Different Modes of Simulation Application (Sterman)

The modeling of the emergency department in a hospital is an example for that specific level. According to Sterman in his book 'The Big Book of AnyLogic':

> "In a model of a hospital emergency department physical space may matter as we do care how long it takes to walk from the emergency care room to x-ray, but physical interaction between people walking in the building is irrelevant because we assume there are no congestions in the building."

There are three ways to deal with the different levels of abstraction in modern simulation modeling. Strategic modeling makes use of system dynamics where it works with the high levels of abstraction. Medium and medium-low levels are supported by discrete

event modeling while that of high abstraction levels require agent based models which could range between being extremely detailed or highly abstract.

When it comes to decision making tools, discrete-event simulation is one of the most appropriate and efficient tools in order to achieve better system performances by the optimization of resources, which is very suitable in this research. It was originally developed for the use of manufacturers and other industries, but it is now extended for other studies. Nowadays' technology in computer facilities and programming played a great role in such enhancements that simulation modeling of sophisticated facilities and complex logics has become doable. Thus, having such an easily usable tool, increased the number of users of simulation techniques and its applications on health care facilities. This is very efficient and effective as it facilitates the flow of patients and decreases health care delivery costs, leading the improvement of service quality, which leaves the patients satisfied with the service provided for them.

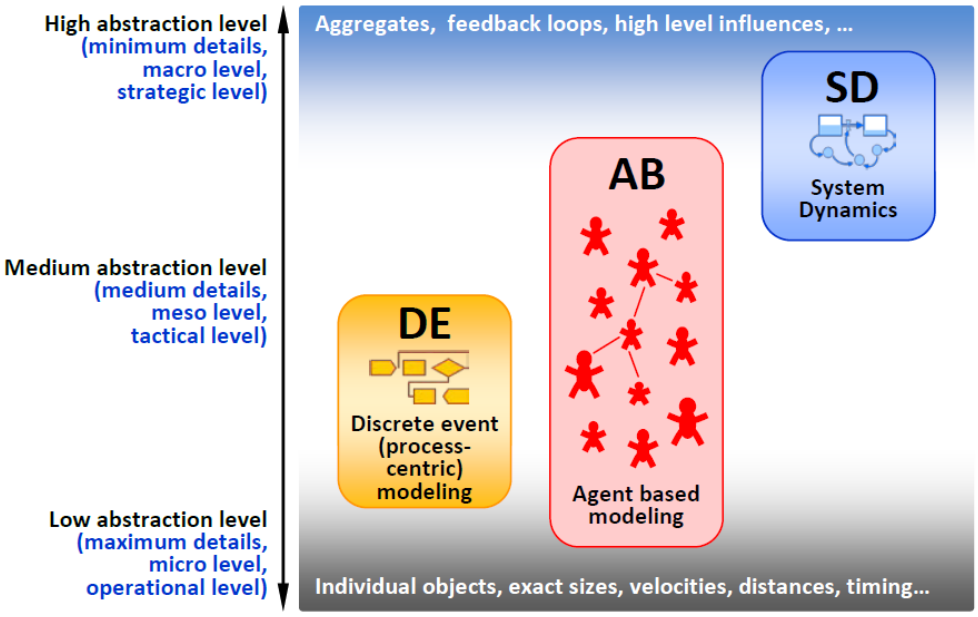


Figure 10: The Suitable Type of Model According to the Abstraction Level (Sterman)

As can be seen in Figure 10, discrete event simulation is suitable in simulating health care facilities due to its low abstraction level. The information required about the system is available on the operational level.

"Discrete Event Simulation (DES) has proved to be an effective tool used for process improvement" (Duguay and Chetouane 311).

A. Descriptive Research

Hwang & Concato () focused on defining overcrowding. Some other researchers focused on overcrowding causes and effects like (Lee), (Derlet), (Haugh)& (Fatovich). Asplin, et al. () proposed a model to clarify the overcrowding issue, while (Weiss, Derlet and Arndahl)& (Epstein and Tian) created a model in order to measure and quantify overcrowding. It has been proposed by (Fatovich) to increase ED capacity by increasing staffing and resources, but this is not always the best solution due to economic and special constraints. And here comes the essential role of optimization and simulation.

Kolker () created a simulation model using a commercial software package named Process Model, Inc, Utah, version 5.2.0. The model was created in order to achieve three goals. The first objective was to "develop an overall methodology to quantitatively link the patients' LOS (length of stay) limits and percent ED diversion" (Kolker 391). The second objective was to detect the maximum LOS limits that will lessen and eradicate the ED diversion significantly. The third objective was to estimate the maximum number of patients in ED waiting room in order to keep the ED diversion percentage on a low single digits level.

Ceglowski, Churilov, & Wasserthiel () used a combination of data-mining and a simulation model to identify the bottle necks in the ED process.

Chockalingam, Jayakumar, & Lawley () defined what overcrowding is and how it reaches a point that causes diversion; explaining that the facility has to redirect the ambulance to

another hospitl close to it. He clarified that the major causes of overcrowding were mainly because of the rules and laws set up by health care authorities which were as follows;“EDs are required by the Emergency Medical Treatment and Active Labor Act (EMTALA), passed in 1986, to screen incoming patients and to provide treatment if needed”. During the time in which the no. of patients has increased and the no. of EDs decreased in the period from 1993 to 2003, 45% of the health care facilities reported ambulance diversion (Chockalingam, Jayakumar and Lawley).

B. Predictive Research

Predictive research has focused on the involvement of optimization, simulation and other techniques in order to solve the overcrowding problem. Some have proposed the variability of resources in order to make best use of them and others suggested modifying the process itself. Simulation in particular has been widely used in health care systems, from the application on outpatient clinics (Swisher and Jacobson) and small sub-systems to national health care systems (Groesser). ED overcrowding is one of problems handled using simulation. One way to solve this problem is to test "what if" scenarios (Mahapatra, Koelling and Patvivatsiri)& (Samaha, W.S. Armel and Starks, Emergency departments I: the use of simulation to reduce the length of stay in an emergency department), and many other ways as will be mentioned.

Paul, Reddy, & DeFlitch () made a study that presented the simulation studies from the 1970s till the 1990s, some of which were published in computer science venues, medical and health science venues and the rest in operation research and management venues. As one can see in Figure 11, the number of research in this field has been increasing by time.

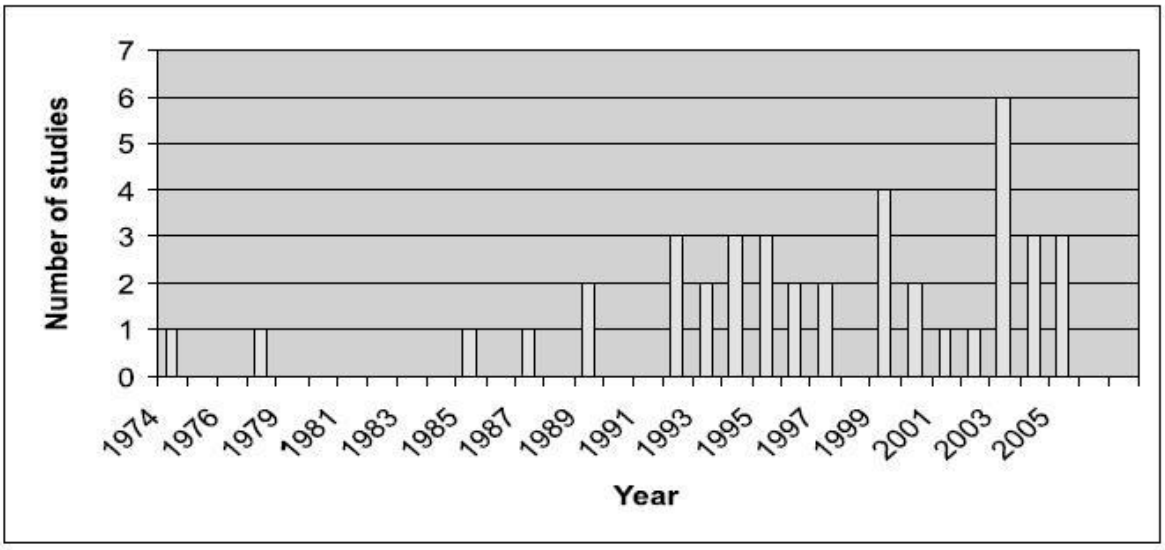


Figure 11: Simulation Papers till 2005 (Paul, Reddy and DeFlitch 561)

Researchers in this category focused on predicting when will ED overcrowding take place in order to create a warning system to overcome the problem before happening (Hoot and Aronsky)& (Hoot, Zhou and Jones).

Hoot, et al. () developed a discrete event simulation of ED patient flow in order to predict near-future operating conditions and to validate the forecasts with several measures of ED crowding. Clarifying and proving that modeling patient flow is a better technique in forecasting near-future ED overcrowding rather than operational summary variables.

In order to minimize the patient waiting time, "what if" scenarios are applied on EDs with several approaches. Some researchers minimize the patient waiting time through the modification of the ED process itself (process re-engineering), while other researchers

minimized the patient waiting time through the modification of resources whether human resources or equipment. This will be explained in the following part of this chapter.

1. Through Process Re-engineering

Based on the recommendations of Blake & Carter's () study, the hospital's administration has implemented a fast track facility for treating patients with minor injuries and has increased the number of physician hours in the emergency room.

Shim, S. J. and Kumar, A. () proposed some variations in the emergency care process in order to minimize patient waiting times. This was done by selecting a case study to work upon, which was the Tan Tock Seng Hospital in Singapore. It contained 1,400 beds providing healthcare services in 17 clinical disciplines. This makes the second largest hospital in Singapore. The no of patients treated daily was around 390 which equals to 28% of all emergency patients treated in the public hospitals in Singapore.

The simulation program used to generate the model above was SIMUL8. The model consisted of four basic elements which are the input (entrance), queues (waits), work stations, and finally, exits (discharged or hospitalized). This can be seen in Figure 12

In order to reduce the patient waiting times, the hospital management considered adding another payment stations and a new short-stay ward. The payment station was added because there were two types of fees; the ordinary fee and extra fees. Having both done on the same payment station created a bottle neck. So it was suggested that PAC (Patients Acuity Class)

2, 3 &4 patients pay the standard fees in the first payment station, which is located after the registration and before the triage, and the cases who have to pay extra fees only go to the second station. All PAC 1 patients go directly to the second payment station as they don't pass by the triage process and they pay more than the standard fees. Patients stay in the observation room quite a long time; therefore it was suggested to add the short-stay ward for the cases that will stay for less than a day. The suggested solutions can be seen in Figure 13.

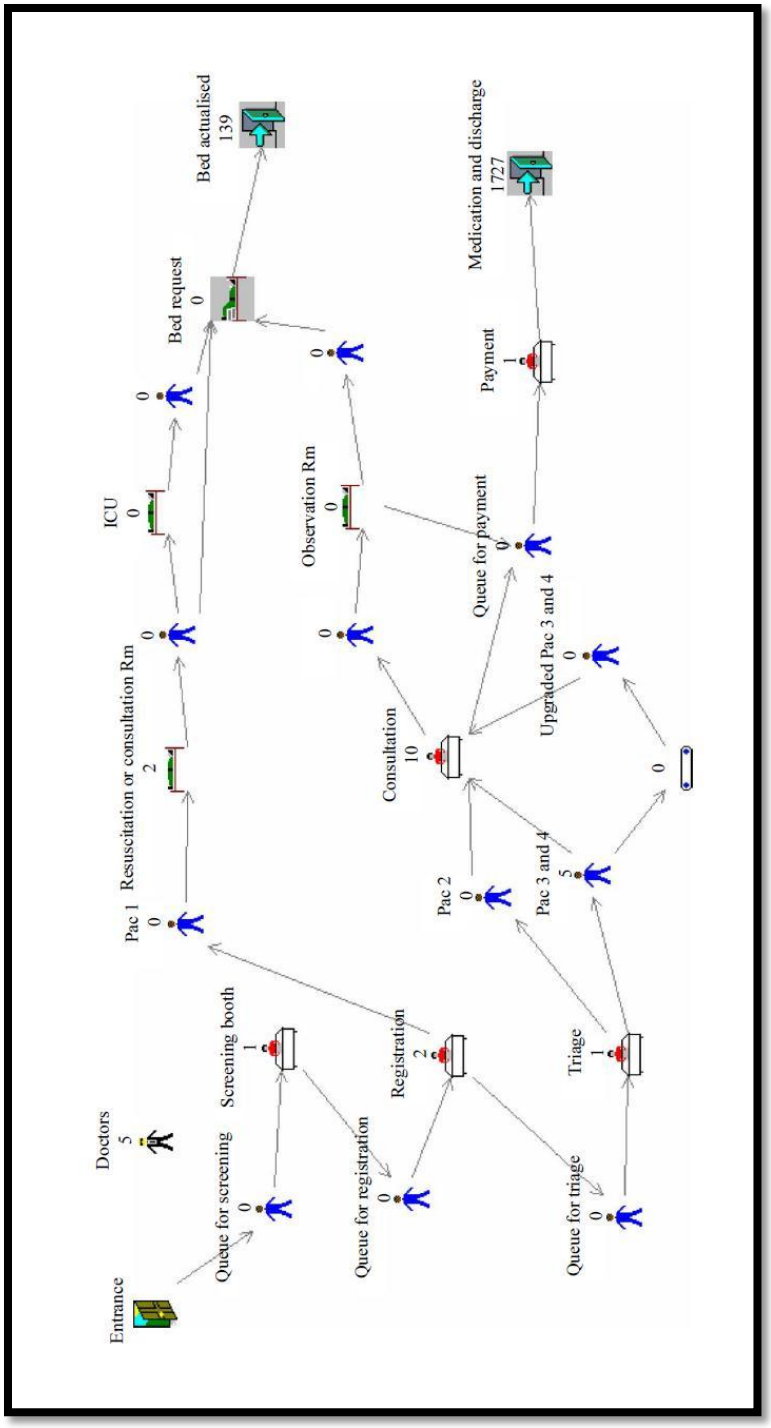


Figure 12: The Simulation Model Done by Shim 2010 prior modification

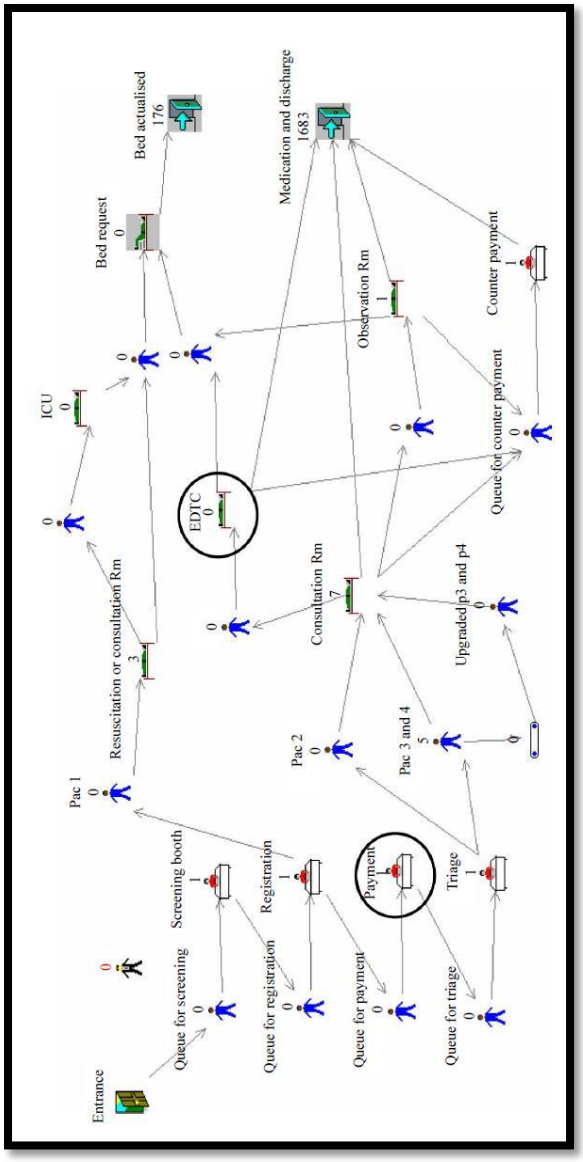


Figure 13: The simulation model after modifications (Shim, 2010).

After running the modified simulation model, it was found that the new payment station and the short-stay ward helped reduce the patient waiting time by 2.2 minutes at the triage station, by 0.64 minutes at the payment station and merely reduced the time at the screening and registration stations. However, the changes elongated the wait times of PAC 3 & 4 patients by 6.01 minutes. This was not a big problem because the main concern in an

emergency department is the PAC 1 & 2 rather than PAC 3 & 4 when it comes to wait time issues because patients categorized under PAC 3 & 4 are of less criticality. On-average, patients stay in the emergency care process for 133.93 minutes prior the modifications, and for 123.33 minutes afterwards (Shim and Kumar).

The limitations found in this model were that the variability of resource availability (doctors, nurses, equipment, etc…) and station locations were not put in consideration, they were constant. And the patients were not categorized according to their clinical disciplines and conditions. This is important because patients experience different wait times according to the different clinical processes (Shim and Kumar).

Medeiros, Swenson, & DeFlitch () implemented a new approach to patient flow in the ED. An emergency care physician at triage is placed by the Provider Directed Queuing (PDQ), who works with the triage nurse as a team for the provision of the resources needed by the patient. For example, the provider may conduct a medical evaluation, order diagnostic tests, or, if a bed is available and needed, send the patient to a traditional ED room.

Karpiel () recommended modifying the inflow strategy (the time taken for a patient to be seen by a physician) and the throughput strategy (the duration between the physician seeing the patient and coming up with a decision to be taken whether admit or send the patient home) by providing some solutions for each. The first was to apply triage-driven bed placement. This means that minimum patient data is needed once he enters the ED, such as, their name, birth date, and social security number, and the rest of data is gathered later on.

The second solution is to provide “Fast Track”. This means that patients of less criticality have the chance to be provided with care by nurse practitioners till the physicians are done with the critically ill patients. However, Peck & Kim () said that: “the increase in resources has not always been accompanied by an increase in the overall patient flow, sometimes leaving the FT resources underutilized”. The last solution offered by Karpiel (2004) is to commit radiology and lab technicians assigned to the ED during operational hours.

2. Through the Modification of Resource Availability

Sharmaet.al (2007) focused on the service management process which is one of the facility management processes. Lean principles have been applied to the service management process in order to detect the value and non-value added activities in the process. So the researcher implemented a simulation model besides the lean principles in order to optimize the size of the staff in different sub processes of the service management process, so as to eliminate the trial and error approach. The input data for the simulation model were of six hospitals in Germany for two months in year 2002. Chockalingam et al. () did almost the same thing but instead of combining the linear process with simulation, combined Petri-nets (PNs) with simulation.

Brenner et, al. () applied a simulation model in the ED at University of Kentucky Chandler Hospital in order to develop its throughput based on process analysis and flow data analysis. The researchers were able to detect bottlenecks and determine the optimal number of human and equipment resources by the application of what-if scenarios.

Blake & Carter () made a study undertaken at the Children's Hospital of Eastern Ontario to quantify issues surrounding the delivery of primary care through the hospital's emergency room. The project centers on a discrete event simulation model of the emergency room used to investigate issues contributing to wait time. Results indicate that patient wait time is affected by the availability of staff physicians and the amount of time physicians are required to spend engaged in the education of medical residents.

Reynolds, et al. () used the simulation technique in order to increase the quality of service by the variation in the staffing levels.

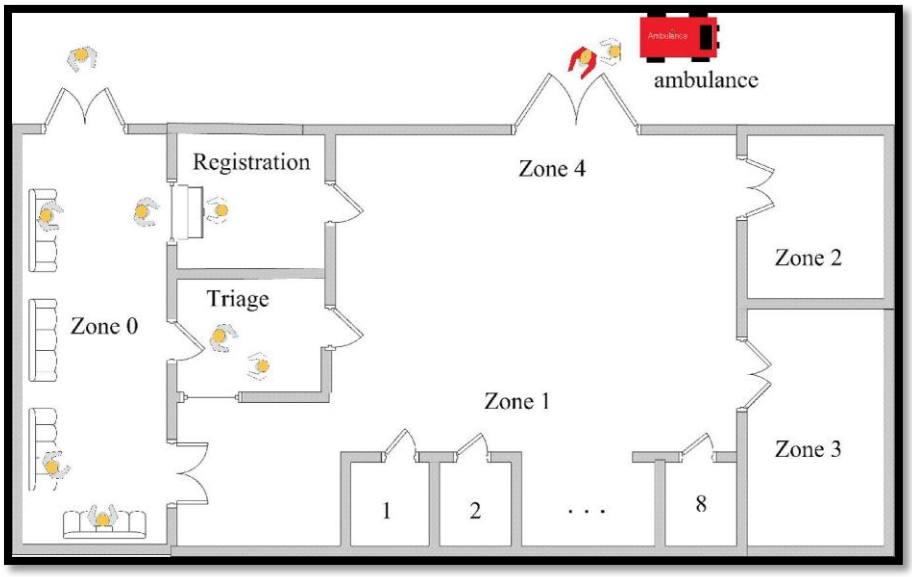


Figure 14: The ED's Plan (Duguay, 2007).

Figure 14 is the plan for the Dr. Georges-L. Dumont Regional Hospital. It is visited by more than 50 000 patients annually. It is open 24h a day with a 16 bed capacity, eight of

which are kept for accident victims and critical care while the rest (seven) are for patients who are intensely ill.

The ED employs five physicians, five nurses, three triage nurses and three registration nurses. It was preferred by the quality management team to increase the staff and room capacity within a certain budget, so five alternatives were proposed by the researchers, as seen in Table 1. Each alternative was simulated for each day using 10 replications of 12 hours long. The time spent in the system from entrance to exit, room usage and number of patients was calculated.

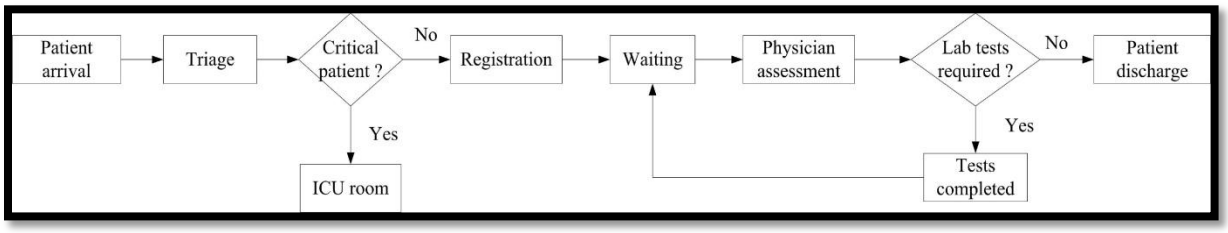


Figure 15: The process flow used by (Duguay and Chetouane).

Table 1: This table represents the suggested alternatives (Duguay and Chetouane).

	Control variables		
	Additional nurse, shift	Additional physician, shift	Additional room
Alternative 1	1 nurse, [0800 h, 1600 h]	1 physician, [0800 h, 1600 h]	0
Alternative 2	1 nurse, [0800 h, 1600 h]	1 physician, [0800 h, 1600 h]	1
Alternative 3	1 nurse, [1000 h, 1700 h]	1 physician, [1000 h, 1700 h]	0
Alternative 4	1 nurse, [1000 h, 1700 h]	1 physician, [1000 h, 1700 h]	1
Alternative 5	1 nurse, [0800 h, 1600 h] 1 nurse, [1600 h, 2000 h]	1 physician, [0800 h, 1600 h] 1 physician, [1600 h, 2000 h]	0

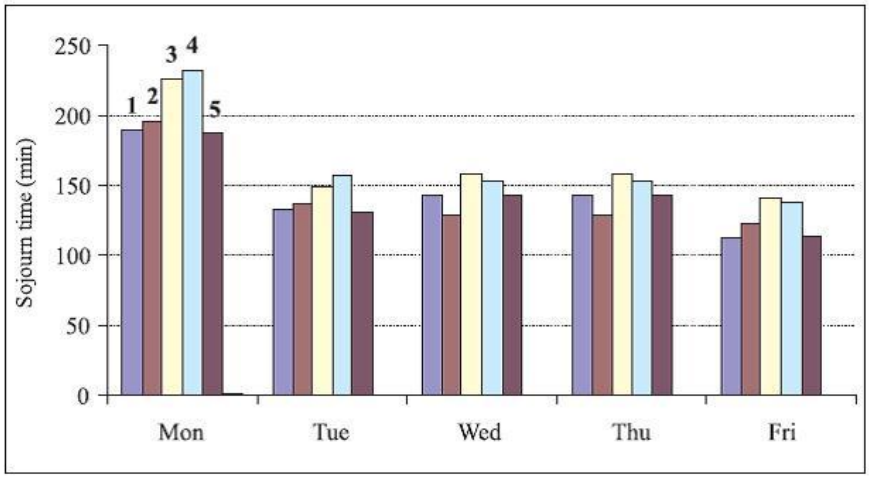


Figure 16: The time spent by patients in the system (Duguay and Chetouane)

The numbers from 1 to 5 in Figure 16 & Figure 17 represent the alternatives suggested by the researchers.

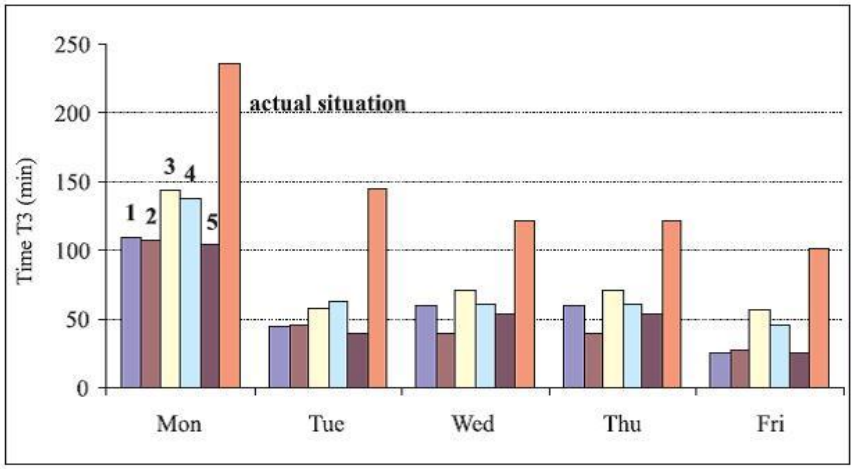


Figure 17: T3 is the time from registration to the exam room.

Time T3, which is the time from the registration to the exam room, has been specifically chosen because it constitutes the largest portion of the total waiting time in the ED. As one can see from the figure above; alternatives 1, 2 and 5 decreased the duration for about two

hours. Alternative one is preferred rather than 5 economic wise because alternative 1 requires only one physician and one nurse while alternative 5 requires four more staff.

Ahmed &Alkhamis () combined between the simulation and optimization in an ED case study in Kuwait. Instead of using a simulation model only, they used an optimization technique in order to come up with the most suitable number of staffing so as to maximize patient throughput and reduce the patient wait time through "what-if" models. The process model used for simulation can be seen in Figure 18.

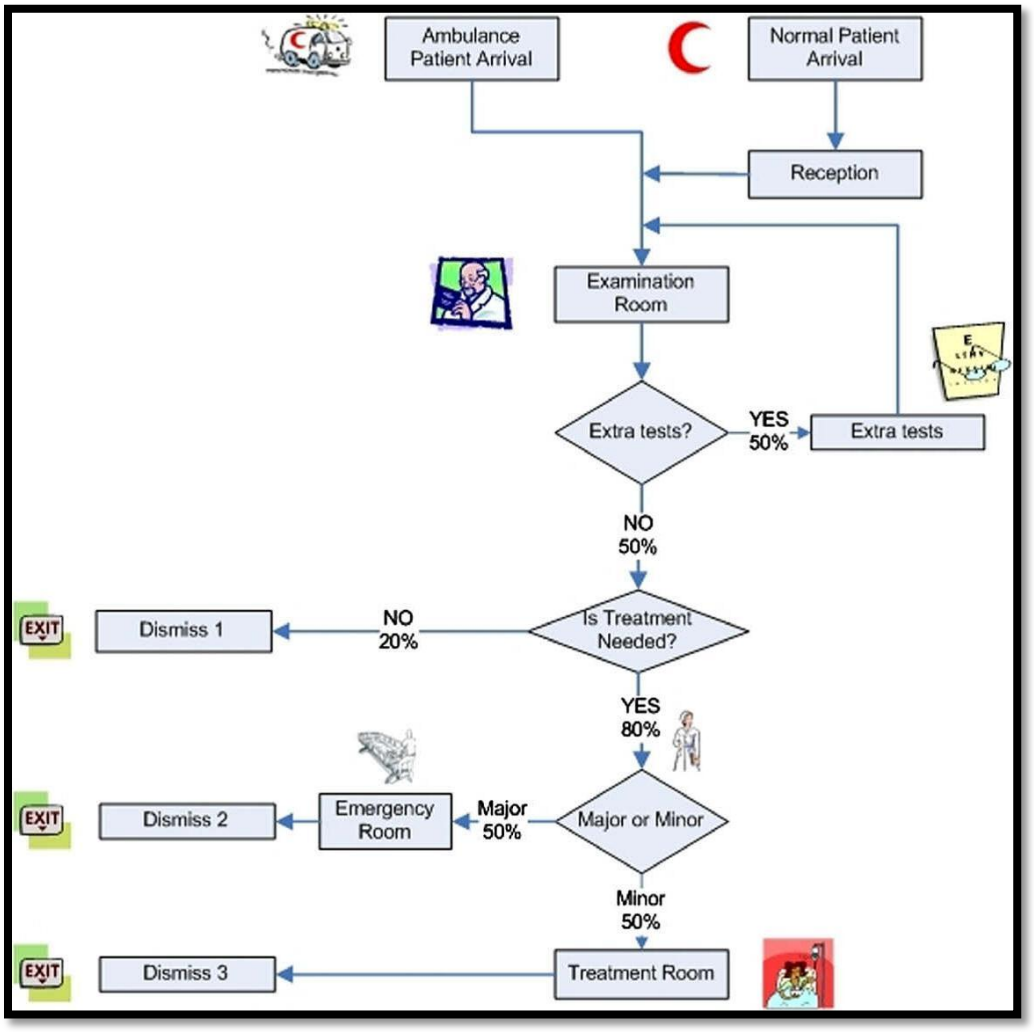


Figure 18: The process flow done by (Ahmed and Alkhamis)

The optimization model used by Ahmed &ALkhamis () involves a complex stochastic objective function subject to a deterministic and stochastic set of constraints. By applying the simulation optimization technique a 28% increase in patient throughput occurred and an average of 48% reduction in patient wait times.

C. A Summary of Publications on the Topic

Figure 21 are classified on the articles reviewed according to the type of decision support tool used. It was found out that the major decision support tool used in the predictive research for EDs, was discrete event simulation.

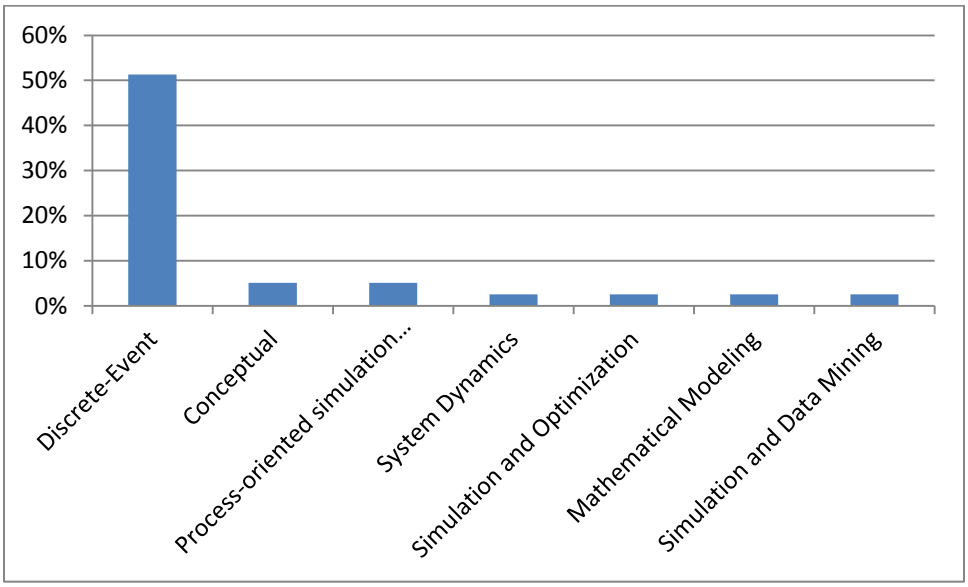


Figure 19: Percentages of Decision Support Tools Used

The following results in Figure 21 are the percentages of the major field of interest by researchers, based on the objectives in Figure 20, was the quality of service, then costs, then re-engineering and finally efficiency. This is because the major concern is customer (patient) satisfaction

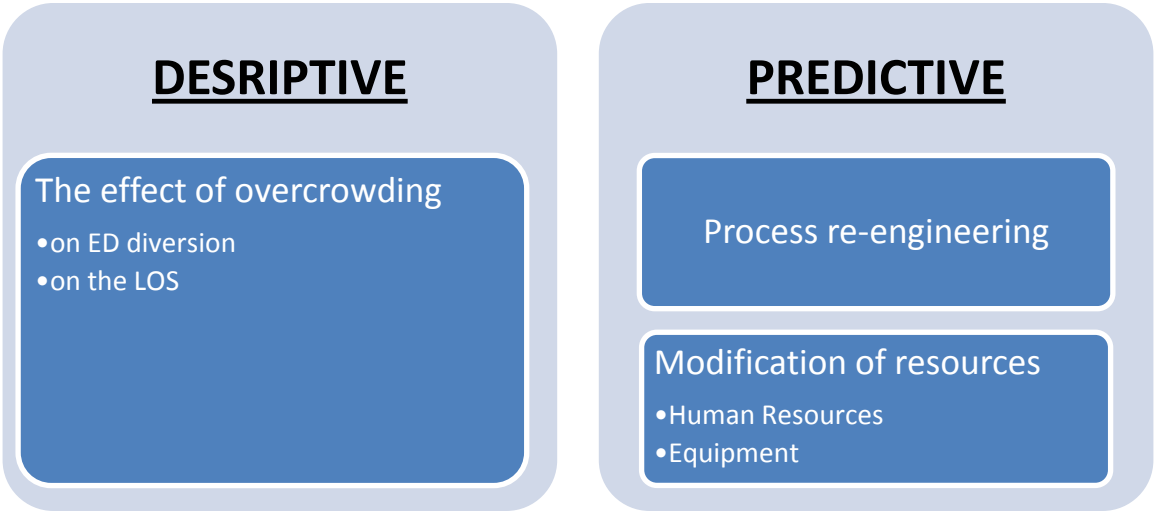


Figure 20: The summary of published papers on the topic.

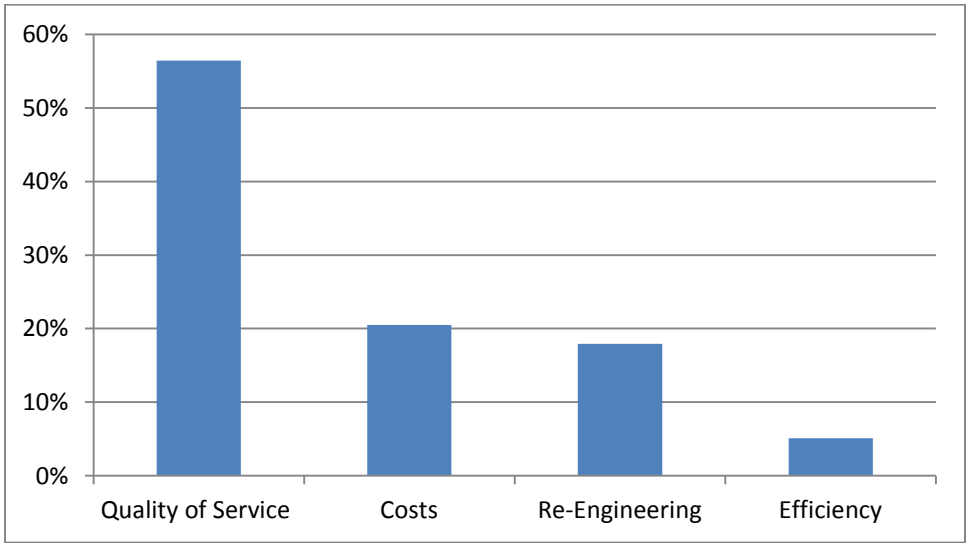


Figure 21: Percentages of the Fields Studied by Researchers

Chapter Three

Framework

III. CHAPTER THREE: FRAMEWORK

In order to come up with a method for improving the ED plan, the following should be done; data collection such as arrival rates, the process and different scenarios taking place in an ED, the population characteristics analyzed. Then, a simulation model is designed based on the process taken from the data collected. Afterwards, the resources and activity durations are collected and entered in the simulation model in order to run the model and come up with results. Then finally, based on the results taken from the simulation model, optimization techniques take place where the objective function, variables and constraints are detected so as to come up with reliable results. This optimization technique is done in order to reorganize the spaces (number of rooms) that will minimize the patient wait times within the specified area with the least cost possible. This can be seen in Figure 22

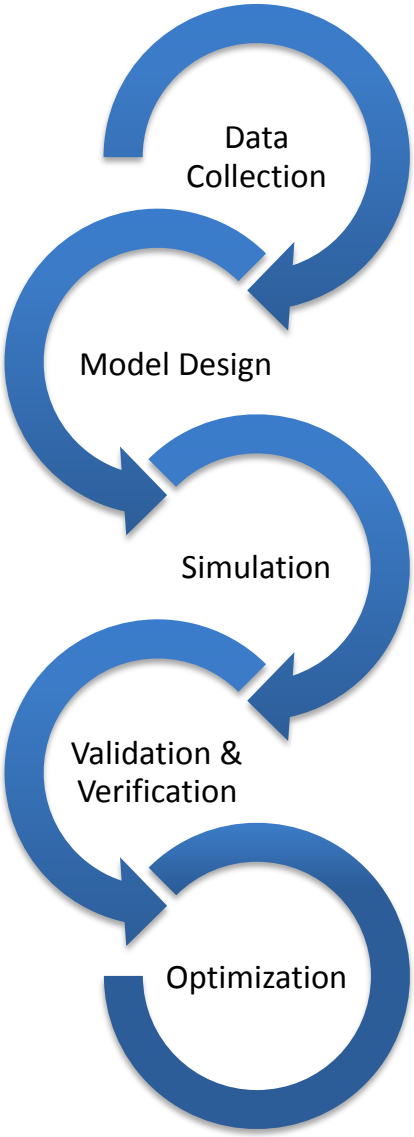


Figure 22: Methodology

This chapter will describe the first three components of the framework suggested above and apply it twice. The first time will be generic, clarifying the steps done in order to come up with the simulation model based on the data collected. And the second time will be specific, by applying the methodology on a chosen case study. The last two components are described in detail in the following chapter.

A. Data collection

As shown in the framework suggested in Figure 22, the first step is data collection. There are 4 main kinds of data that need to be collected in order to carry out the simulation and the optimization. These data are as follows; the arrival rates of patients, the different scenarios taking place in an ED, the population characteristics and last but not least, the durations of each activity taking place in an ED.

1. Arrival Rate/ Patient Flow

The random flow of patients has three main characteristics:

- Seasonal illness or incident. Lung infection and flu viruses are common in winter, while outdoor incidents and allergies are more frequent in summer
- The flow fluctuates considerably depending on week days.
- Patient arrivals increase at certain hours of the day. (Exponential, Poisson) (Duguay and Chetouane)

Another important data needed about the flow of patients is not only their numbers but also from where do they enter the ED; Patients arrive into the ED by either walking in or by the ambulance. (Kolker). In order to get this data, according to Fletcher & Worthington, () arrival rates can be collected from computer records of the ED by each day of the week.

In order to calculate patient arrival rates, a sample size of patients must be chosen for a certain period of time. It is preferred that the chosen period of time is the busiest period of

the day because the main objective is to reduce patient wait times in the system. After collecting the sample size of the selected period of time, the best fitting curve is identified. It is mostly found that it fits and exponential curve.

2. Activity& Wait Time Durations

Activity & wait time durations can be collected from on-site observations and interviews. The activity duration is the time spent in each stage or activity, while the wait time durations is the time spent from the end of a previous activity to the beginning of the following one.

A thorough data is collected in order to come up with detailed durations for each activity taking place in an ED. This data can be collected from the literature review done and it is a reliable resource, because the researchers have collected accurate data of patient flows and activity durations. This data is statistically accurate enough because the patient flows and activities have been studied for a whole year.

B. Model Design

1. Process Flow Chart

A process flow chart is used to clarify the different possible scenarios that can take place in an ED and their sequence. There can be generic process flow chart in most of the cases, but it is difficult to find one process flow chart that suits all ED in a very precise way. Therefore, in order to come up with a process flow chart, some of the following actions take place; Interview several doctors, nurses, and technicians about the process flow taking place in their ED, and, review previous process flow charts and make sure it suits the case that is being studied or update it if needed. The outcome will look very similar to Figure 23.

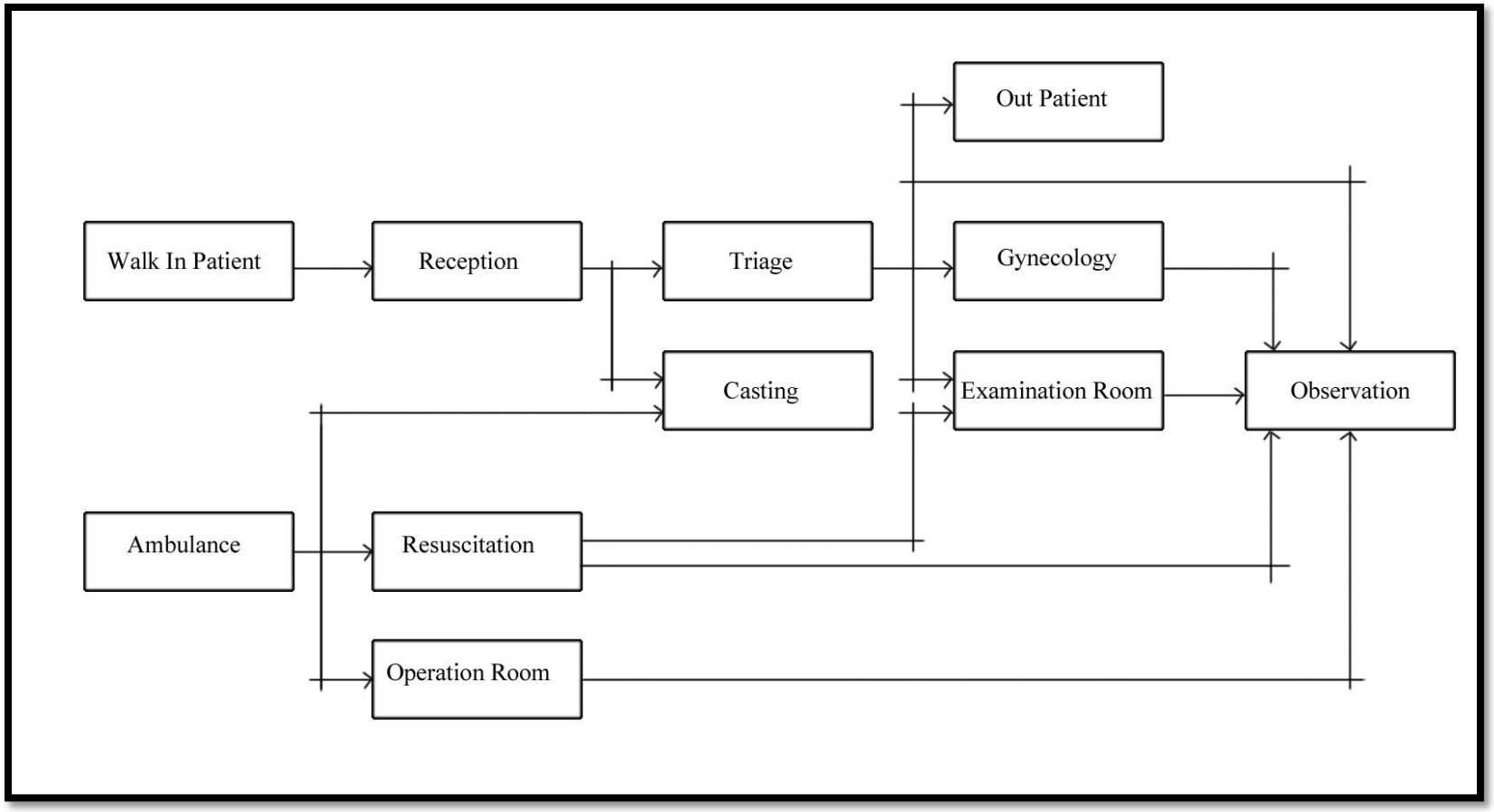


Figure 23: A generic flow chart identifying the process

Once the process flow chart is accurately and precisely done, population characteristics need to be studied.

2. Population Characteristics

The population characteristics represents the number of patients entering each activity, thus the utilization rate for each activity can be easily calculated. These percentages or utilization rates differ from one ED to another. They might even differ in the same ED from time to another. There cannot be a standardized utilization rate for each activity to perform a generic tool, because these percentages depend on several aspects which are as follows, and can be seen in Figure 24.

1. The location of the ED plays an important role in identifying the percentages of activities. For example, if it is near a high way, patients entering the ED from accidents are more frequent than other cases. If it is near a factory, the rate of chest pain might be higher than any other case due to the smoke coming out of the chimneys.
2. The percentages generated, differ with the change of seasons. For example, lung infection and flu viruses are more common in winter than the summer, while outdoor incidents are more common in summer. This has been previously explained in the patient flow section.
3. Durations affect the percentages in terms of week days. For example, in the US the rate of drunken patients reaches its peak on weekends; maximizing accident rates and resuscitation cases.
4. Sometimes the percentages even vary in the same day. For example, patients with cardio problems mostly enter the ED by five in the morning, while the peak of walk-in patients who enter the triage is after work in the evening.

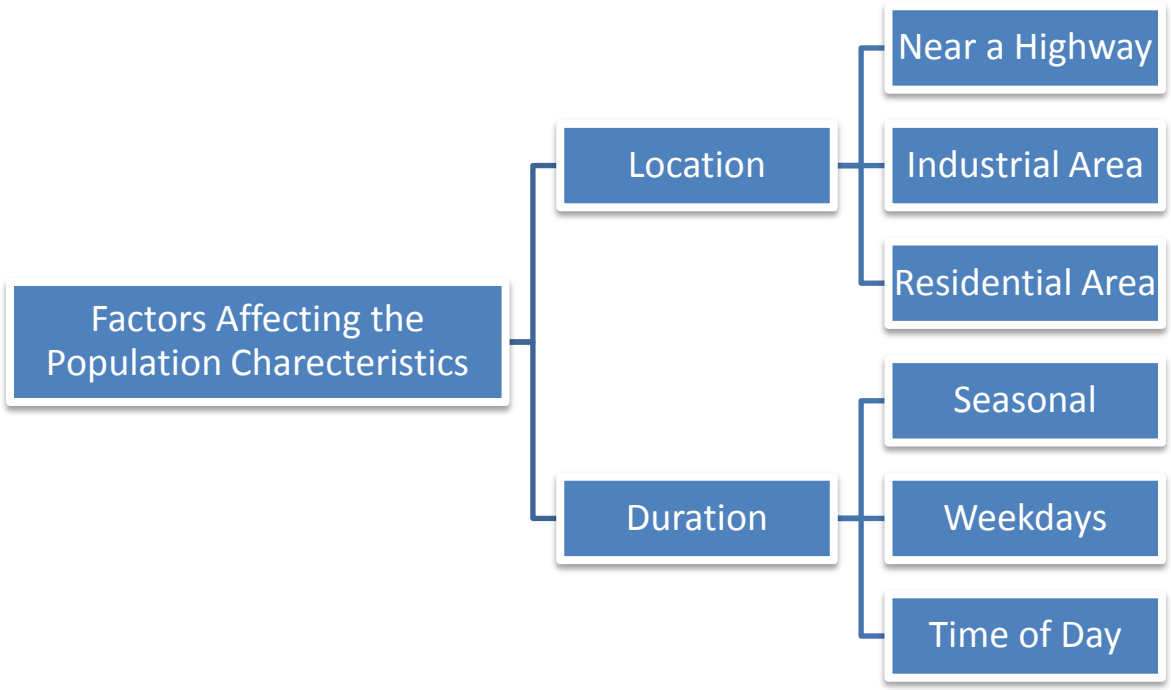


Figure 24: Factors Affecting the Population Characteristics

Therefore, spread sheets of actual data from the specified ED are needed. This data must consist of the number of patients who entered the ED and their division in each department for three months at least. These months must be carefully chosen from all over the year so as to provide a range of various samples. The more months one gets the more precise the percentages are.

After knowing the number of patients in each activity for each month, the percentages can be easily calculated. First, we calculate the total number of patients entering the ED and the total number of patients entering each activity. Then we divide the total number of patients entering the ED by the total number of patients in each activity. An example can be seen in Table 2.

Table 2: Distribution of Patients in an ED According to Activities.

		Patients/	Month		
Activity	**Month 1**	**Month 2**	**Month 3**	**Total no. of Patients**	**%**
Resuscitation	R1	R2	R3	R1+R2+R3	(R1+R2+R3)/ Total Patients
Gynecology	G1	G2	G3	G1+G2+G3	(G1+G2+G3)/ Total Patients
Operation	O1	O2	O3	O1+O2+O3	(R1+R2+R3)/ Total Patients
Casting	C1	C2	C3	C1+C2+C3	(R1+R2+R3)/ Total Patients
Examination	E1	E2	E3	E1+E2+E3	(R1+R2+R3)/ Total Patients
Outpatient	Out1	Out2	Out3	Out 1+2+3	(R1+R2+R3)/ Total Patients
				Total Patients	100%

It would make sense that the percentages in the above table would not add up to 100% because one patient may enter more than one activity. These percentages in the above table were only used to determine the utilization rates for each activity (denoted as the flow of each fork in the simulation model).

Now, that we have all the required data, a simulation model will be the next step.

C. The Simulation Model

1. Introduction

Simulation modeling is used to imitate what exists in the real world. The real system is represented with specific key elements or behaviors of either a chosen physical system or an abstract one. The basic elements in a simulation model are as follows:

- A process flow chart illustrating the logical pattern of the process.
- Input Entities (entrance) such as patients, doctors, etc…
- Queues (waiting phase).
- Work Stations/Activities taking place in the process (registration, triage, treatment, payment, etc…)
- Resources used to perform activities and move entities.
- Entity routings that describe directions and reasonable situations flow for entities.
- Exits (either discharged and go home, or hospitalized, or other).

2. Build the model

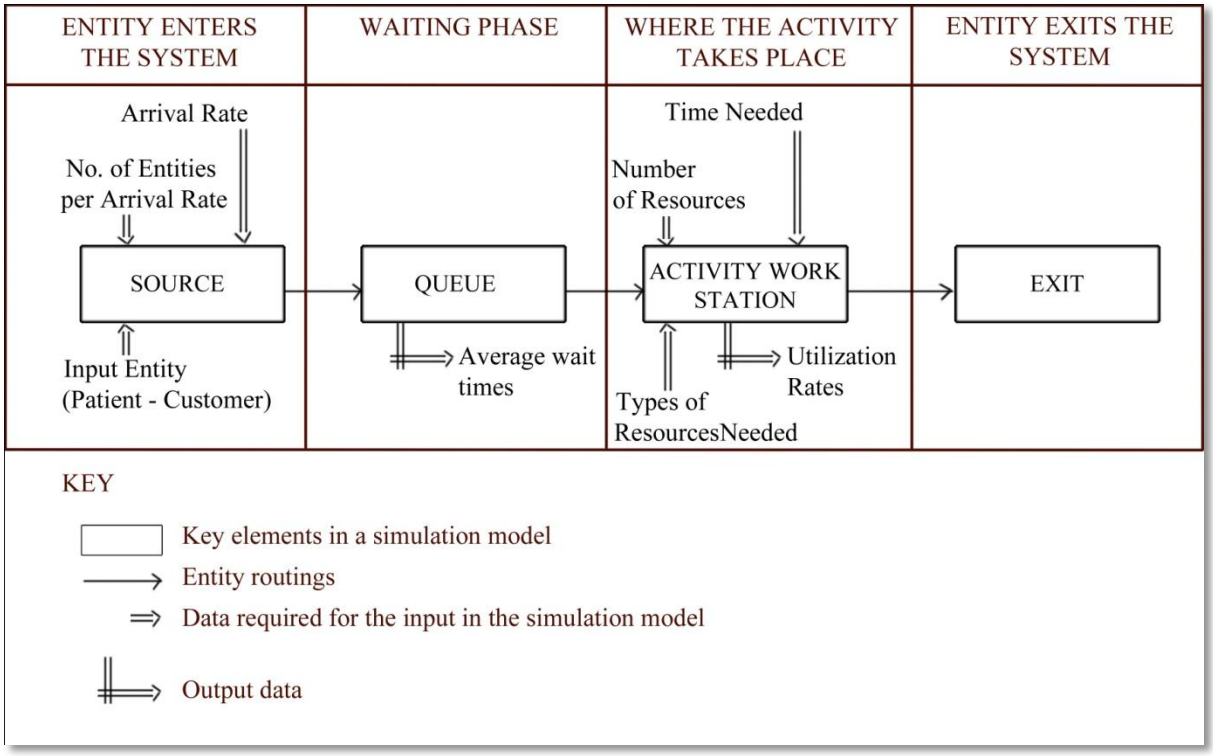


Figure 25: Basics of Simulation Modelling

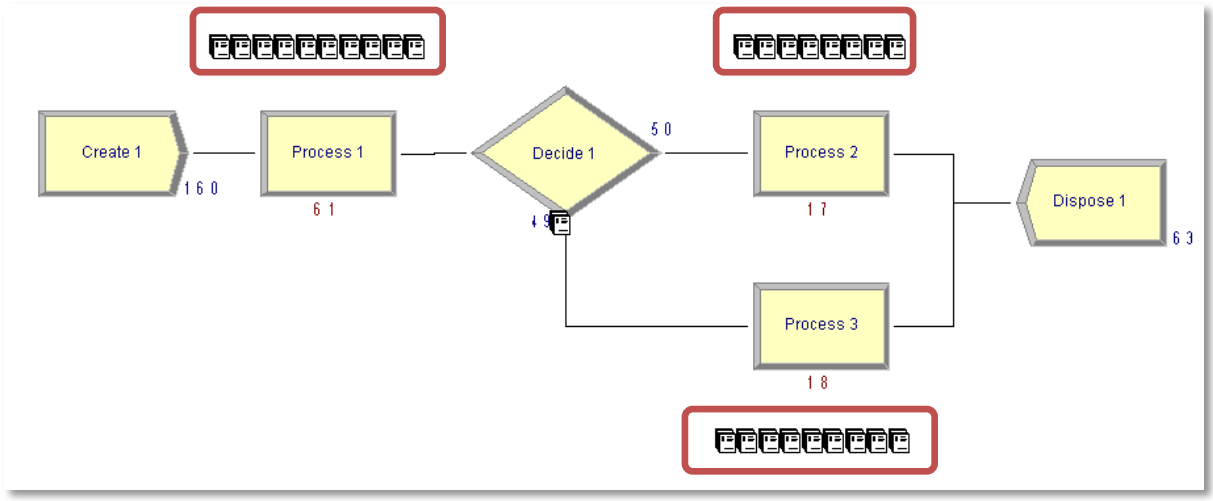


Figure 26: A Generic Simulation Model Using Arena Software

Model Key for Figure 26:

Create 1: Input entities

 : Queue (waiting phase)

Process 1,2 & 3: Work stations/ Activities

Decide 1: Entity routings

Dispose 1: Exit

The steps done in order to build the model is as follows:

Step 1: Create the source which provides the process with patients, indicating the arrival rates like in Figure 27

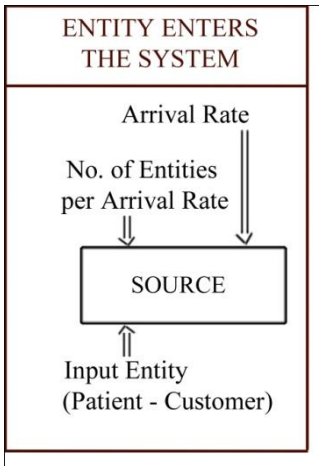


Figure 27: Creating the Recourse (Patient arrival flow)

Step 2: Create the activities that take place in an ED with the exact same flow known or given of the ED from real life data. After applying the process flow on the model, insert the activity durations known and received from the data collection stage. As seen in Figure

28, while applying the flow, one will need to add entity routings, which are named “Decide”. These are the diamond shaped forms that can be seen in Figure 29 & Figure 30.

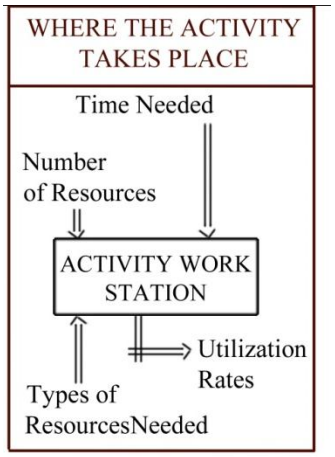


Figure 28: Step 2: Create the activities of the process

Step 3: The diamond shaped form (decide tool) acts like a distributer, where it sends the entering entity (patients) to different destinations according to the percentages collected from real life scenarios. The fork out put (decide tool) could be only two conditions, presented as true of false like Figure 29, or could be more than two, like Figure 30. The percentages of these decision tools are calculated and explained in the following part; applying the population characteristics on the simulation model.

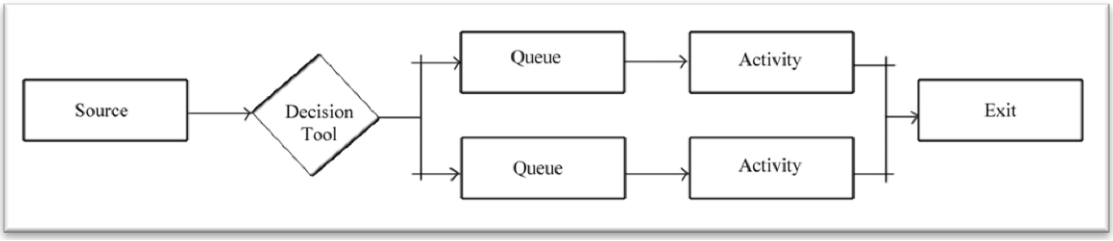


Figure 29: A decision tool with 2 way chance (true or false)

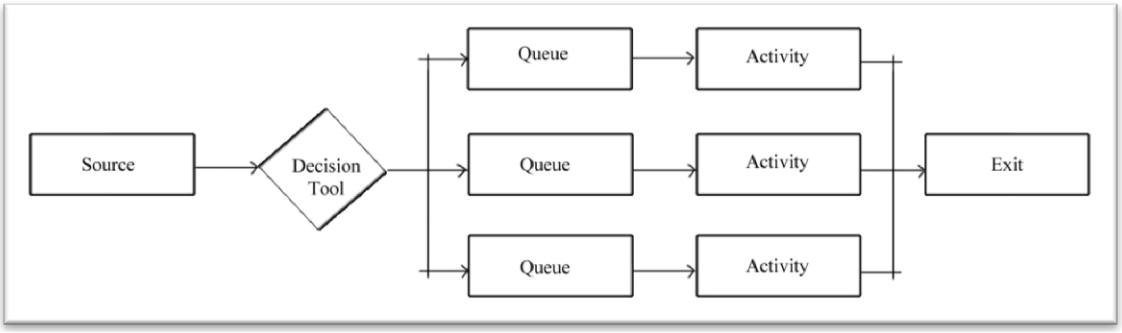


Figure 30: A decision tool with more than two probabilities

Step 4: Enter the available resources for each activity. These resources are the number of rooms, and the number of beds. Since the main focus of this research is the evaluation of ED plan design (areas), human resources are not put in consideration. But receptionists were a must because, even though they are human resources, they affect the flow of patients and are translated in terms of reception area.

3. Applying the Population Characteristics on the Simulation Model

In order to run the model further calculations need to be done. These calculations are the percentages that have to be inserted in the diamond shaped form.

These percentages, Table 2, could not be directly used to run the simulation model because these numbers represent the total number of patients in each activity disregarding from where they come from. This is not how simulation works.

For example, 14% of the total number of patients enters the examination and treatment room, but not all of the patients come from the same source/ work station. Some come after going to the triage room and the rest come after going to the resuscitation room. Therefore, solver, the MS Excel plug-in, had to be used in order to determine the percentages of which each scenario enters the examination and treatment room with a constraint that the total percentage should be equal to 14%. This has been applied not only to the examination and treatment room but also to all similar cases.

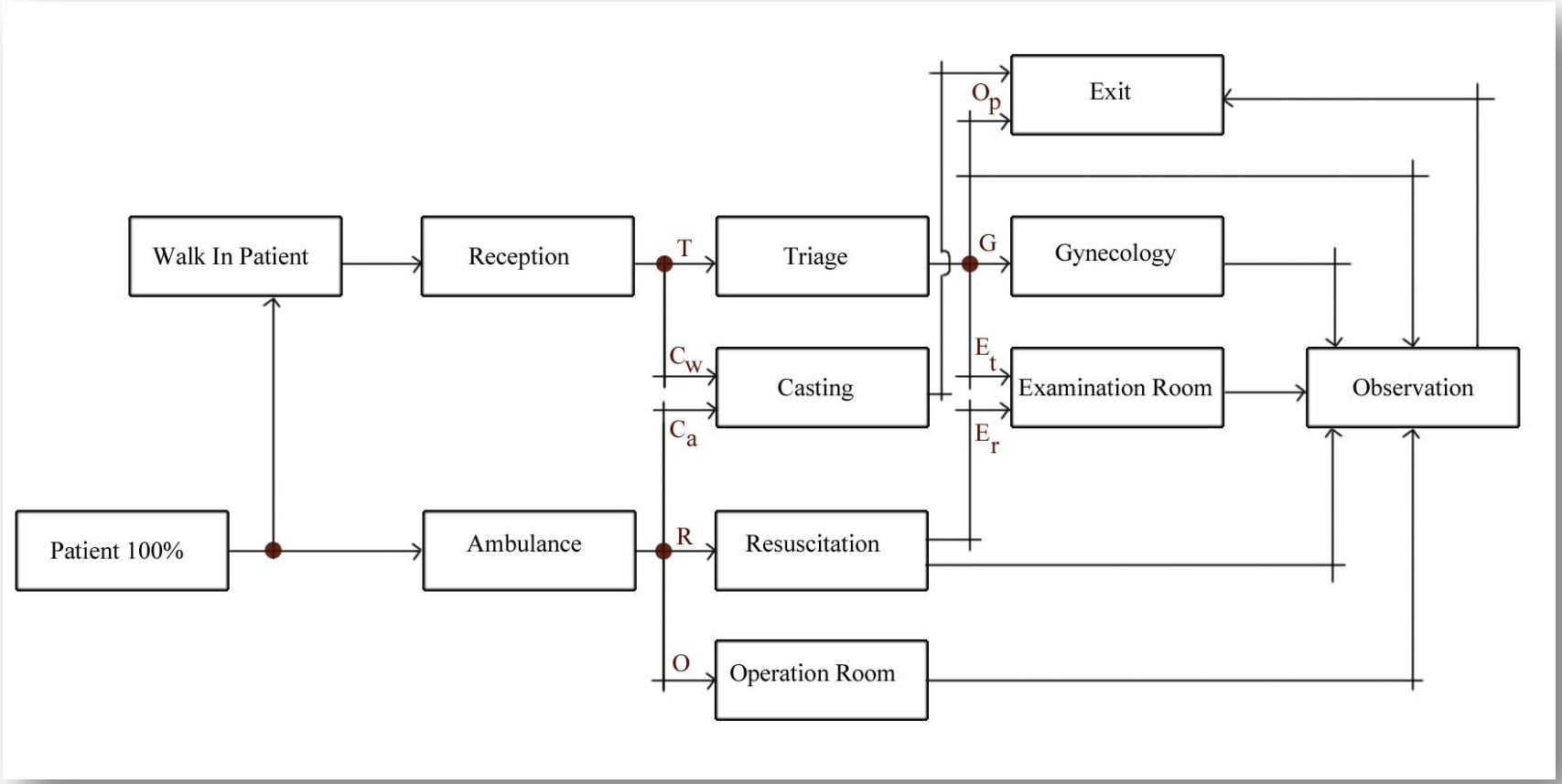


Figure 31: The calculated percentages which will be put in the simulation model

Key for Figure 31:

T: Percentage of patients entering triage from the walk-in ED entrance.

C_w: Percentage of patients entering casting room from the walk-in ED entrance.

C_a: Percentage of patients entering casting room from the ambulance ED entrance.

R: Percentage of patients entering resuscitation room from the ambulance ED entrance.

O: Percentage of patients entering operation room from the ambulance ED entrance.

O_p: Percentage of patients exiting the ED from triage.

G: Percentage of patients entering gynecology room from triage.

E_t: Percentage of patients entering examination room from triage.

E_r: Percentage of patients entering examination room from the resuscitation room.

Equation 1: The percentage of patients entering the operation room from the ambulance ED entrance.

$$O_{Fork\ from\ Ambulance} = \frac{O_{Real}}{Ambulance_{Fork}}$$

In order to determine the percentage of patients entering the operation room from the ambulance ED entrance, the real percentage collected from the ED data is divided by the that from the ambulance ED entrance.

Equation 2: The percentage of patients entering the resuscitation room from the ambulance ED entrance.

$$R_{Fork\ from\ Ambulance} = \frac{R_{Real}}{Ambulance_{Fork}}$$

In order to determine the percentage of patients entering the resuscitation room from the ambulance ED entrance, the real percentage collected from the ED data is divided by that from the ambulance ED entrance.

Equation 3: The percentage of patients entering the casting room from the ambulance ED entrance.

$$C_{Fork\ from\ Ambulance} = 100\% - R_{Fork\ from\ Ambulance} - O_{Fork\ from\ Ambulance}$$

In order to determine the percentage of patients entering the casting room from the ambulance ED entrance, the percentage of patients entering the resuscitation room (Equation 2) and operation room (

Equation 1) from the ambulance ED entrance is subtracted by 100%.

Equation 4: The percentage of patients entering the casting room from the walk-in ED entrance.

$$C_{Fork\ from\ Walk-in} = \frac{C_{Real} - (C_{Fork\ from\ Ambulance} \times Ambulance_{Fork})}{Walk - in_{Fork}}$$

In order to determine the percentage of patients entering the casting room from the walk-in ED entrance, the percentage of patients entering the casting room from the ED ambulance entrance (Equation 3) is subtracted from the real percentage of patients entering the casting room and then divided by the percentage from the walk-in fork.

Equation 5: The percentage of patients entering the triage room from the walk-in ED entrance.

$$T_{Fork\ from\ Walk-in} = 100\% - C_{Fork\ from\ Walk-in}$$

In order to determine the percentage of patients entering triage from the walk-in ED entrance, the percentage of patients entering the casting room from the ED walk-in entrance (Equation 4) is deducted from the 100%

Equation 6: The percentage of patients entering the gynecology room from the triage room.

$$G_{Fork\ from\ Triage} = \frac{G_{Real}}{\left(T_{Fork\ from\ Walk-in} \times Walk - in_{Fork}\right)}$$

In order to determine the percentage of patients entering the gynecology room from the triage, the percentage of patients entering the triage from the ED walk-in entrance Equation 5), and the percentage of patients entering the ED from the walk-in entrance are divided by the real percentage (total percentage taken from the ED Database).

Equation 7: The percentage of patients leaving the ED from the triage room.

$$OP_{Fork\ from\ Triage} = \frac{OP_{Real}}{\left(T_{Fork\ from\ Walk-in} \times Walk - in_{Fork}\right)}$$

In order to determine the percentage of patients leaving/ exiting the ED from triage, an equation similar to Equation 6 takes place, which is the division of the percentage entering the triage from the ED walk-in entrance (Equation 5), and the percentage of patients entering the ED from the walk-in entrance by the real percentage (collected from the Ed base case).

Equation 8: The percentage of patients entering the examination room from the hot case and cold case.

$$E_{Real} = \left(E_{Fork\ from\ T} \times T_{Fork\ from\ Walk-in} \times Walk - in_{Fork}\right)$$

$$+ \left(E_{Fork\ from\ R} \times R_{Fork\ from\ Ambulance} \times Ambulance_{Fork}\right)$$

In order to solve this equation, $E_{Fork\ from\ T}$ and $E_{Fork\ from\ R}$ must be calculated, therefore the equation for the observation room (
Equation 9) will be formed.

Equation 9: the percentage of patients entering the observation room.

$$\boldsymbol{Ob_{Real}} = \boldsymbol{O_{Real}} + \boldsymbol{G_{Real}} + \boldsymbol{E_{Real}} + \left(\left(\mathbf{100\%} - \boldsymbol{Op_{Fork\ from\ T}} - \boldsymbol{G_{Fork\ from\ T}} - \boldsymbol{E_{Fork\ from\ T}}\right) \times \boldsymbol{T_{Fork\ from\ Walk-in}} \times \boldsymbol{Walk - in_{Fork}}\right) + \left(\left(\mathbf{100\%} - \boldsymbol{E_{Fork\ from\ R}}\right) \times \boldsymbol{R_{Fork\ from\ Ambulance}} \times \boldsymbol{Ambulance_{Fork}}\right)$$

Now we have 2 unknowns and 2 equations (Equation 8 & Equation 9), which can be solved simultaneously. These two equations will solve for $\boldsymbol{E_{Fork\ from\ R}}$ and $\boldsymbol{E_{Fork\ from\ T}}$

D. Model Verification

In order to verify the simulation model, the process is done on twice on different software; ARENA and Anylogic. Then a comparative analysis takes place to see to what extent the models are similar.

Once there is a certainty about the model's accuracy, the optimization process takes place.

E. Optimization

After the simulation has been verified and validated, optimization needs to take place in order to determine the best allocation of resources within a specified area and within a certain budget.

In order to achieve the optimized ED design allocation of resources, the following steps are done.

1. Data compilation of waiting times for each activity; in order to obtain a diverse data set, different arrival rates are tested on the simulation model, and waiting times for each activity are recorded.
2. A regression analysis is essential to formulate equations from the compiled data, in order to be used as the objective function in the optimization model. Regression is done to relate waiting times and resources for each activity/ work station with the arrival rate. This is done on two phases. The first phase is the generation of an equation relating all activities/ work stations with the arrival rate, while the

second phase is the generation of equations relating each single activity/ work station with its resources and arrival rate.

3. Setting-up the model is a critical phase and should be crafted carefully, because it is the core of the optimization process. The model is divided into three main elements; the first is the objective function, which is the function needed to be optimized. The second is variables, which are the elements which could be changed in order to reach the optimized model, in this study the variables are the number of resources in each activity/ work station. The third is constraints, which are equations that limit the optimization process from resulting in infeasible outputs. In this study, the constraints are minimum and maximum values for each resource, in addition there are other constraints concerning the maximum cost, maximum space, and maximum waiting time.
4. The final step is to run the optimization algorithm. There are different algorithms that may be applied for solving the model, but for the purpose of this research a Genetic Algorithm was chosen.

Chapter Four

Application on a Case Study

IV. CHAPTER FOUR: APPLICATION ON A CASE STUDY

The chosen case study is the ED in the Sheikh Zayed Hospital, which is located in 6 of October, Cairo, Egypt. The Ed consists of two reception areas, one for the walk-in patients and the other for the ambulance entrance, two resuscitation beds, six observation beds, six examination and treatment beds, and one casting room. Due to the lack of space, triage takes place by the main waiting area at the reception desk.

Figure 32: Sheikh Zayed ED Plan

A. Data collection

The four types of data mentioned in the generic part (arrival rates, process flow chart, population characteristics, activity and wait time durations) will be repeated in this section for the chosen case study of Sheikh Zayed ED

1. Arrival Rates

In order to determine the arrival rates of patients in the Sheikh Zayed ED, three months were chosen as a sample to find the mean number of patients entering the ED, either walking or by through the ambulance.

The mean number of patients entering the ED was obtained by the use of curve fitting techniques which yielded the following results seen in

Figure 33, Figure 34 &Figure 35.

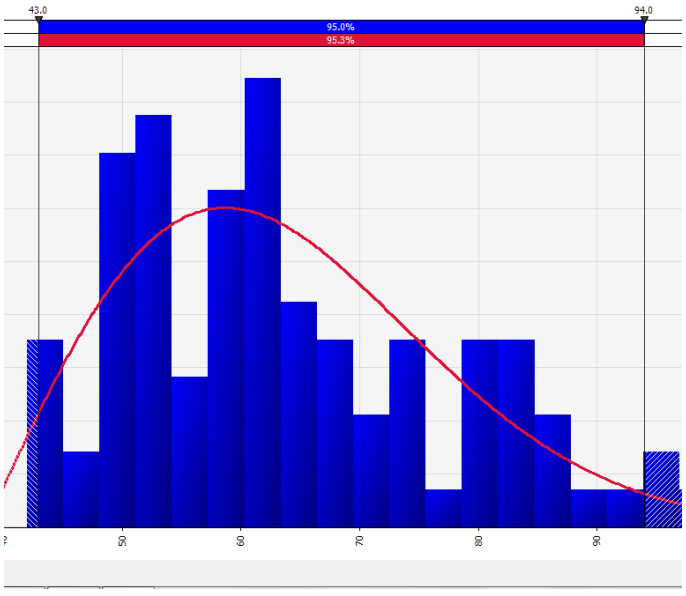


Figure 33: Best fit curve for patient arrival rates

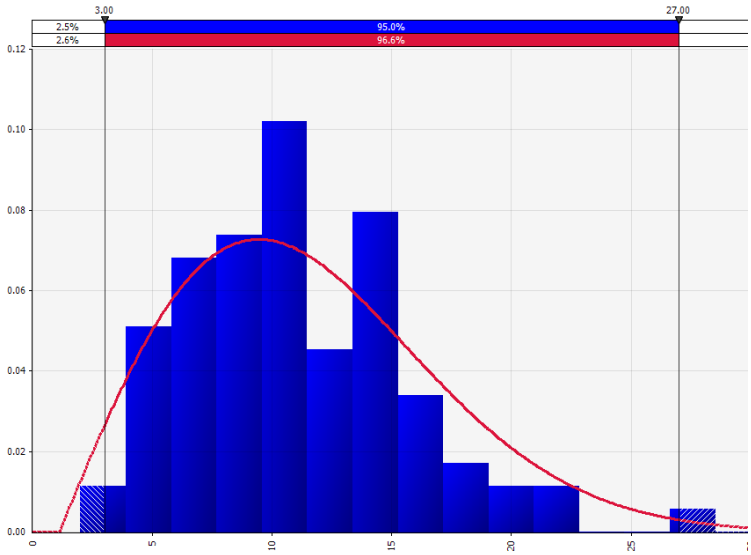


Figure 34: Best fit curve for ambulance patient arrival rates

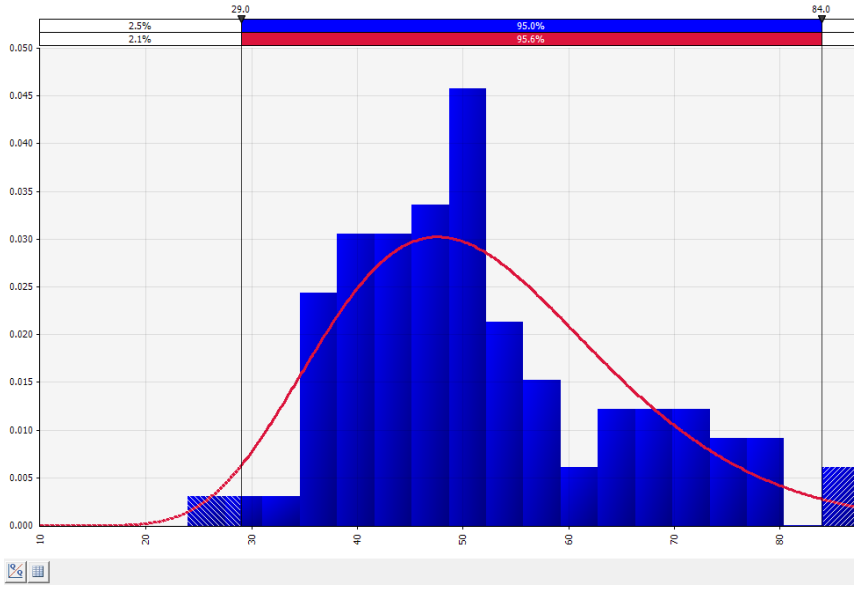


Figure 35: Best fit curve for walk-in patient arrival rates

2. Activity Durations

A thorough data was needed to be collected in order to come up with detailed durations of the processes taking place in the various ED scenarios. This data was collected from the literature review done and it is a reliable resource, because the researchers have collected statistically accurate data of patient flows and activity durations. This data has been accurate enough because the patient flows and activities have been studied for a whole year. The activity durations in Table 3 were done by the researchers Ahmed & Alkhamis and published in 2009

Table 3: Service time distributions at each process stage. (Ahmed and Alkhamis)

Stage	Distribution (minutes)
Reception	Uniform (5, 10)
Lab tests	Triangular (10,20,30)
Examination room	Uniform (10,20)
Reexamination process	Uniform (7, 12)
Treatment room	Uniform (20,30)
Emergency room	Uniform(60,120)

B. Model Design

1. Process Flow Chart

In order to come up with the flow chart of the different ED processes, interviews took place with remarkable doctors with high positions. One of them was the manager of the Sheikh Zayed Hospital, Dr. Moustafa el Mallah, who has been very helpful and patient. An interview was recorded with him, where he explained different scenarios and cases of patients. Another interview for the same purpose was done with Dr. Hafez Mohamed, the Manager of the Maadi Medical Institute. This interview was then translated into a flow chart which was seen and reviewed by him. The outcome can be seen in Figure 36.

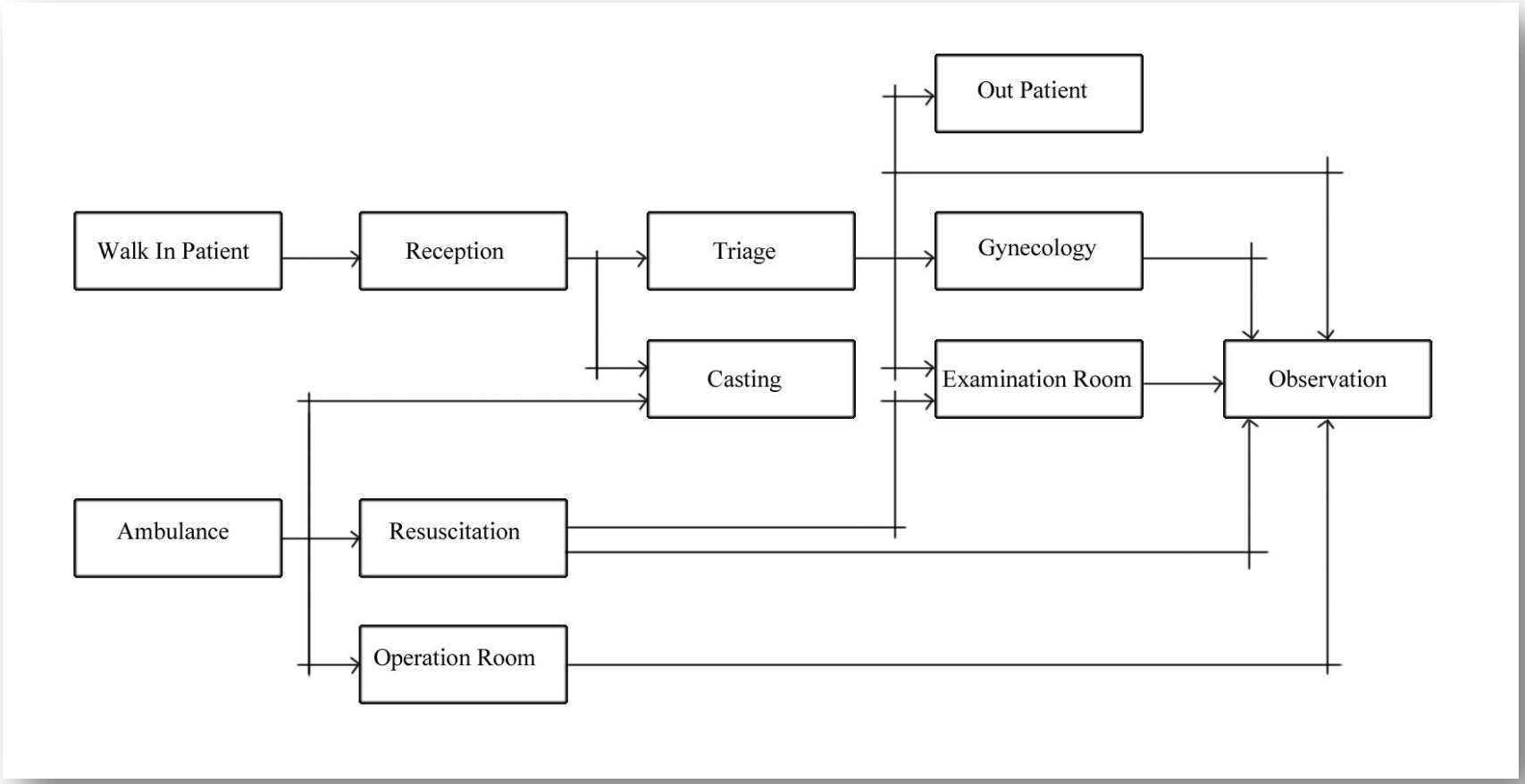


Figure 36: The flow chart identifying the process

2. Population Characteristics

After making sure that the flow was correct, the number of patients and their percentages in each activity was essential in order to be able to create a simulation model. Therefore, spread sheets of actual data from the Sheikh Zayed ED were collected. This data consisted of the number of patients who entered the ED and their division in each department for three months. These months were carefully chosen from all over the year so as to provide a range of various samples. These months were July, October, and December. After collecting the data of the number of patients in each activity the percentages were calculated and it was found that 4% enter resuscitation, 13% entered gynecology, 15% had minor operations, 29% entered the casting room, 14% got examined and treated in the examination and treatment room, and last but not least, 25% were outpatient cases; that did not need to enter the ED. This is clarified in Table 4

Table 4: Distribution of Patients in the ED According to the Activity

Case	June	October	December	Total	%
Resuscitation	18	5	12	35	4%
Gynecology	35	34	40	109	13%
Operation	30	41	52	123	15%
Casting	74	78	94	246	29%
Examination	32	39	47	118	14%
Outpatient	67	72	68	207	25%
				838.00	100%

C. The Simulation Model

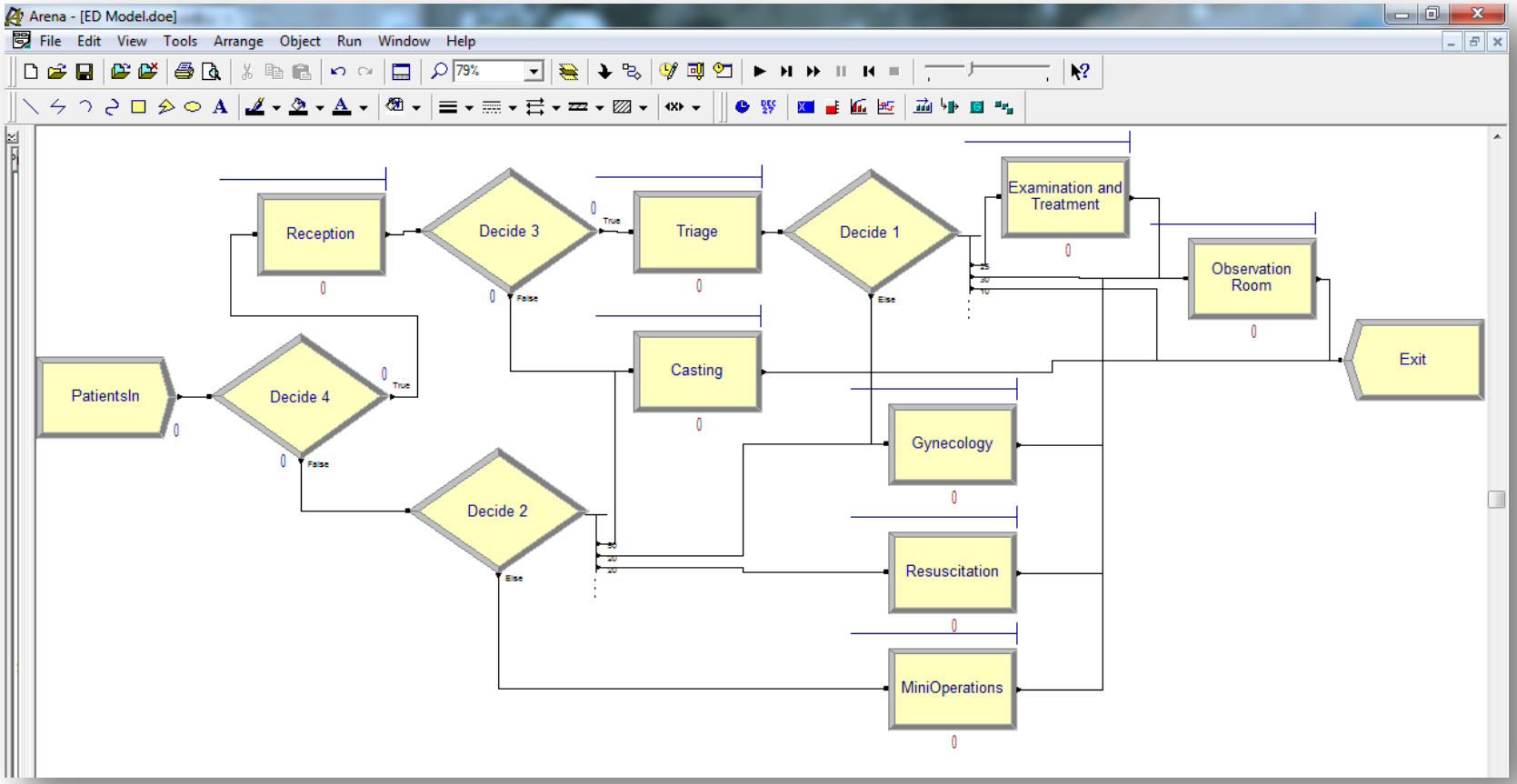


Figure 37: The Proposed Simulation Model Using Arena Software

Step 1: Create the source which provide the process with patients, indicating the arrival rates

Step 2: Create the activities that take place in an ED with the exact same flow know or given of the ED from real life data. And the exact durations known and received from the data collection stage.

Step 3: the diamond shaped form (decide tool) acts like a distributer, where it sends the entering entity (patients) to different destinations according to the percentages collected from real life scenarios. The fork out put (decide tool) could be only two conditions, presented as true of false ,or could be more than two. This has been previously explained. The percentages of these decision tools were calculated as explained previously and inserted in the simulation model.

Step 4: Enter the data collected concerning resource availability for each activity. These resources are the number of rooms, and the number of beds. Human resources were not added as they are not the concern of this research. The main focus is the resource in terms of areas. But receptionists were a must even though because they affect the flow of patients and are translated into area. In other words, the area of the reception desk depends on the number of people standing behind it. The resources in the system can be seen in Figure 38

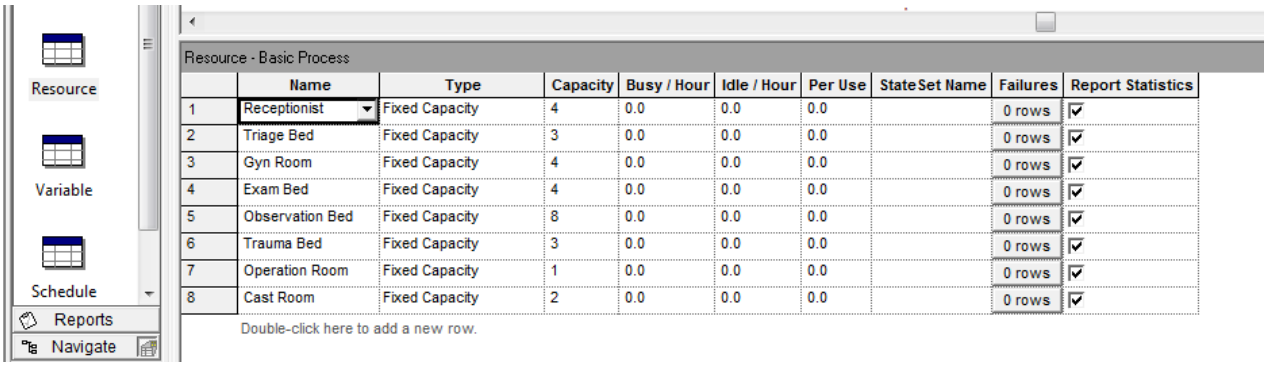


Figure 38: Step 4: Defining the Resources

A discrete event simulation model was built using software named “Arena”. But in order to run the model further calculations had to be done.

These percentages, in Table 4, could not be directly used to run the simulation model because these numbers represent the total number of patients in each activity disregarding from where they come from. This is not how simulation works, because

For example, 14% of the total number of patients enters the examination and treatment room, but not all of the patients come from the same source. Some come from the triage room and the rest come after resuscitation. Therefore, solver, the MS Excel plug-in, had to be used in order to determine the percentages of which each scenario enters the examination and treatment room with a constraint that the total percentage should be equal to 14%. This has been applied not only to the examination and treatment room but also to all similar cases.

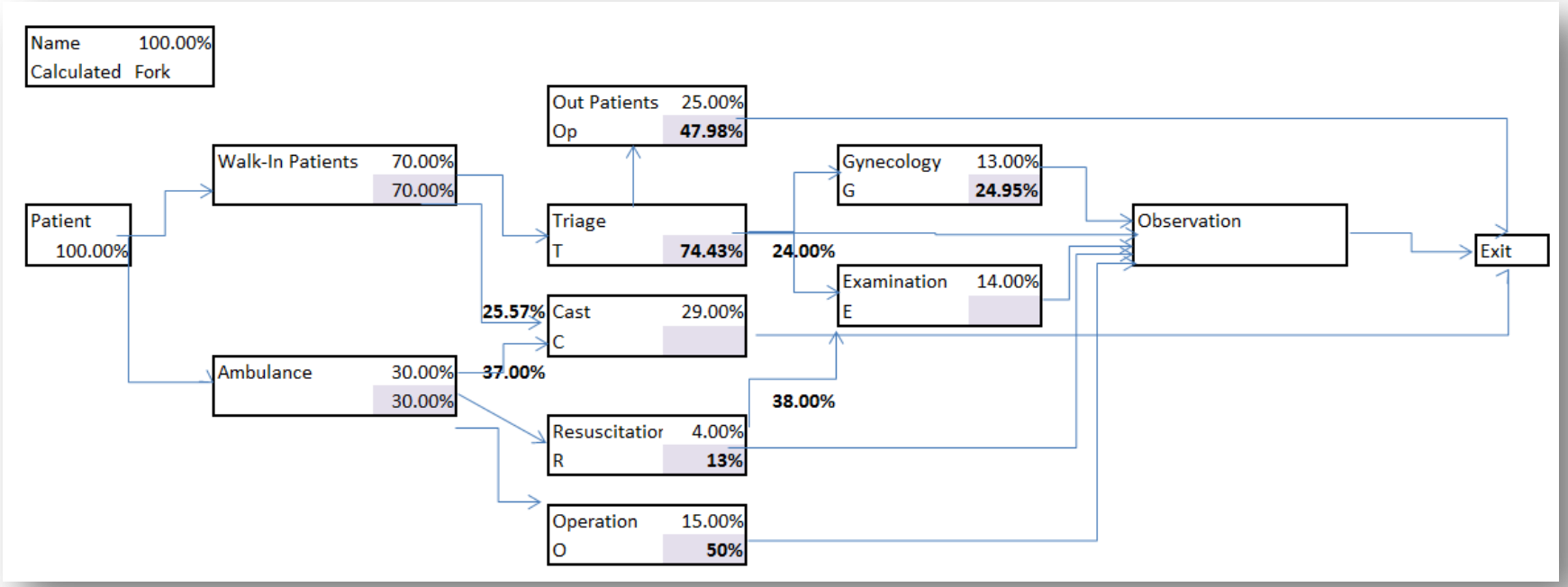


Figure 39: The calculated percentages which will be put in the simulation model

Equation 1

$$\boldsymbol{O_{Fork\ from\ Ambulance}} = \frac{\boldsymbol{O_{Real}}}{\boldsymbol{Ambulance_{Fork}}}$$

$$\boldsymbol{O_{Fork\ from\ Ambulance}} = \frac{\mathbf{15\%}}{\mathbf{30\%}} = \mathbf{50\%}$$

Equation 2

$$\boldsymbol{R_{Fork\ from\ Ambulance}} = \frac{\boldsymbol{R_{Real}}}{\boldsymbol{Ambulance_{Fork}}}$$

$$\boldsymbol{R_{Fork\ from\ Ambulance}} = \frac{\mathbf{4\%}}{\mathbf{30\%}} = \mathbf{13\%}$$

Equation 3

$$\boldsymbol{C_{Fork\ from\ Ambulance}} = \mathbf{100\%} - \boldsymbol{R_{Fork\ from\ Ambulance}} - \boldsymbol{O_{Fork\ from\ Ambulance}}$$

$$\boldsymbol{C_{Fork\ from\ Ambulance}} = \mathbf{100\%} - \mathbf{13\%} - \mathbf{50\%} = \mathbf{37\%}$$

Equation 4

$$\boldsymbol{C_{Fork\ from\ Walk-in}} = \frac{\boldsymbol{C_{Real}} - \left(\boldsymbol{C_{Fork\ from\ Ambulance}} \times \boldsymbol{Ambulance_{Fork}}\right)}{\boldsymbol{Walk-in_{Fork}}}$$

$$\boldsymbol{C_{Fork\ from\ Walk-in}} = \frac{\mathbf{29\%} - (\mathbf{37\%} \times \mathbf{30\%})}{\mathbf{70\%}} = \mathbf{25.57\%}$$

Equation 5

$$\boldsymbol{T_{Fork\ from\ Walk-in}} = \mathbf{100\%} - \boldsymbol{C_{Fork\ from\ Walk-in}}$$

$$\boldsymbol{T_{Fork\ from\ Walk-in}} = \mathbf{100\%} - \mathbf{25.57\%} = \mathbf{74.43\%}$$

Equation 6

$$\boldsymbol{G_{Fork\ from\ Triage}} = \frac{\boldsymbol{G_{Real}}}{\left(\boldsymbol{T_{Fork\ from\ Walk-in}} \times \boldsymbol{Walk-in_{Fork}}\right)}$$

$$\boldsymbol{G_{Fork\ from\ Triage}} = \frac{\mathbf{13\%}}{(\mathbf{74.43\%} \times \mathbf{70\%})} = \mathbf{24.95\%}$$

Equation 7

$$\boldsymbol{OP_{Fork\ from\ Triage}} = \frac{\boldsymbol{OP_{Real}}}{\left(\boldsymbol{T_{Fork\ from\ Walk-in}} \times \boldsymbol{Walk - in_{Fork}}\right)}$$

$$\boldsymbol{OP_{Fork\ from\ Triage}} = \frac{\mathbf{25\%}}{(\mathbf{74.43\%} \times \mathbf{70\%})} = \mathbf{47.98\%}$$

Equation 8

$$\boldsymbol{E_{Real}} = \left(\boldsymbol{E_{Fork\ from\ T}} \times \boldsymbol{T_{Fork\ from\ Walk-in}} \times \boldsymbol{Walk - in_{Fork}}\right) + \left(\boldsymbol{E_{Fork\ from\ R}} \times \boldsymbol{R_{Fork\ from\ Ambulance}} \times \boldsymbol{Ambulance_{Fork}}\right)$$

Equation 9

$$\boldsymbol{Ob_{Real}} = \boldsymbol{O_{Real}} + \boldsymbol{G_{Real}} + \boldsymbol{E_{Real}} + \Big(\left(\mathbf{100\%} - \boldsymbol{Op_{Fork\ from\ T}} - \boldsymbol{G_{Fork\ from\ T}} - \boldsymbol{E_{Fork\ from\ T}}\right) \times \boldsymbol{T_{Fork\ from\ Walk-in}} \times \boldsymbol{Walk - in_{Fork}}\Big) + \Big(\left(\mathbf{100\%} - \boldsymbol{E_{Fork\ from\ R}}\right) \times \boldsymbol{R_{Fork\ from\ Ambulance}} \times \boldsymbol{Ambulance_{Fork}}\Big)$$

The percentages on the arrows in Figure 39 are the result of the above calculations.

D. Results and Analysis

The simulation model discussed has been run for several times with different inter-arrival rates and different scenarios. This was done for the purpose of detecting the effect of the inter-arrival rates of patients on the utilization rates of resources and waiting times at different workstations, like the number of operation rooms, gynecology rooms, trauma beds, etc… and the following results were found;

1. Average wait time for each activity

Table 5 represents the average waiting time for each activity, when the Sheikh Zayed ED simulation model was run with the inter-arrival rate of EXP (12). The inter-arrival rate EXP (12) was chosen due to the best fit curve found using regression from the data taken from the Sheikh Zayed ED for three consecutive months.

Table 5: Average Wait Time for Each Activity

Waiting Time	Average
Casting.Queue	4.6296
Examination and Treatment.Queue	0.00
Gynecology.Queue	1.7243
MiniOperations.Queue	46.5892
Observation Room.Queue	0.2525
Reception.Queue	1.1647
Resuscitation.Queue	0.00
Triage.Queue	0.00

It was found that mini-operations queue was the longest in terms of time; this is due to the long duration of the operation and the availability of one operation room. The next longest que found was the casting room due to the large percentage of patients entering the casting room, and the mean time there is only one casting room. There is no need to add another casting room because the average waiting time is approximately 5 minutes, which is a tolerable waiting time. As for the gynecology the reason behind having such a short average waiting time is the low percentage of gynecology cases entering the Sheikh Zayed ED. The reception average waiting time was also relatively low due to the availability of two receptionists at the information desk and the relatively small time spent at this activity.

The remaining activities (resuscitation, triage, observation, and examination and treatment rooms) all had approximately zero average waiting times due to the either excess resources (beds), or due to the low percentage of patients needing these activities.

2. Utilization rate of spaces

Another way of analyzing the simulation model is by studying the utilization rate of spaces. This is by studying the percentage of usage of the resource. This is done to detect which resources are in excess and which others are in shortage. This is an important analysis in order to find ways to optimize the ED by re-allocating resources.

Figure 40 represents the utilization rates for each activity/ work station.

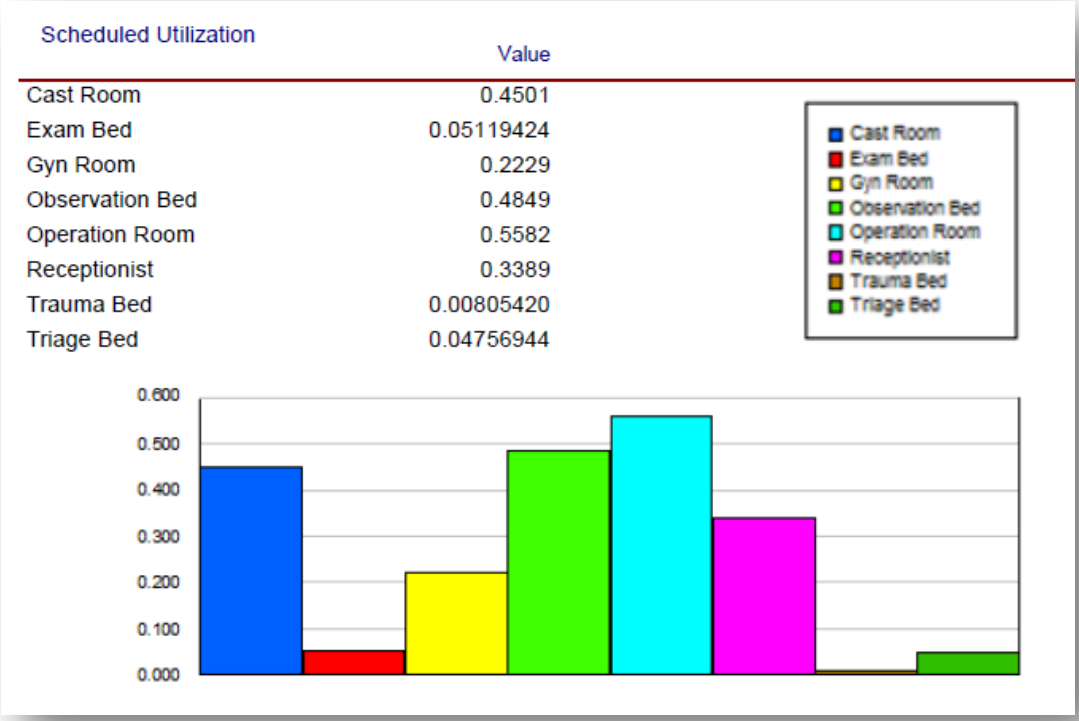


Figure 40: Utilization rates for each activity

The operation room had the maximum utilization rate because it was only a single room in the system, had a relatively longer duration than the other activities/ workstations, and had a relatively higher demand than other activities.

Trauma/ resuscitation room had the least utilization rate due to the small percentage of patients in need for this activity, while the examination room had the least utilization rates due to the excess number of resources (beds).

3. Average wait time for each activity with different arrival rates

After studying the average waiting time for each activity on the base case with an inter-arrival rate of EXP (12), the model was run again for several times with different inter-arrival rates. This was done in order to detect the affect of the inter-arrival rates on the average waiting times and the utilization rates for each activity/ work station.

Table 6 was compiled on the basis of only changing the inter-arrival rates, while keeping the number of resources unchanged as per Sheikh Zayed ED to study the effect of the change of inter-arrival rates on the ED; it is a sensitivity analysis.

Table 6: Applying different Arrival Rate Scenarios on the Sheikh Zayed ED Model

Run	Inter-Arrival Rate	Patients/day	Waiting Time (mins)							
			Cast Room	Exam Bed	Gyn Room	Mini Operations Bed	Observation Bed	Receptionist	Trauma Bed	Triage Bed
	Expo()		1	5	1	1	6	3	2	4
1	5	203	123	0	37.25	321	220	83.5	0	0
2	6	197	135.45	0	45.1	279	43.4	11.9	0	0
3	7	175	28.1	0	23.25	176.11	45.76	4.4	0	0
4	9	139	11.83	0	12.72	73.5	3.5	3.7	0	0
5	12	89	4.63	0	1.72	46.59	0.25	1.16	0	0
6	15	86	7.34	0	10.14	72.9	1.12	1.64	0	0
7	17	89	6.3	0	3.8	29.7	0	2.5	0	0
8	20	65	6.3	0	4.6	55.4	0	0.8	0	0
9	25	49	3	0	4.6	30.4	0	0.6	0	0
10	30	50	0.1	0	0	20	0	0.7	0	0

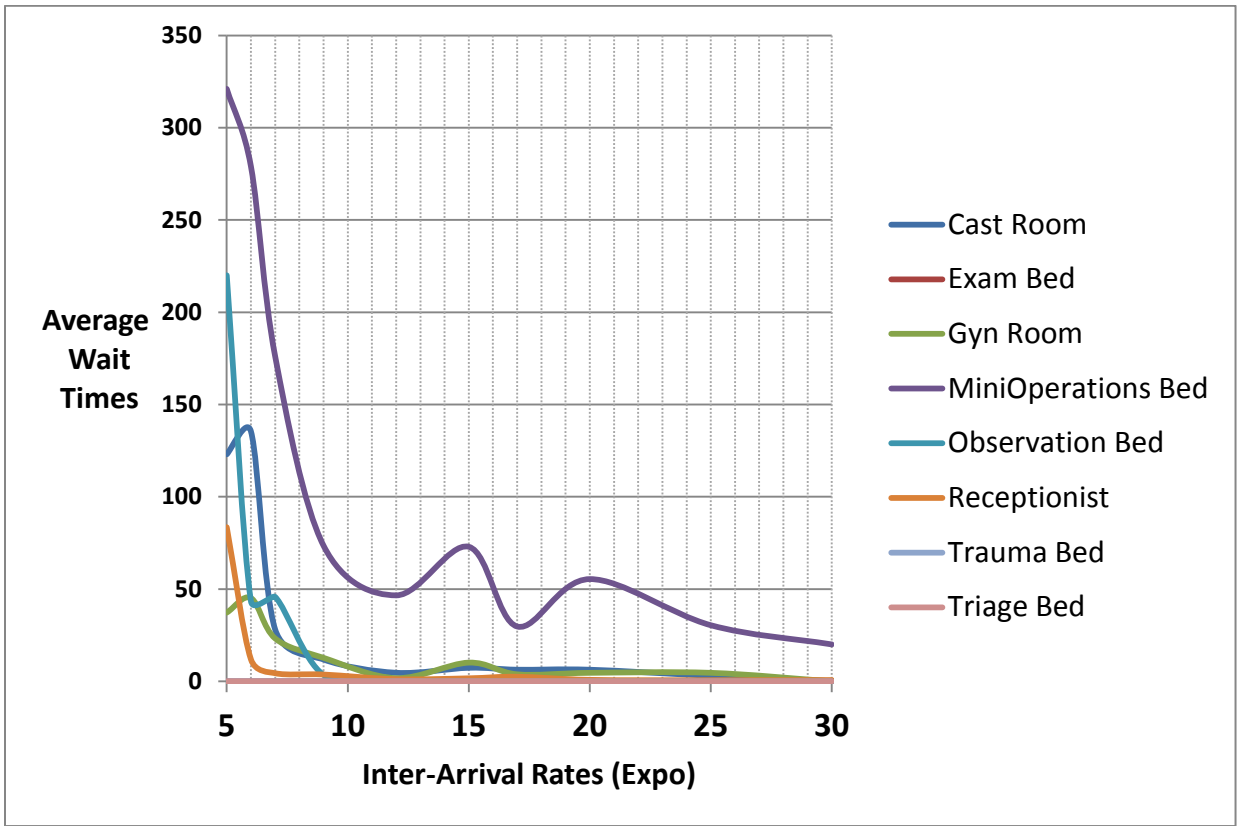


Figure 41: The Effect of Different Inter-Arrival Scenarios on patient wait time for each activity/ work station.

Figure 41 represents the findings from Table 6 in a graphical form. It is evident that the inter-arrival rates higher than EXP (10), with the exception of mini-operation rooms, have a very low waiting time.

Some bumps can be seen in the graph in Figure 38, which show that the relationship between the arrival rate and average wait time is not linearly proportional, for example the increase of average waiting time at EXP (15) mini-operation room, this may be due to one or more of the following:

- The duration of the mini-operation activity is represented as a random distribution in the simulation model. Therefore; it may be due to the selection of higher mini-operation durations during this simulation run.

- The mini-operations activity is dependent on other activities, so in the case that the previous activities took less time, the average waiting time for the mini-operations activity will be higher.
- In some cases, activities become synchronous, which lead to a lower average waiting time. In this case, the opposite may have happened.

4. Utilization Rate for each activity with different arrival rates

After studying the utilization rate for each activity on the base case with an inter-arrival rate of EXP (12), the model was run again for several times with different inter-arrival rates. This was done in order to detect the affect of the inter-arrival rates on the utilization rates for each activity/ work station.

Table 7 was compiled on the basis of only changing the inter-arrival rates, while keeping the number of resources unchanged as per Sheikh Zayed ED to study the effect of the change of inter-arrival rates on the ED; it is a sensitivity analysis.

Table 7: The effect of different inter-arrival rates on the utilization rates of activities/ work stations

Run	Arrival Rate	Patients/day	Utilization Rates/ Work Station(Resource)							
			Cast Room	Exam Bed	Gyn. Room	Minor Operations Bed	Observation Bed	Receptionist	Trauma Bed	Triage Bed
	Expo()		1	5	1	1	6	3	2	4
1	5	203	99.45%	11.85%	79%	99.86%	93.25%	96.60%	3%	15.75%
2	6	197	93.80%	8.40%	62%	99.80%	88.30%	84.60%	3.90%	11.80%
3	7	175	77%	8%	59.20%	99.80%	93%	68.30%	2.60%	9.70%
4	9	139	59%	4.90%	45.90%	95%	70.70%	55.20%	0.80%	8%
5	12	89	45%	5%	2.30%	55.80%	48.50%	34%	0.80%	4.80%
6	15	86	28.70%	3.50%	30%	70.70%	51.20%	30%	1.60%	5.30%
7	17	89	40.30%	2.50%	33.60%	70%	54.30%	33%	2%	5%
8	20	65	41.30%	3%	22%	57.50%	37.30%	24.60%	1%	3%
9	25	49	3%	3.30%	14.20%	29%	26.60%	21%	0.35%	2.50%
10	30	50	14.50%	2.30%	17%	37%	36%	19.60%	1%	3%

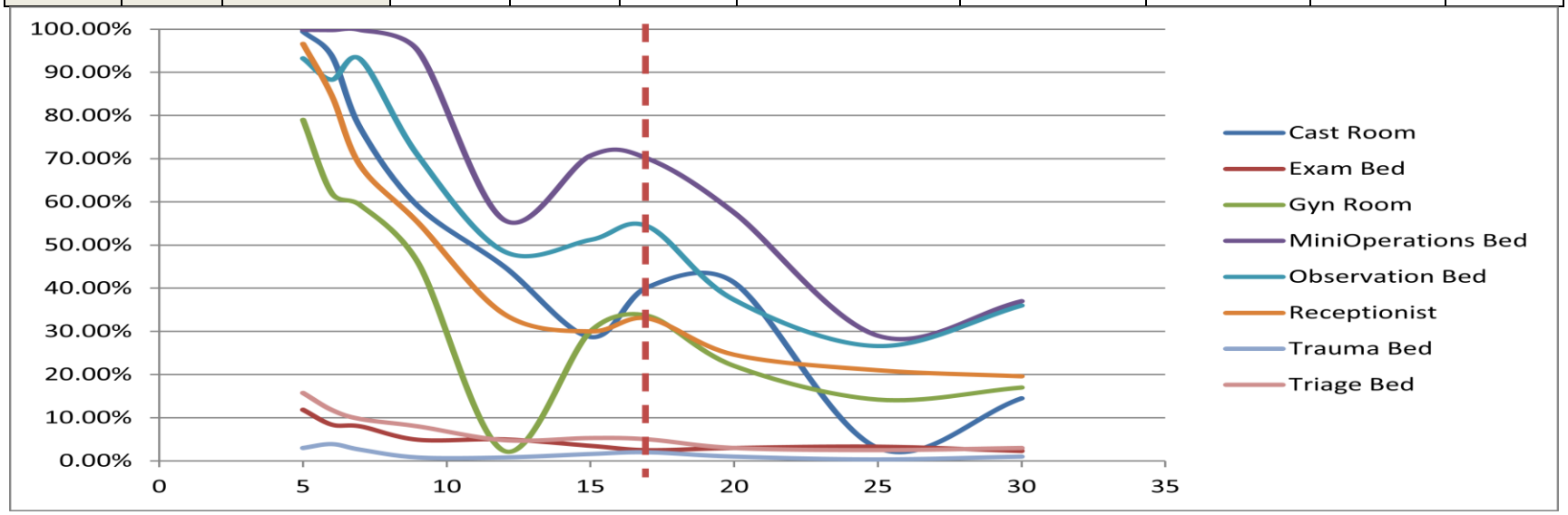


Figure 42: The Effect of Different Arrival Scenarios the utilization rate for each activity, work station

Figure 42 represents the findings from Table 7 in a graphical form. It is evident that there are three significant inter-arrival rates, EXP(12), EXP(18), and EXP(26), where noteworthy changes in the utilization rates take place, which show that the relationship between the arrival rate and average wait time is not linearly proportional

The utilization rate for most activities significantly decrease at EXP(12), which is the current condition at Sheikh Zayed ED. At EXP(18), utilization rates reach a peak, and then decreases till the inter-arrival rate of EXP(26).

This may be due to one or more of the reasons, which are:

- The durations of the different activities are represented as a random distribution in the simulation model. Therefore; it may be due to the selection of higher durations during this simulation run.
- The utilization rate is defined as the amount of time the resource was utilized, so in the case that the activities took longer times, the utilization rates will be higher.

5. Cost analysis

Lists of equipment needed in each work station of the ED of Sheikh Zayed Hospital are prepared and priced (Please find attached in Appendices).

The prices prepared can be seen in Table 8; the prices collected are then divided by the capacity of each work station, in order to have a rough estimate of the cost of increasing an extra resource (refer to #3 in Table 9).

Table 8: Average Cost for each Activity/ Work Station.

Work Station	EGP
Delivery Room	388061.1
Examination Room	86965.88
Operation Room	1139320
Triage	57263.04
Observation Room	192932.2
Resuscitation	429764.5

Table 8 will be used for the optimization of the ED with respect to cost and waiting time. The waiting time is inversely proportional to the number of resources, while cost is directly proportionate to the number of resources. An optimum allocation of resources will decrease the initial cost of an ED, as well as decrease the average waiting time of patients.

6. Spatial analysis

The durations of each activity in the ED has been determined and gathered from the previous works of researchers as shown in Table 9.

Area Take offs for the ED of the Sheikh Zayed Hospital were also conducted (refer to #1 in Table 9). These areas were also then divided by the capacity of each sub-department; in order to have a rough estimate of the area needed per patient (refer to #2 in Table 9).

Table 9: Spatial & Cost Analysis.

	No. of Resources	Sheikh Zayed (m2)	Area / Resource	Cost (EGP) / Resource
Casting	1	42.1	42.1	86,966.00
Examination	6	53.2	8.9	86,966.00
Gynecology	1	25.9	25.9	388,061.00
Operation	1	45.7	45.7	1,139,320.00
Observation	6	54.0	9.0	192,932.00
Reception	3	12.4	4.1	30,200.00
Resuscitation	2	38.0	19.0	214,882.50
Triage	7	88.0	12.6	57,263.00

Column #1 of Table 9 is the result of the take-off of the areas of different sub-departments of the Sheikh Zayed Hospital.

Column #2 of Table 9 is the result of dividing the areas by the number of resources in each sub-department.

Column #3 of Table 9 is dividing the costs of the sub-departments shown in Table 8 by the number of resource in each sub-department.

Table 9 added a new parameter to be used for the optimization of the ED. It will achieve optimization to the ED with respect to cost and waiting time, in addition to the areas needed.

Chapter Five

Model Verification

V. CHAPTER FIVE: SIMULATION MODEL VERIFICATION

Verifying the simulation model is a very important process, because it determines if the simulation model generated is a useful representation of the real system or not. The most definitive method is to compare the output data from the simulation with a similar simulation model of different software or the actual data from the existing system.

1. Model implementation

After completing the simulation model using ARENA software, it was rebuilt using Anylogic software in order to verify that the model has been designed correctly and that the results are fairly similar.

Both models used in this research have the same approach. They both begin with the source that provides entities (patients), which enter a queue that calculates the waiting time before each activity, then enter the activity/ work station for a certain period of time entered by the user, and finally exits the model.

Anylogic seems more complicated, as can be seen in Figure 44, because it requires other functions to run the model which has to do with animating the simulation model, where the process is as follows:

- The entity enters the network system.
- The entity waits till an available resource is released (nurse, stretcher,…etc).
- The entity is attached to the resource.

- The entity and resource are sent to the specified activity/ work station which is known as the delay.
- Once the activity is finished, the resource and entity are detached where the resource is sent back to its original location and the entity is either sent to the next activity/ work station.
- The last step in the process is sending the entity to the ED exit door where it exits the network system and disappears from the animation plan.

a. ARENA Simulation Model

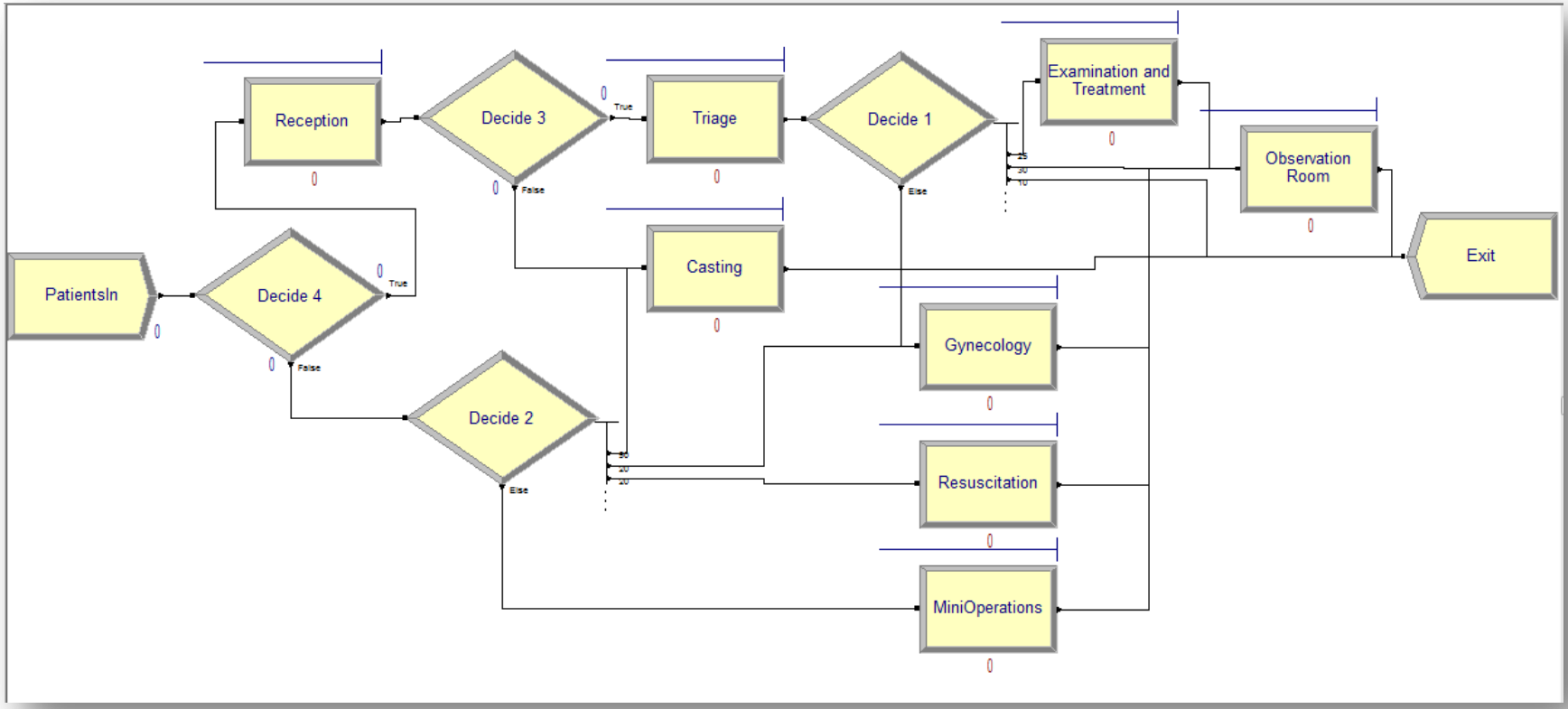


Figure 43: ARENA Simulation Model

b. *Anylogic Simulation Model*

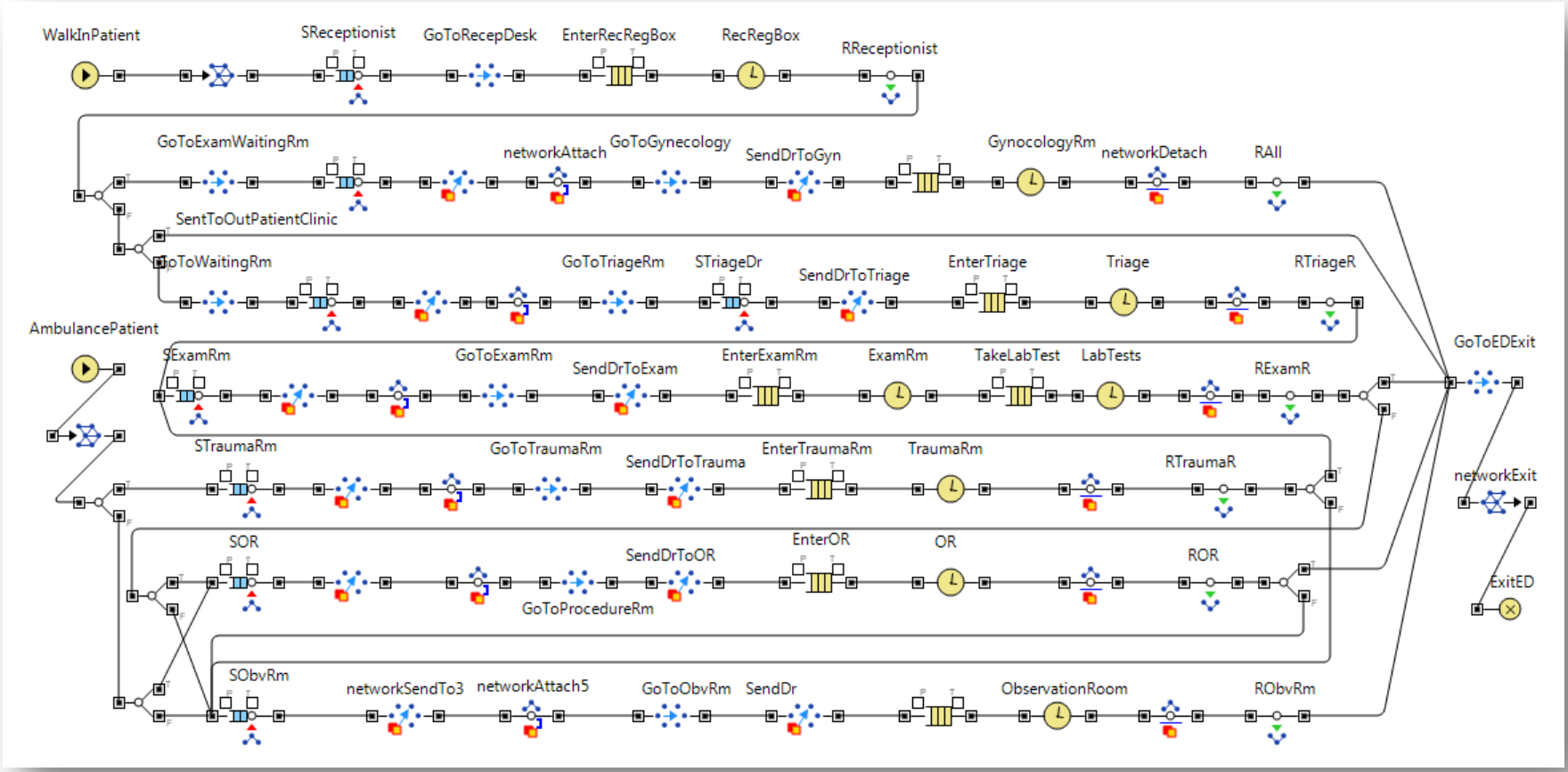


Figure 44: AnyLogic Simulation Model

2. Sample Test Analysis

After running both simulation models, the results in regards to average waiting time and utilization rates for each activity/ work station were obtained. This can be seen in Table 10 for the ARENA model and Table 11 for the AnyLogic model.

a. ARENA Results

Table 10: Results from ARENA Simulation Model

Activity/ Work Station	Average Wait Time (mins.)	Utilization Rates (%)
Casting Room	4.63	45%
Examination & Treatment Room	0	5%
Gynecology Room	1.72	23%
Mini-Operations Room	46.59	49%
Observation Room	0.25	56%
Reception	1.16	34%
Resuscitation	0	1%
Triage	0	5%

b. Anylogic Results

Table 11: Results from Anylogic Simulation Model

Activity/ Work Station	Average Wait Time (mins.)	Utilization Rates (%)
Casting Room	5.22	51%
Examination & Treatment Room	0	12%
Gynecology Room	0.97	18%
Mini-Operations Room	43.64	36%
Observation Room	0.1	52%
Reception	1.25	54%
Resuscitation	0	2%
Triage	0.13	10%

3. Comparative Analysis

In order to validate the designed simulation model, a comparison was made between the results obtained from both simulation software. The standard deviation was essential to determine the efficiency of the models concerning the average waiting time and the utilization rates for each activity/ work station. This can be seen in Table 12 and Table 13.

Due to comparing two software models only, the most meaningful statistical method to determine whether the two models gave close results was finding the mean and standard deviation.

Table 12: Comparison table for the average wait time for each activity

	Average Wait Time (mins.)					
Activity/ Work Station	**Arena**	**AnyLogic**	**Difference**	**%**	**Mean**	**St Dev**
Casting Room	4.63	5.22	0.59	13%	4.93	0.30
Exam. & Treatment Room	0	0	0.00	0%	0.00	0.00
Gynecology Room	1.72	0.97	0.75	44%	1.35	0.38
Mini-Operations Room	46.59	43.64	2.95	6%	45.12	1.48
Observation Room	0.25	0.1	0.15	60%	0.18	0.08
Reception	1.16	1.25	0.09	8%	1.21	0.05
Resuscitation	0	0	0.00	0%	0.00	0.00
Triage	0	0.13	0.13	0%	0.07	0.07

All results in Table 12 show that both software models obtained similar values, and low standard deviations, which verify that the model was designed correctly.

Table 13: Comparison table for the utilization rates

	Utilization Rates (%)				
Activity/ Work Station	Arena	AnyLogic	Difference	Mean	St Dev
Casting Room	45%	51%	0.06	48%	0.03
Exam. & Treatment Room	5%	12%	0.07	9%	0.04
Gynecology Room	23%	18%	0.05	21%	0.03
Mini-Operations Room	49%	36%	0.13	43%	0.07
Observation Room	56%	52%	0.04	54%	0.02
Reception	34%	54%	0.2	44%	0.10
Resuscitation	1%	2%	0.01	2%	0.01
Triage	5%	10%	0.05	8%	0.03

All results in Table 13 show that both software models obtained similar values, and low standard deviations, which verify that the model was designed correctly.

Table 14 represents the average wait times generated from both Arena and AnyLogic models with the difference between them. The results are represented in Figure 45

Table 14: Sensitivity Analysis Table

Runs	Expo	Average Wait Times		Difference
		Arena	AnyLogic	
1	30	99.02	100.53	1.52%
2	25	82.47	80.92	1.88%
3	20	90.63	89.21	1.57%
4	17	92.10	90	2.28%
5	15	96.57	98.52	2.02%
6	12	85.68	85.1	0.68%
7	9	92.10	93.77	1.81%
8	7	126.71	125.12	1.25%
9	6	152.35	150.67	1.10%
10	5	245.13	245.98	0.35%

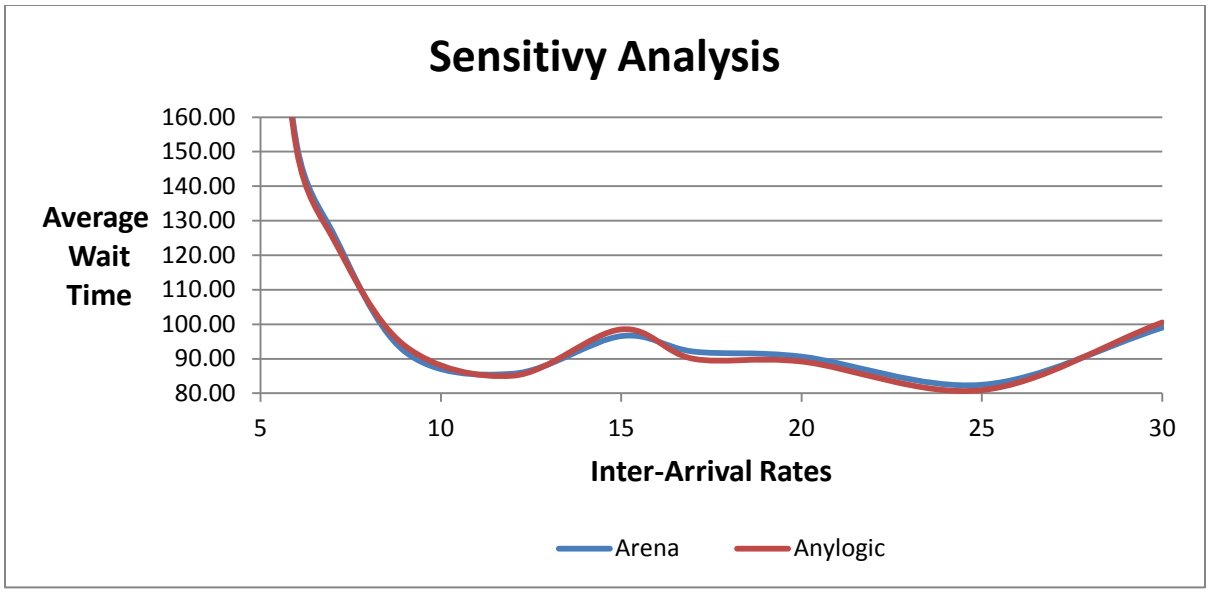


Figure 45: Sensitivity Analysis Graph

Chapter Six

Optimization

VI. CHAPTER SIX: OPTIMIZATION

Equation 10: Linear Model

$$W_i = K_i^1 \times AR + K_i^2 \times N_i + C_i$$

Where W_i is the waiting time for activity i, K_i^1 is the factor, AR represents the arrival rate, K_i^2 is the other factor, N_i equals the number of resources for activity I, and C_i is the constant.

The objective is to minimize the waiting time of patients by changing the number of resources for each activity (Equation 11), subject to a certain cost and area that should not be exceeded (Equation 12 and Equation 13).

Equation 11: The Objective Function

$$Objective = MIN \sum_{i=1}^{n} W_i$$

Equation 12: First Constraint

$$N_i \times q_i < Q$$

Where qi is the cost for each activity/ work station, and Q is the total ED cost.

Equation 13: Second Constraint

$$N_i \times a_i < A$$

Where ai is the area for each activity/ work station, and A is the total ED area.

A. Data Compilation

Data compilation of waiting times for each activity; in order to obtain a diverse data set, different arrival rates are tested on the simulation model, and waiting times for each activity are recorded.

In order to obtain data values which could be used for the optimization of hospitals, the simulation was run for 20 times. Each run had 9 different variables; 8 resource variables, in addition to the Arrival Rate. This can be seen in Table 15

Table 15: 20 different Runs for the Simulation Model.

Run	Arrival Rate	Cast Room		Exam Bed		Gyn Room		Observation Bed		Operation Room		Receptionist		Trauma Bed		Triage Bed	
		Resources	Wait Time	Resources	Wait Time	Resources	Wait Time	Resources	Wait Time	Resources	Wait Time	Resources	Wait Time	Resources	Wait Time	Resources	Wait Time
1	11	1	4.4	5	0	1	17.4	7	0.76	3	0.43	3	0	3	0	6	0
2	15	4	18.6	7	24.7	1	34.5	6	113.8	4	67	1	7	6	11	9	6
3	11	2	1.5	5	0	3	0	9	0	1	32.9	5	0	7	0	10	0
4	6	1	42.2	7	0	2	0.93	5	219.22	2	33.1	1	21.3	4	0	7	0
5	6	1	57	3	0	1	13	6	138	3	0.24	1	10.4	2	0	7	0
6	12	3	0	6	0	1	10.1	7	3.58	2	5.85	4	0	7	0	7	0
7	8	1	35	7	0	2	0	5	40	1	167	2	0.33	3	0	6	0
8	11	2	0.66	6	0	3	0	10	0	2	0.83	2	0.23	2	0	9	0
9	8	2	1.1	3	0	1	14.55	7	1.53	1	257	3	0.02	6	0	9	0
10	9	3	0	3	0	2	0.77	7	3.13	4	0	2	0.2	6	0	4	0
11	12	2	0.33	3	0	1	0.87	6	11.54	2	0.46	1	1.94	4	0	2	0
12	11	1	17.8	4	0	1	8.76	5	6.8	2	0.8	1	3.73	2	0	3	0
13	10	3	0.39	4	0	4	0	6	10.38	2	11.65	5	0	3	0	3	0
14	10	1	12.8	3	0.13	2	0	5	145.1	2	6.35	2	0.25	5	0	5	0
15	6	2	3.11	3	0.1	2	0.71	10	2.94	5	0	1	11.93	3	0	2	0
16	9	2	0.36	4	0	2	0	5	168	3	3	1	7	2	0	4	0
17	12	4	0	5	0	1	10.22	5	67	5	0	3	0	2	0	4	0
18	11	2	1.51	4	0	4	0	8	0	1	32.87	4	0	3	0	3	0
19	12	1	8.18	3	0	2	0	5	7.57	2	10	1	4.1	4	0	5	0
20	12	2	0	4	0	2	0.65	6	2.45	2	0	3	0	2	0	5	0
Min	6	1		3		1		5		1		1		2		2	
Max	12	4		7		4		10		5		5		7		10	

B. Regression

After completing the 20 runs of the simulation, two types of Linear Regression were performed, in order to be able to optimize the model.

A regression analysis is essential to formulate equations from the compiled data, in order to be used as the objective function in the optimization model. Regression is done to relate waiting times and resources for each activity/ work station with the arrival rate. This is done on two phases. The first phase is the generation of an equation relating all activities/ work stations with the arrival rate, while the second phase is the generation of equations relating each single activity/ work station with its resources and arrival rate.

1. Regression on the whole system

   In order to be able to perform optimization a general equation for the whole system had to be derived. For ease of calculations the "Arrival Rate" was chosen to be the "Y", while the Resources and Waiting Time were chosen to be the "X"s.

   The general equation of the system is:

Equation 14: Regression on the whole system

$$Arrival\ Rate = 0.42 \times Casting_{Resources} - 0.06 \times Casting_{Waiting\ Time} + 0.18 \times Examination_{Resources} + 4.19 \times Examination_{Waiting\ Time} - 0.36 \times Gynecology_{Resources} + 0.01 \times Gynecology_{Waiting\ Time} - 0.56 \times Observation_{Resources} - 0.01 \times Observation_{Waiting\ Time} - 0.88 \times Operation_{Resources} - 0.02 \times Operation_{Waiting\ Time} - 0.15 \times Reception_{Resources} - 0.08 \times Reception_{Waiting\ Time} - 0.18 \times Trauma_{Resources} - 8.86 \times Trauma_{Waiting\ Time} + 0.21 \times Triage_{Resources} + 0 \times Triage_{Waiting\ Time}$$

The coefficient of the waiting time for the Triage is zero, due to it being highly correlated with many other variables. This is due to the Triage being a central stage for several sub-departments.

2. Regression on each sub-department

   Due to the regression technique used not showing the effect of Resources on the Waiting Time, additional regressions were needed, in order to study the effect of the Arrival rate and the Resource rate of each individual department on its Waiting Time.

   After performing such regressions the following equations were obtained:

Equation 15: Regression on the Casting work station

$$Casting_{Waiting\ Time} = -2.44 \times Arrival\ Rate - 4.92 \times Casting_{Resources} + 44.74$$

Equation 16: Regression on the examination work station

$$Examination_{Waiting\ Time} = 0.97 \times Arrival\ Rate + 1.22 \times Examination_{Resources} - 13.98$$

Equation 17: Regression on the gynecology work station

$$Gynecology_{Waiting\ Time} = -1.19 \times Arrival\ Rate - 5.33 \times Gynecology_{Resources} + 3.78$$

Equation 18: Regression on the observation work station

$$Observation_{Waiting\ Time} = -10.8 \times Arrival\ Rate - 22.92 \times Observation_{Resources} + 305.25$$

Equation 19: Regression on the operation room

$$Operation_{Waiting\ Time} = -5.86 \times Arrival\ Rate - 22.13 \times Operation_{Resources} + 144.88$$

Equation 20: Regression on the Trauma or Resuscitation work station

$$Trauma_{Waiting\ Time} = 0.46 \times Arrival\ Rate + 0.29 \times Trauma_{Resources} - 5.18$$

Equation 21: Regression on the reception work station

$$Reception_{Waiting\ Time} = -1.01 \times Arrival\ Rate - 2.03 \times Reception_{Resources} + 18.30$$

Equation 22: Regression on the Triage work station

$$Triage_{Waiting\ Time} = 0.26 \times Arrival\ Rate + 0.16 \times Triage_{Resources} - 3.21$$

C. Setting-up the model

Setting-up the model is a critical phase and should be crafted carefully, because it is the core of the optimization process. The model is divided into three main elements; the first is the objective function, which is the function needed to be optimized. The second is variables, which are the elements which could be changed in order to reach the optimized model, in this study the variables are the number of resources in each activity/ work station. The third is constraints, which are equations that limit the optimization process from resulting in infeasible outputs. In this study, the constraints are minimum and maximum values for each resource, in addition there are other constraints concerning the maximum cost, maximum space, and maximum waiting time.

The final step is to run the optimization algorithm. There are different algorithms that may be applied for solving the model, but for the purpose of this research a Genetic Algorithm was chosen.

Table 16 represents the optimization set up.

Table 16: Optimization Set-Up

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
1			Equation	Arrival Rate	Intercept	C Res	C WT	E Res	E WT	G Res	G WT	Ob Res	Ob WT	Op Res	Op WT	R Res	R WT	Re Res	Re WT	T Res	T WT
2					16.46	0.42	-0.06	0.18	4.19	-0.36	0.01	-0.56	-0.01	-0.88	-0.02	-0.15	-0.08	-0.18	-8.86	0.21	0.00
3	AR	15.00	1	15.00	1.00	6.23		4.16		4.71		1.03		4.60		2.56		2.87		1.13	
4				0.00		6.00		4.00		5.00		1.00		5.00		3.00		3.00		1.00	
5																					
6	AREA	720.20	<	1000		42.10		8.86		25.90		9.00		45.70		4.1		19.00		12.57	
7	COST	8,933,727	<	10000000		86,966.00		86,966.00		388,061.00		192,932.00		1,139,320.00		30,200.00		214,882.50		57,263.00	
8	WT	119.52	<	240																	
9																					
10	C WT		2	-2.44	44.74	-4.92															
11	E WT		3	0.97	-13.98			1.22													
12	G WT		4	1.19	3.78					-5.33											
13	Ob WT		5	-10.80	305.25							-22.92									
14	Op WT		6	-5.86	144.88									-22.13							
15	R WT		7	-1.01	18.30											-2.03					
16	Re WT		8	0.46	-5.18													0.29			
17	T WT		9	0.26	-3.21															0.16	

1. Objective Function:

In this case, the objective function is highly complicated, due to it being composed of 9 functions, internally iterating within each iteration of the Genetic Algorithm used to solve the function. The 9 functions are the main system function (#1 in Table 17), in addition to the 8 sub-department function (#2 in Table 17). The internal iterations are due to that the Arrival Rate is a variable in each of the 8 Waiting Time functions for each sub-department, and in the meantime the 8 Waiting Time functions are variables within the main system function. This technique was used in order to minimize the Variables to be the resources needed for each sub-department. This technique would also mimic real decision-makers who according to budgets plan resources, not waiting times. These resources were translated into areas and cost, according to each sub-department's needed space and equipment per patient.

Table 17: Setting the Objective Function

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
1			Equation	Arrival Rate	Intercept	C Res	C WT	E Res	E WT	G Res	G WT	Ob Res	Ob WT	Op Res	Op WT	R Res	R WT	Re Res	Re WT	T Res	T WT
3	AR	15.00	1	15.00	1.00	6.23		4.16		4.71		1.03		4.60		2.56		2.87		1.13	
5																					
6	AREA	720.20	<	1000		42.10		8.86		25.90		9.00		45.70		4.1		19.00		12.57	
7	COST	8,933,727	<	10000000		86,966.00		86,966.00		388,061.00		192,932.00		1,139,320.00		30,200.00		214,882.50		57,263.00	
8	WT	119.52	<	240																	
9																					
10	C WT		2	-2.44	44.74	-4.92															
11	E WT		3	0.97	-13.98			1.22													
12	G WT		4	1.19	3.78					-5.33											
13	Ob WT		5	-10.80	305.25							-22.92									
14	Op WT		6	-5.86	144.88									-22.13							
15	R WT		7	-1.01	18.30											-2.03					
16	Re WT		8	0.46	-5.18													0.29			
17	T WT		9	0.26	-3.21															0.16	

1

2

2. Variables:

The only variables needed are the resources for each of the 8 sub-departments. The resources (#3 in Table 18) in this study are the equipment needed to sustain 1 patient; it is the capacity of the sub-department. In other words, it is the number of patients the sub-department can treat in the same time.

Table 18: The Variables in the Optimization Model.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
1			Equation	Arrival Rate	Intercept	C Res	C WT	E Res	E WT	G Res	G WT	Ob Res	Ob WT	Op Res	Op WT	R Res	R WT	Re Res	Re WT	T Res	T WT
2					16.46	0.42	-0.06	0.18	4.19	-0.36	0.01	-0.56	-0.01	-0.88	-0.02	-0.15	-0.08	-0.18	-8.86	0.21	0.00
3	AR	15.00	1	15.00	1.00	6.23		4.16		4.71		1.03		4.60		2.56		2.87		1.13	
4				0.00		6.00		4.00		5.00		1.00		5.00		3.00		3.00		1.00	
5																					
6	AREA	720.20	<	1000		42.10		8.86		25.90		9.00		45.70		4.1		19.00		12.57	
7	COST	8,933,727	<	10000000		86,966.00		86,966.00		388,061.00		192,932.00		1,139,320.00		30,200.00		214,882.50		57,263.00	
8	WT	119.52	<	240																	
9																					
10	C WT		2	-2.44	44.74	-4.92															
11	E WT		3	0.97	-13.98			1.22													
12	G WT		4	1.19	3.78					-5.33											
13	Ob WT		5	-10.80	305.25							-22.92									
14	Op WT		6	-5.86	144.88									-22.13							
15	R WT		7	-1.01	18.30											-2.03					
16	Re WT		8	0.46	-5.18													0.29			
17	T WT		9	0.26	-3.21															0.16	

3

3. Constraints:

The constraints for this study were:

- Non-negativity constraint for all variables
- Optional Constraints used to test the model(#4 in Table 19)

  These Optional Constraints give the user the flexibility to choose to constrain:

  - The Area of the main sub-departments of the ED
  - The Cost of the main sub-departments of the ED
  - The Waiting Time of the main sub-departments of the ED

Table 19: The Constraint in the Optimization Model.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
1			Equation	Arrival Rate	Intercept	C Res	C WT	E Res	E WT	G Res	G WT	Ob Res	Ob WT	Op Res	Op WT	R Res	R WT	Re Res	Re WT	T Res	T WT
2					16.46	0.42	-0.06	0.18	4.19	-0.36	0.01	-0.56	-0.01	-0.88	-0.02	-0.15	-0.08	-0.18	-8.86	0.21	0.00
3	AR	15.00	1	15.00	1.00	6.23		4.16		4.71		1.03		4.60		2.56		2.87		1.13	
4				0.00		6.00		4.00		5.00		1.00		5.00		3.00		3.00		1.00	
5																					
6	AREA	720.20	<	1000		42.10		8.86		25.90		9.00		45.70		4.1		19.00		12.57	
7	COST	8,933,727	<	10000000	4	66.00		86,966.00		388,061.00		192,932.00		1,139,320.00		30,200.00		214,882.50		57,263.00	
8	WT	119.52	<	240																	
9																					
10	C WT		2	-2.44	44.74	-4.92															
11	E WT		3	0.97	-13.98			1.22													
12	G WT		4	1.19	3.78					-5.33											
13	Ob WT		5	-10.80	305.25							-22.92									
14	Op WT		6	-5.86	144.88									-22.13							
15	R WT		7	-1.01	18.30											-2.03					
16	Re WT		8	0.46	-5.18													0.29			
17	T WT		9	0.26	-3.21															0.16	

D. Analysis and Results

After running the optimization several times with different Arrival Rates, Table 20 was obtained. These, according to the simulation, are the most efficient designs in terms of lowest cost, and lowest waiting time.

Table 20: Results

Exp()	Casting	Examination	Gynaecology	Observation	Operation	Reception	Resuscitation	Triage	Area	Cost	Waiting Time
Expo(6)	2	4	2	1	2	2	5	3	428.53	5,096,551	214.38
Expo(7)	1	4	3	1	2	2	4	7	418.09	5,233,034	206.81
Expo(8)	1	5	2	1	2	1	6	6	435.83	5,287,859	195.99
Expo(9)	2	5	2	1	2	2	6	5	459.77	5,383,635	179.83
Expo(10)	2	6	3	1	1	2	7	3	428.14	4,971,075	174.25
Expo(11)	2	4	2	1	2	2	4	6	412.09	4,959,741	163.63
Expo(12)	2	6	2	1	2	2	6	5	466.27	5,676,221	152.84
Expo(13)	1	5	2	2	2	2	5	4	417.60	5,268,285	120.18
Expo(14)	2	5	2	1	2	1	5	1	412.88	5,078,884	131.27
Expo(15)	2	5	3	1	2	3	3	3	398.23	5,061,726	120.49

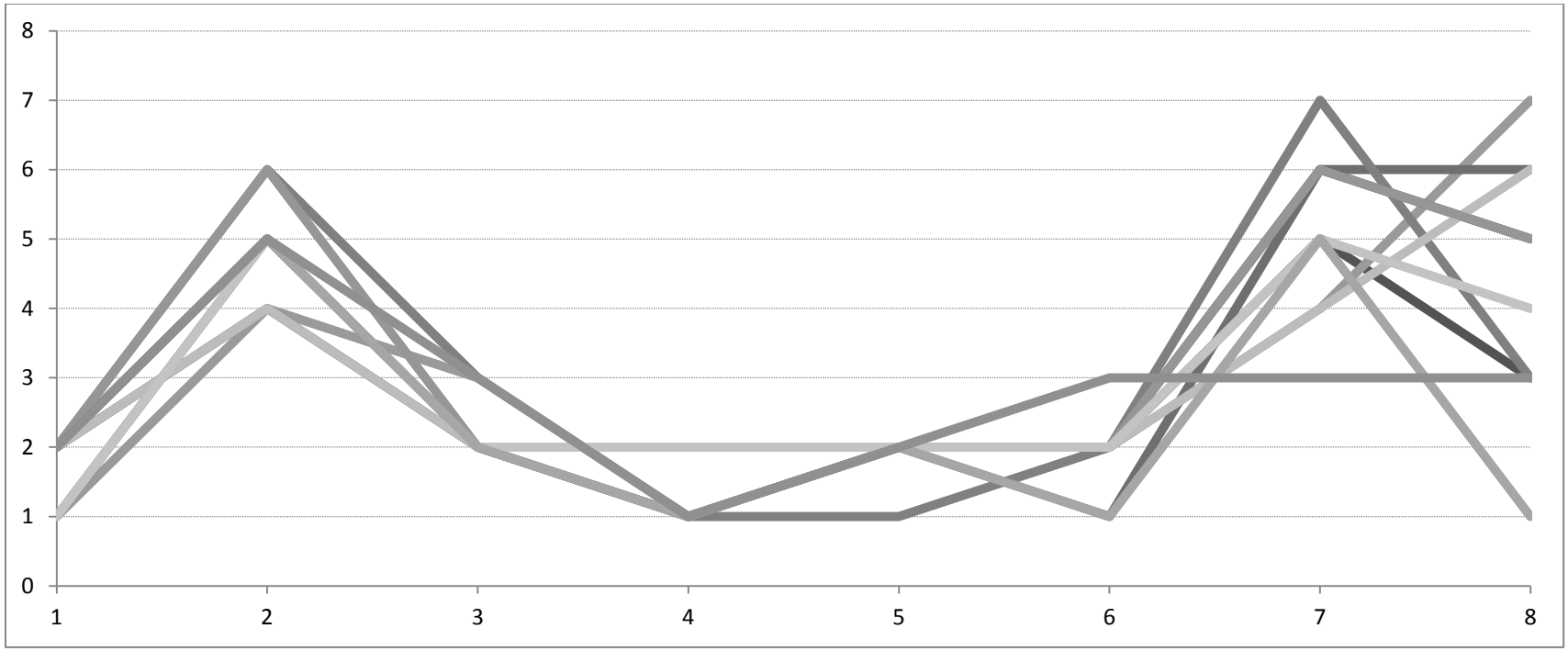
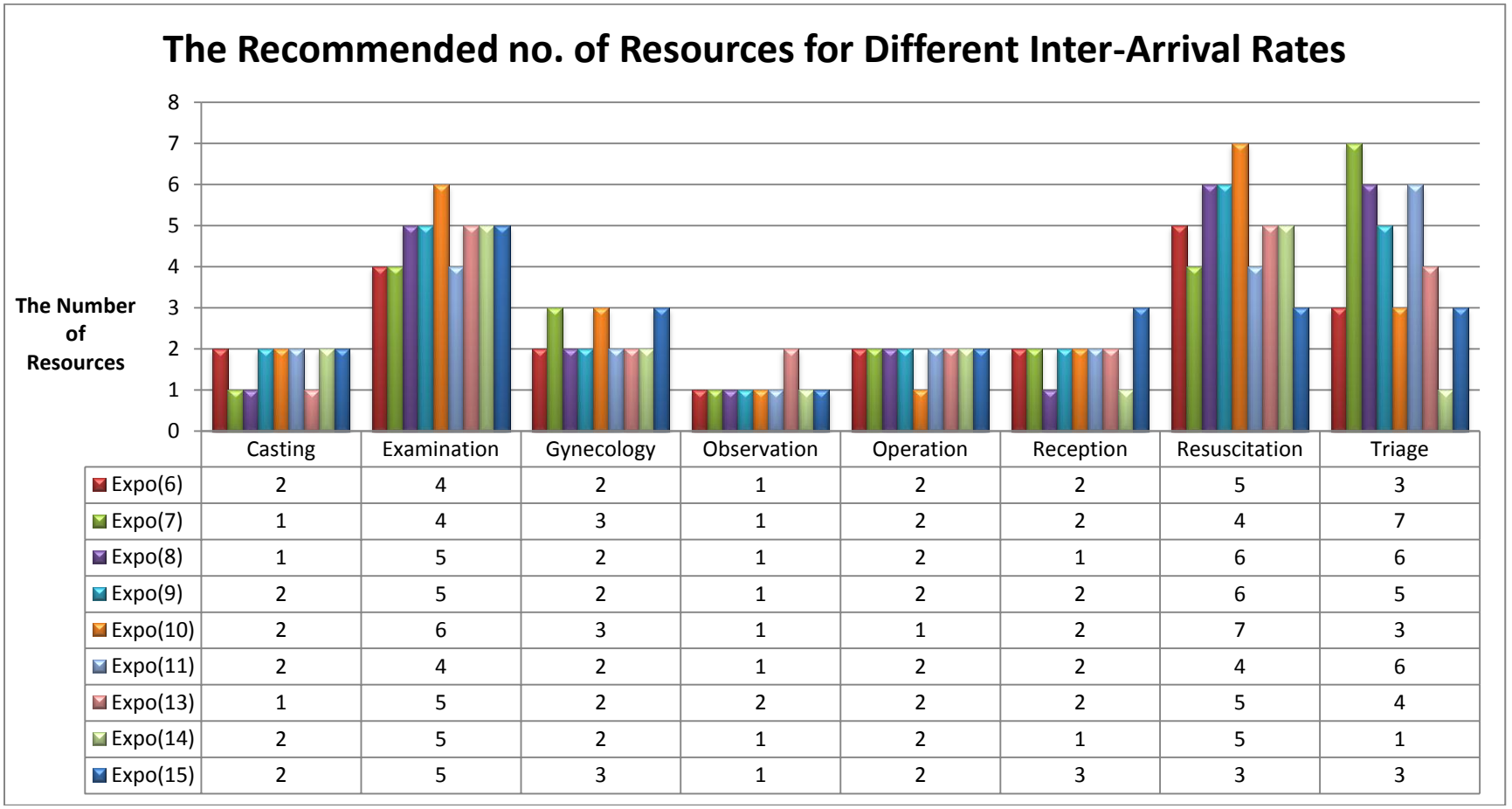


Figure 46: Results from the Optimization Model

Figure 46 is a summary of all the recommended number of resources for each activity/ work station where the numbers on the vertical axe represent the number of resources (beds or rooms) required while the numbers on the horizontal axe represent the activities/ work stations which are as follows;

1. Casting rooms	2. Examination beds, cubicles	3. Gynaecology rooms	4. Observation beds/ cubicles
5. Operation rooms	6. Receptionists	7. Trauma room/ beds	8. Triage beds/ cubicles



	Casting	Examination	Gynecology	Observation	Operation	Reception	Resuscitation	Triage
Expo(6)	2	4	2	1	2	2	5	3
Expo(7)	1	4	3	1	2	2	4	7
Expo(8)	1	5	2	1	2	1	6	6
Expo(9)	2	5	2	1	2	2	6	5
Expo(10)	2	6	3	1	1	2	7	3
Expo(11)	2	4	2	1	2	2	4	6
Expo(13)	1	5	2	2	2	2	5	4
Expo(14)	2	5	2	1	2	1	5	1
Expo(15)	2	5	3	1	2	3	3	3

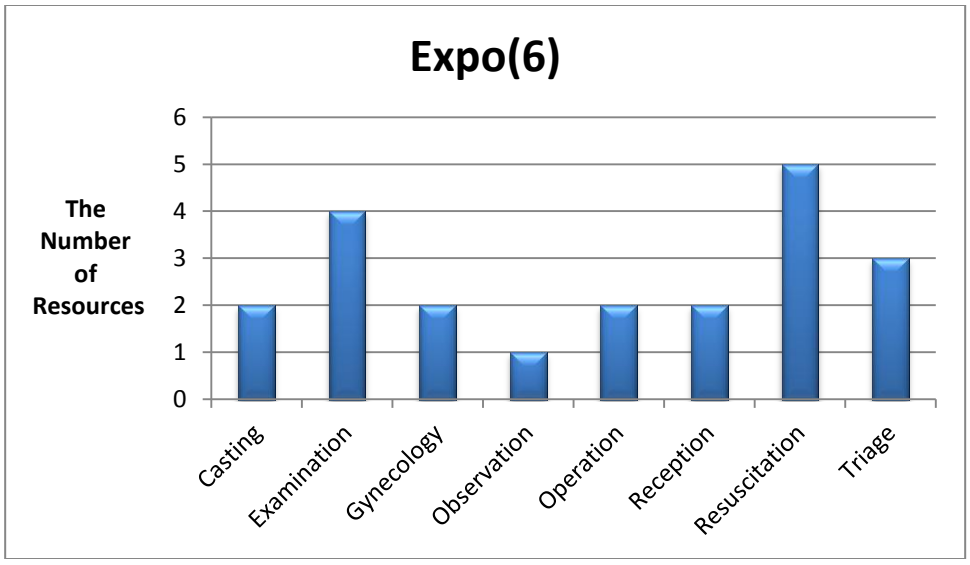


Figure 47: The number of resources recommended for each activity/ work station based on the inter-arrival rate Expo (6).

It was found that the number of resources needed for each activity/ work station based on the inter-arrival rate Expo (6) is as follows; two casting rooms, four examination beds/ cubicles, two gynaecology rooms, one observation room, two operation rooms, two receptionists, five resuscitation beds/ cubicles, and three triage beds. This can be seen in Figure 47.

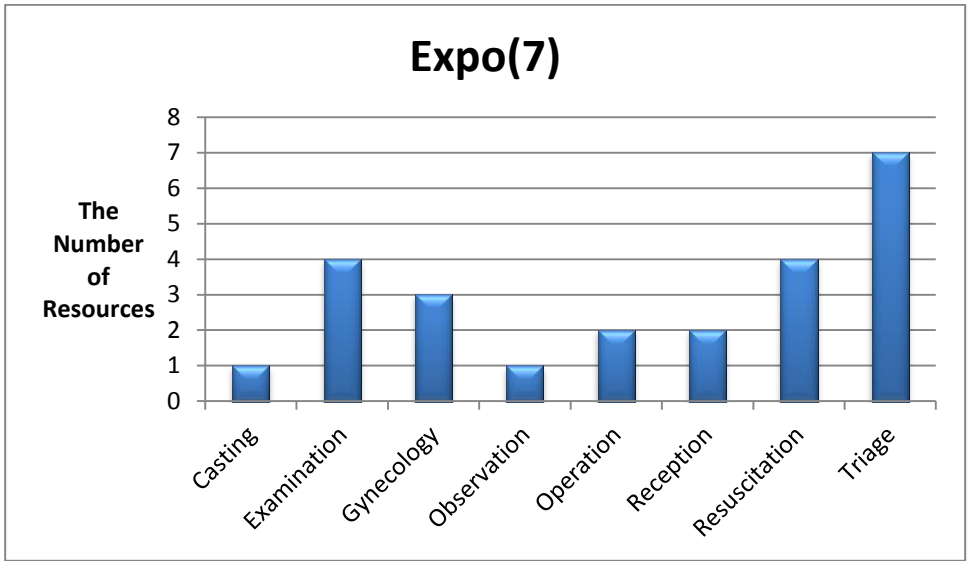


Figure 48: The number of resources recommended for each activity/ work station based on the inter-arrival rate Expo (7).

It was found that the number of resources needed for each activity/ work station based on the inter-arrival rate Expo (7) is as follows; one casting rooms, four examination beds/ cubicles, three gynaecology rooms, one observation room, two operation rooms, two receptionists, five resuscitation beds/ cubicles, and seven triage beds. This can be seen in Figure 48.

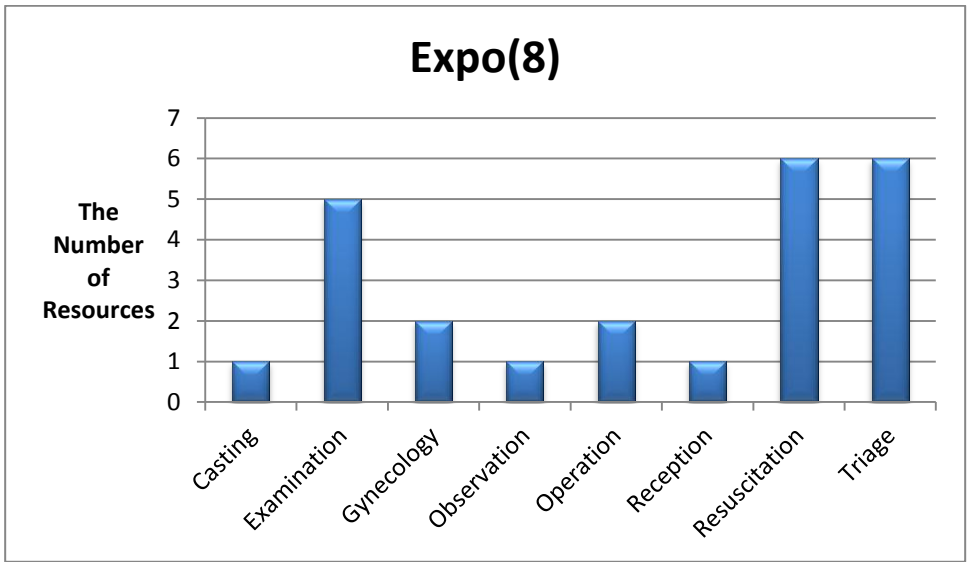


Figure 49: The number of resources recommended for each activity/ work station based on the inter-arrival rate Expo (8).

It was found that the number of resources needed for each activity/ work station based on the inter-arrival rate Expo (8) is as follows; one casting room, five examination beds/ cubicles, two gynaecology rooms, one observation room, two operation rooms, one receptionist, six resuscitation beds/ cubicles, and six triage beds. This can be seen in Figure 49.

It was found that the number of resources needed for each activity/ work station based on the inter-arrival rate Expo (9) is as follows; two casting rooms, five examination beds/ cubicles, two gynaecology rooms, one observation room, two operation rooms, two receptionists, six resuscitation beds/ cubicles, and five triage beds. This can be seen in Figure 50.

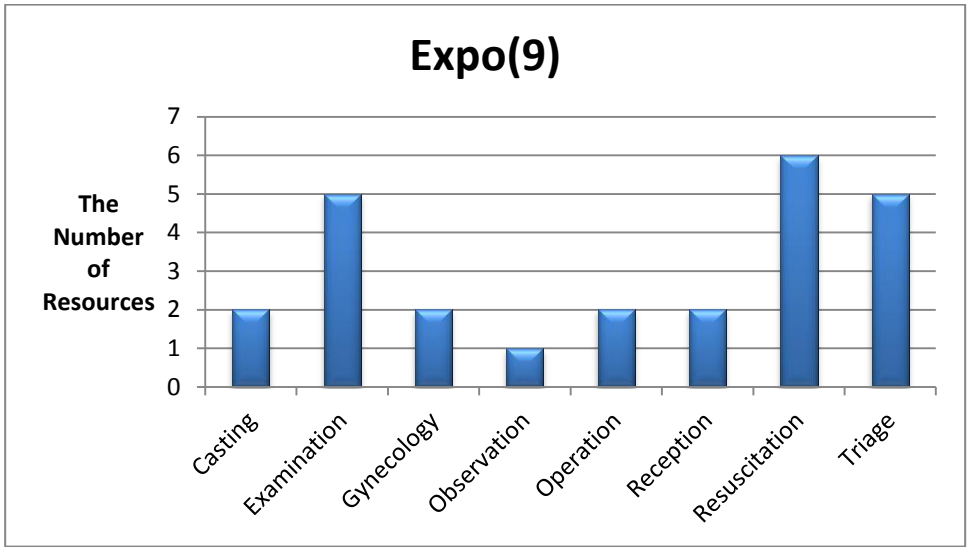


Figure 50: The number of resources recommended for each activity/ work station based on the inter-arrival rate Expo (9).

It was found that the number of resources needed for each activity/ work station based on the inter-arrival rate Expo (10) is as follows; two casting rooms, six examination beds/ cubicles, three gynaecology rooms, one observation room, one operation rooms, two receptionists, seven resuscitation beds/ cubicles, and three triage beds. This can be seen in Figure 51.

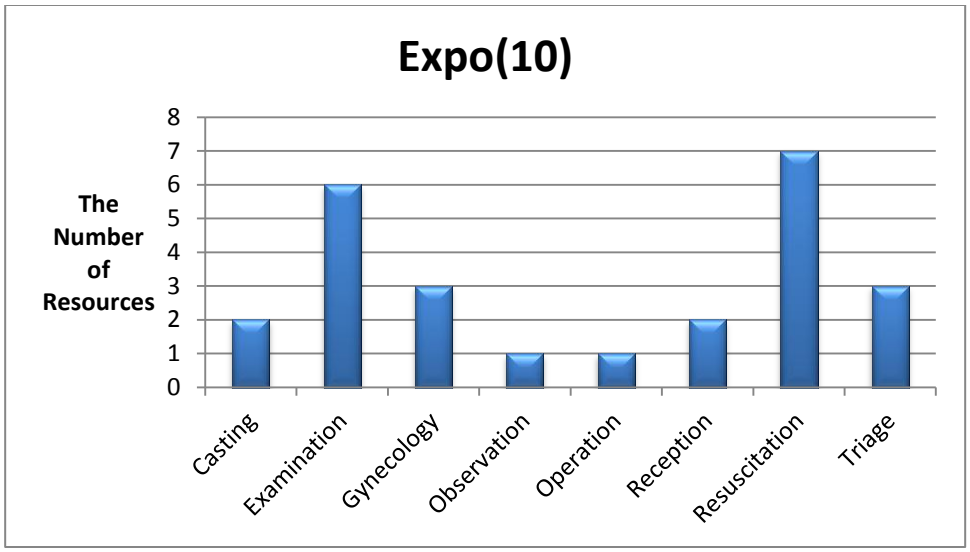


Figure 51: The number of resources recommended for each activity/ work station based on the inter-arrival rate Expo (10).

It was found that the number of resources needed for each activity/ work station based on the inter-arrival rate Expo (11) is as follows; two casting rooms, four examination beds/ cubicles, two gynaecology rooms, one observation room, two operation rooms, two receptionists, four resuscitation beds/ cubicles, and six triage beds. This can be seen in Figure 52.

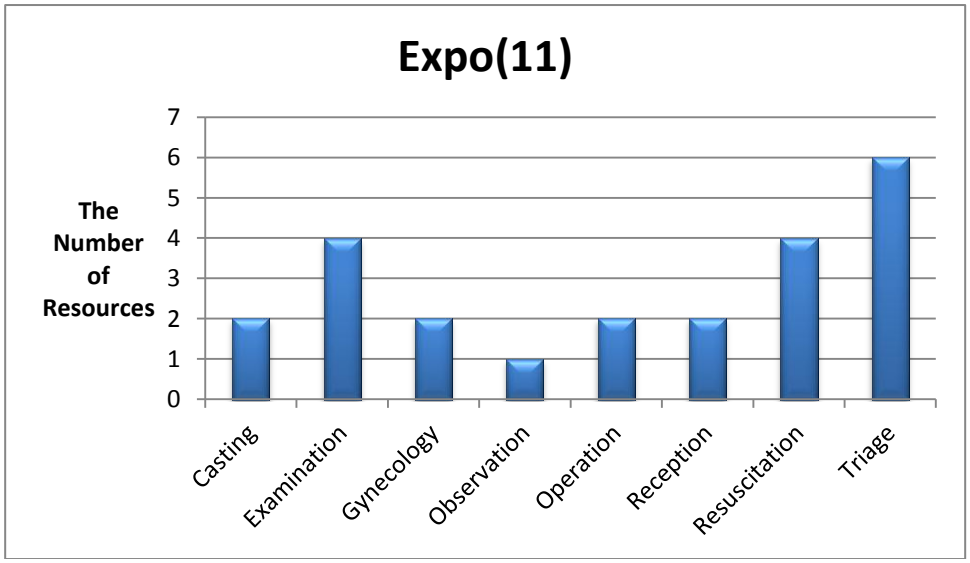


Figure 52: The number of resources recommended for each activity/ work station based on the inter-arrival rate Expo (11).

It was found that the number of resources needed for each activity/ work station based on the inter-arrival rate Expo (12) is as follows; two casting rooms, six examination beds/ cubicles, two gynaecology rooms, one observation room, two operation rooms, two receptionists, six resuscitation beds/ cubicles, and five triage beds. This can be seen in Figure 53.

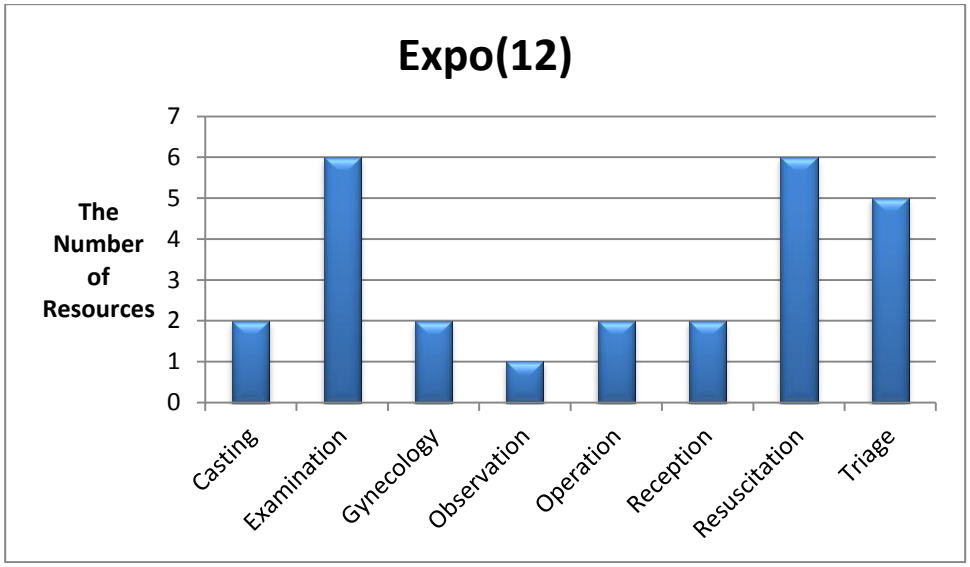


Figure 53: The number of resources recommended for each activity/ work station based on the inter-arrival rate Expo (12).

It was found that the number of resources needed for each activity/ work station based on the inter-arrival rate Expo (13) is as follows; one casting room, five examination beds/ cubicles, one gynaecology room, one observation room, one operation room, one receptionist, five resuscitation beds/ cubicles, and four triage beds. This can be seen in Figure 54.

It was found that the number of resources needed for each activity/ work station based on the inter-arrival rate Expo (14) is as follows; two casting rooms, five examination beds/ cubicles, two gynaecology rooms, one observation room, two operation rooms, one receptionist, five resuscitation beds/ cubicles, and one triage bed. This can be seen inFigure 55.

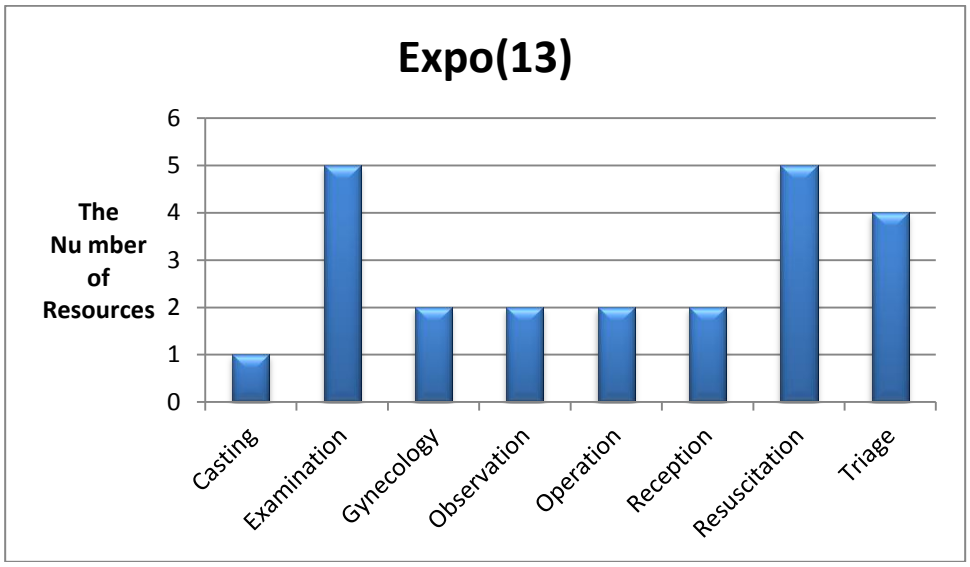


Figure 54: The number of resources recommended for each activity/ work station based on the inter-arrival rate Expo (13).

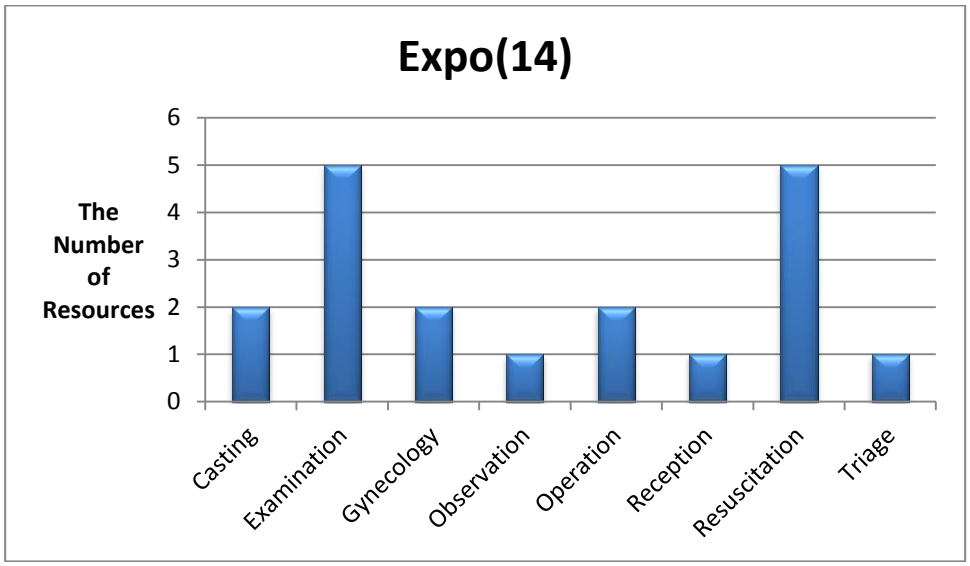


Figure 55: The number of resources recommended for each activity/ work station based on the inter-arrival rate Expo (14).

It was found that the number of resources needed for each activity/ work station based on the inter-arrival rate Expo (14) is as follows; two casting rooms, five examination beds/ cubicles, three gynaecology rooms, one observation room, two operation rooms, three receptionists, three resuscitation beds/ cubicles, and three triage beds. This can be seen in Figure 56.

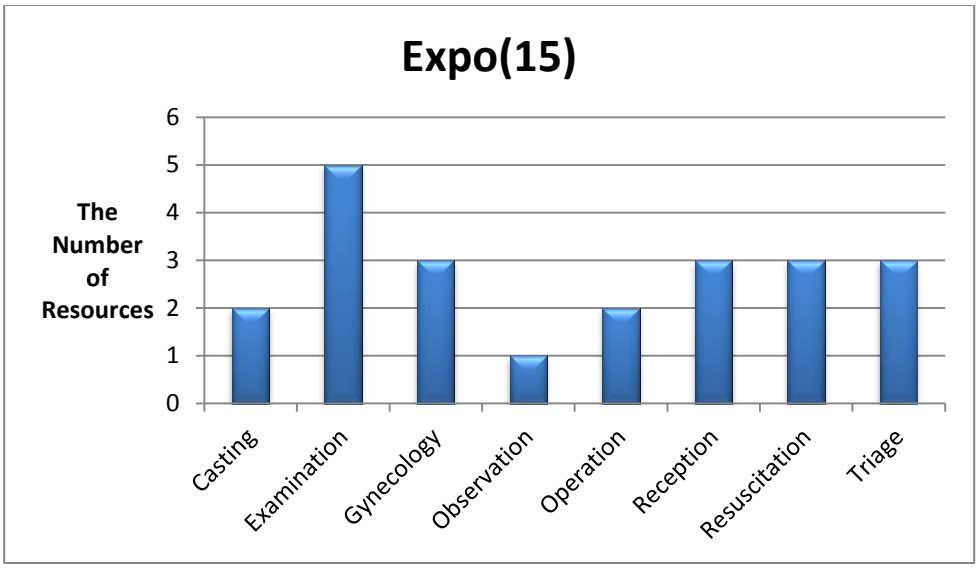


Figure 56: The number of resources recommended for each activity/ work station based on the inter-arrival rate Expo (15).

When the optimization model was run for the Sheikh Zayed ED it was found that the number of resources (beds) could be reduced as follows:

- Three examination beds instead of six
- Four observation beds instead of six.
- One receptionist instead of three.
- One trauma/ resuscitation room instead of two.
- Two triage beds instead of seven.

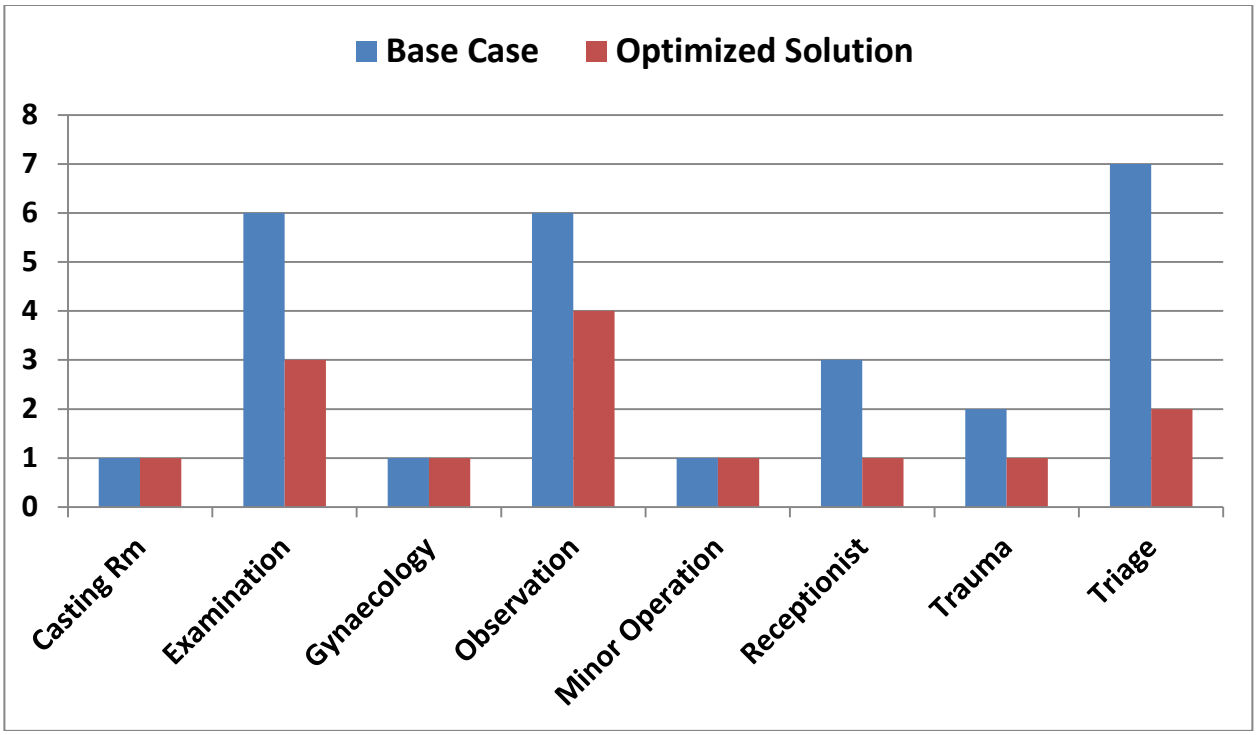


Figure 57: The number of resources reduced after optimization

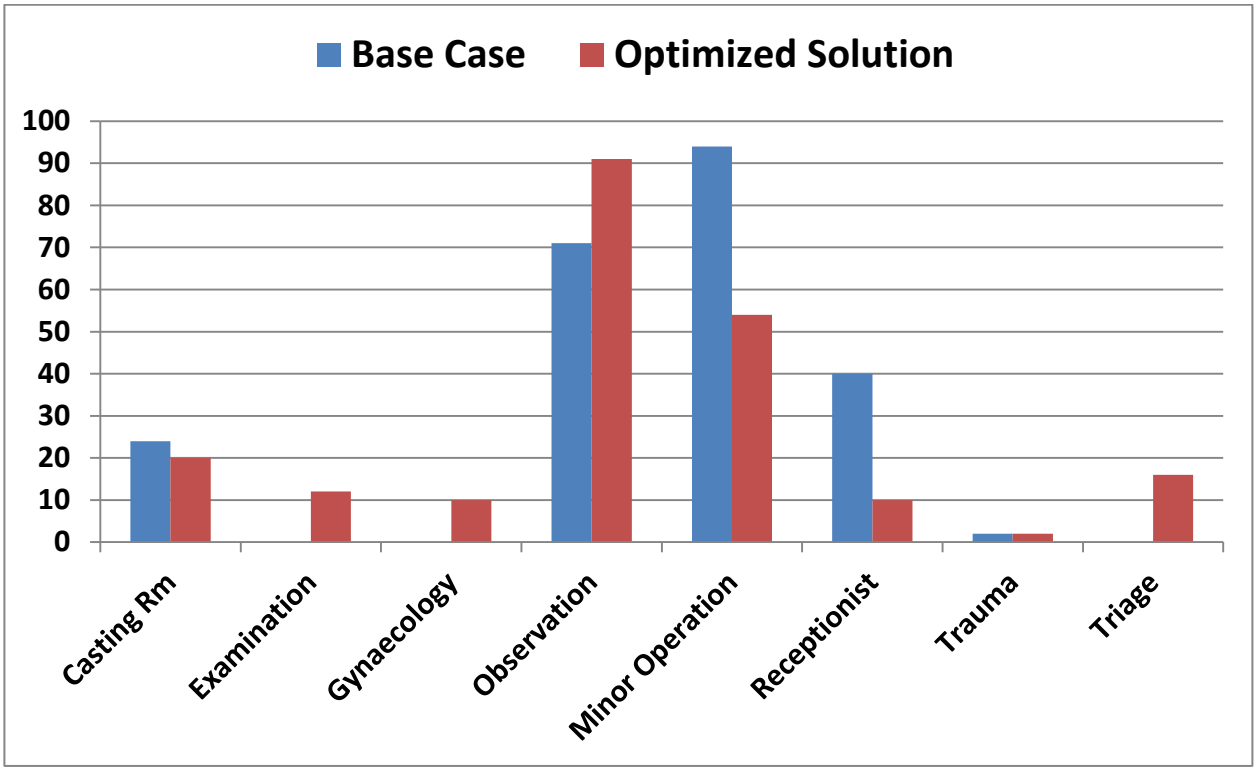


Figure 58: Utilization rate before and after optimization.

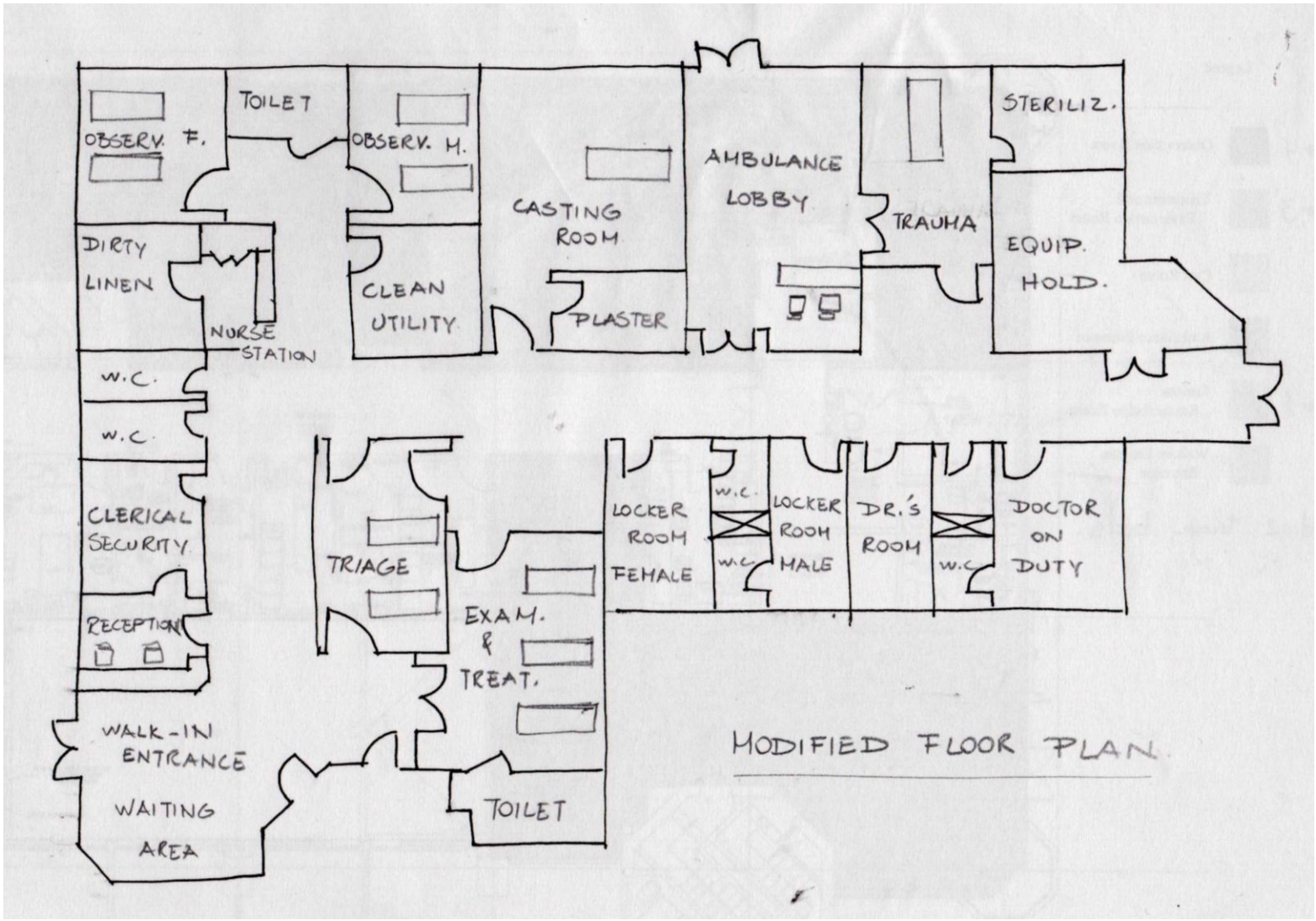


Figure 59: The modified Sheikh Zayed ED plan after Optimization

Chapter Seven

Conclusion

VII. CHAPTER SEVEN: CONCLUSION

A. Discussion

The table and graphs drawn above would help any architect/owner decide the sizes of each sub-department of the ED, as well as have an estimated price for the ED, in order to optimally serve patients entering the ED with a known arrival rate.

The flow of the research proves the efficiency of this study. A thorough literature review was undertaken to collect data concerning the application of decision support tools for minimizing patient waiting times in health care systems. Interviews were made with hospital managers in order to verify process flow, waiting times, activity durations, and resources. In addition, several floor plans of EDs have been studied in order to assure the logical flow of the process. Based on the data collected and the several verifications, a discrete event simulation model was developed using ARENA software. This simulation model was then verified by building a similar model on different software, which was Anylogic. The results proved the accuracy of the model. Twenty additional simulation runs were performed to be used for the regression analysis. The equations resulted from the regression analysis were used for the optimization model. A genetic algorithm was used for the purpose of obtaining optimized resource allocation for different arrival rates within a constrained budget, area, and patient waiting time in the system.

This study will add to the body of knowledge in regards to architecture and construction management, as it will increase the efficiency of emergency departments' architectural design.

B. Limitations

- The time of day was not considered in the designed simulation model.
- Human resources were not considered in this study except for the reception, because it affects the area of the reception and the flow of patients entering the ED. The reason behind neglecting the effect of human resources on the ED because the focus of this study is the construction (initial) costs and not the running costs of salaries and the like.
- The areas mentioned in this study were only for the main activities/ work stations; storage areas, wet areas, staff rooms, lounges and corridors were not included. This is because the focus on this study was on the main activities which contribute the most on the patient waiting time, and the initial cost.
- The running cost wasn't put in consideration even though it has a great effect on the total cost of the emergency department.

C. Recommended Research

- Further research may undergo research in order to determine the effect of the time of day on the arrival rates of patients.
- Human resources could be put in consideration.
- Areas such as storage areas, wet areas, staff rooms, lounges and corridors should be included.
- Consider the running cost because it has a great effect on the total cost of the emergency department.

VIII. REFERENCES

1. Ahmed, M. A. and T. M. Alkhamis. "Simulation Optimization for an Emergency Department Healthcare Unit in Kuwait." European Journal of Operatinal Research 198 (2009): 936-942.

2. Alvarez, A.M. and M.A. Centeno. "Enhancing simulation models for emergency rooms using VBA." Proceedings of the 31st Conference on Winter Simulation. 1999. 1685–1693.

3. Asplin, B.R., et al. "A conceptual model of emergency department crowding." Annals of Emergency Medecine 42.2 (2003): 173-180.

4. Baesler, F.F., H.E. Jahnsen and M. DaCosta. "Emergency departments I: the use of simulation and design of experiments for estimating maximum capacity in an emergency room." Proceedings of the 35th Conference on Winter Simulation. 2003. 1903–1906.

5. Bardi, M.A. and J. Hollingsworth. "A simulation model for scheduling in the emergency room." International Journal of Operation and Production Management. 13.3 (1993): 13-24.

6. BLAKE, J and M CARTER. "An Analysis of Emergency Room Wait Time Issues Via Computer Simulation." Information Systems & Operational Research 34.4 (1996): 263-273.

7. Blasak, R.E., et al. "Healthcare process analysis: the use of simulation to evaluate hospital operations between the emergency department and a medical telemetry unit." Proceedings of the 35th Conference on Winter Simulation. 2003. 1887–1893.

8. Brenner, S, et al. "Modeling and Analysis of the Emergency Department at University of Kentucky Chandler Hospital using Simulation." Research 36.4 (2010): 303-310.

9. Ceglowski, R, L Churilov and J Wasserthiel. "Combining DataMining and Discrete Event Simulation for a value-added view of a hospital emergency department." Journal of the Operational Research Society 58 (2007): 246-254.

10. Centeno, M.A., et al. "Emergency departments II: a simulation-ILP based tool for scheduling ER staff." Proceedings of the 35th Conference on Winter Simulation. 2003. 1930–1938.

11. Chockalingam, A, K Jayakumar and M Lawley. "A STOCHASTIC CONTROL APPROACH TO AVOIDING EMERGENCY DEPARTMENT OVERCROWDING." Proceedings of the 2010 Winter Simulation Conference. 2010. 2399-2411.

12. Derlet, R.W. "Overcrowding in emergency departments: increased demand and decreased capacity." Annals of Emergency Medicine 39.4 (2002): 430-432.

13. Duguay, C. and F. Chetouane. "Modeling and Improving Emergency Department Systems Using Discrete Event Simulation." Simulation 83.4 (2007): 331-320.

14. Epstein, S. and L. Tian. "Development of an emergency department work score to predict ambulance diversion." Academic Emergency Medecine 13.4 (2006): 421-426.

15. Evans, G.W., T.B. Gor and E. Unger. "A simulation model for evaluating personnel schedules in a hospital emergency department." Proceedings of the 28th Conference on Winter Simulation. 1996. 1205–1209.

16. Fatovich, D.M. and R.L. Hirsch. "Entry overload, emergency department overcrowding, and ambulance bypass." Emergency Medicine Journal 20 (2003): 406-409.

17. Fletcher, A and D Worthington. "What is a 'generic' hospital model?—a comparison of 'generic' and 'specific' hospital models of emergency patient flows." Health Care Manag Sci 12 (2009): 374-391.

18. Gale Encyclopedia of Medicine. 2008. 12 November 2011 <http://medical-dictionary.thefreedictionary.com/resuscitation>.

19. Garcia, M.L., et al. "Reducing time in an emergency room via a fast-track." Proceedings of the 27th Conference on Winter Simulation (1995): 1048–1053.

20. GoldSim. 2011. 10 November 2011 <http://www.goldsim.com/Web/Introduction/SimulationTypes/>.

21. Gonzalez, C.J, M. Gonzalez and N.M. Rios. "Improving the quality of service in an emergency room using simulationanimation and total quality management." Computer and Industrial Engineering 23.2 (1997): 87–100.

22. Groesser, S. "Modeling the health insurance system of Germany: a system dynamics approach." 23rd Internatational Conferences of the System Dynamics Society. 2005. 1-30.

23. Gunal, M. and Pidd, M. "Understanding Accident and Emergency Department Performance using Simulation." Proceedings of the 2006 Winter Simulation Conference. 2006. 446-452.

24. Hamilton, Kerk and Mardelle Shepley. Design for critical care: An evidence-based approach. Architectural Press, 2010.

25. Hannan, E.L., R.J. Giglio and R.S. Sadowski. "A simulation analysis of a hospital emergency department." Proceedings of the 7th Conference on Winter Simulation. 1974. 379–388.

26. Haugh, R. "A true picture of what ails your emergency department." Hospital and Health Networks 78.6 (2004): 66-70.

27. Health, Ministry of. 2003. 2010 <www.moh.gov.sg>.

28. Hoot, N, et al. "Forecasting Emergency Department Crowding: A Discrete Event Simulation." Annals of Emergency Medicine 52.2 (2008): 116-125.

29. Hoot, N. and D. Aronsky. "An early warning system for overcrowding in the emergency department." American Medical Informatics Association (AMIA 2006). 2006. 339-343.

30. Hoot, N., et al. "Measuring and forecasting emergency department crowding in real time." Annals of Emergency Medecine. 49.6 (2007): 747-755.

31. Hwang, U. and J. Concato. "Care in the emergency department: how crowded is overcrowded?" Academic Emergency Department 11.10 (2004): 1097-1101.

32. Jensen, Kirk and Jody Crane. "Improving Patient Flow in the Emergency Department." Healthcare Financial Management (2008): 104-108.

33. Karpiel, Marty. "Improving Emergency Department Flow: Eliminating ED inefficiencies reduces patient wait times." Satisfying Your Customers Jan/Feb 2004: 40-41.

34. Kirtland, A., et al. "Simulating an emergency department ‘is asmuch fun as. . . ’." Proceedings of the 27th Conference on Winter Simulation. 1995. 1039–1042.

35. Kobus, Richard, et al. Building type basics for healthcare facilities. Ed. Stephen Kliment. New Jersy: John Wiley & Sons Inc, 2008.

36. Kolker, A. "Process Modeling of Engineering Department Patient Flow: Effect of Patient Lengh of Stay on ED Diversion." J Med Syst (2008): 389-401.

37. Komashie, A. and A. Mousavi. "Modeling emergency departments using discrete even simulation techniques." Proceedings of the 37th Conference on Winter Simulation. 2005. 2681–2685.

38. —. "Modeling Emergency Departments using Discrete Event Simulation Techniques." WInter Simulation Conference. 2005. 2681-2685.

39. Kumar, A.P. and R. Kapur. "Discrete simulation application scheduling staff for the emergency room." Proceedings of the 21st Conference on Winter Simulation. 1989. 1112–1120.

40. Kyriacou, D.N., et al. "A 5-year time study analysis of emergency department patient care efficiency." Annals of Emergency Medecine 34 (1999): 326-335.

41. Lane, D.C., C. Monefeldt and J.V. Rosenhead. "Looking in the wrong place for healthcare improvements: a system dynamics study of an accident and emergency department." Journal of the Operations Research Society 51.9 (2000): 518–531.

42. Lee, T.M. "An EMTALA primer: the impact of changes in the emergency medicine landscape on EMTALA compliance and enforcement." Annals of Health Law 13 (2004): 145-178.

43. Liyanage, L. and M. Gale. "Quality improvement for the Campbelltown Hospital Emergency Service." IEEE International Conference on Systems, Man, and Cybernetics. 1995. 1997–2002.

44. Lowery, J.C. "Simulation of a hospital's surgical suite and critical care area." Proceedings of the 24th Conference onWinter Simulation. 1992. 1071–1078.

45. Mahapatra, S., et al. "Emergency departments II: Pairing Emergency Severity Index5-level triage data with computer aided system design to improve emergency department access and throughput." 35th Conference on Winter Simualation. 2003. 1917-1925.

46. Marshall, A., C. Vasilakis and E. El-Darzi. "Length of stay-based patient flow models: recent developments and future directions." Health Care Mangement vol. 8 (2005): 213-220.

47. McGuire, F. "Using simulation to reduce length of stay in emergency departments." Proceedings of the 26th Conference on Winter Simulation. 1994. 861–867.

48. Medeiros, D.J., E. Swenson and C. DeFlitch. "IMPROVING PATIENT FLOW IN A HOSPITAL EMERGENCY DEPARTMENT." Proceedings of the 2008 Winter Simulation Conference. 2008. 1526-1531.

49. Miller, M.J., D.M. Ferrin and J.M. Szymanski. "Emergency departments II: simulating Six Sigma improvement ideas for a hospital emergency department." Proceedings of the 35th Conference on Winter Simulation. 2003. 1926–1929.

50. NHS Estates, Windsor House, et al. HBN 22: Accident and Emergnecy Facilities for Adults and Children. London: The Stationery Office (TSO), 2003.

51. Pallin, A. and R. P. Kittell. "Mercy Hospital: simulation techniques for ER processes." Industrial Engineering 24.2 (1992): 35-37.

52. Paul, S.A., M.C. Reddy and C.J. DeFlitch. "A Systematic Review of Simulation Studies Investigating Emergency Depatment Overcroding." Simulation 86.8-9 (2010): 559-571.

53. Peck, J and S Kim. "Improving Emergency Department Patient Flow Through Optimal Fast Track Usage." Annals of Emergency Medicine 52.4 (2008).

54. Physicians., Canadian Association of Emergency. Position Statement on Emergency Department Overcrowding. February 2007. <www.CAEP.ca>.

55. Reynolds, J, et al. "Design and analysis of a health care clinic for homeless people using simulations." International Journal of Health Care Quality Assurance 23.6 (2010): 607-620.

56. Rossetti, M.D., G.F. Trzcinski and S.A. Syverud. "Emergency department simulation and determination of optimal attending physician staffing schedules." Proceedings of the 31st Conference on Winter Simulation. 1999. 1532–1540.

57. Samaha, S., W.S. Armel and D.W. Starks. "Emergency departments I: the use of simulation to reduce the length of stay in an emergency department." Proceedings of the 35th Conference on Winter Simulation. 2003. 1907–1911.

58. Samaha, S., W.S. W.S. Armel and D.W. Starks. "Emergency departments I: the use of simulation to reduce the length of stay in an emergency department." 35th Conference on Winter Simulation. 2003. 1907-1911.

59. Sharma, Vishal, et al. "Simulation application for resource allocation in facility management processes in hospitals." Facility management in hospitals 25.14 (2007): 493-506.

60. Shim, S. J. and A. Kumar. "Simulation for Emergency Care Process Reengineering in Hospitals." Business Process Management 16 (2010): 795-805.

61. Sinreich, D. and Y.N. Marmor. "A simple and intuitive simulation tool for analyzing emergency department operations." Proceedings of the 36th Conference on Winter Simulation. 2004. 1994–2002.

62. Steins, K., F. Persson and M. Holmer. "Increasing Utilization in a Hospital Operating Department Using Simulation Modeling." SIMULATION 88.9 (2010): 463–480.

63. Sterman, John. The Big Book of AnyLogic. 2010.

64. Swisher, J.R. and S.H. Jacobson. "Evaluating the Design of a Family Practice Healthcare Clinic Using Discrete-Event Simulation." Health Care Management Science 5 (2002): 75-88.

65. Takakuwa, S and H. Shiozaki. "Functional analysis for operating emergency department of a general hospital." Proceedings of the 36th Conference on Winter Simulation. 2004. 2003–2011.

66. VanBerkel, P.T. and J.T. Blake. "A comprehensive simulation for wait time reduction and capacity planning applied in general surgery." Health Care Manage Sci 10 (2007): 373-385.

67. Vos, L., S. Groothuis and G. Godefridus. "Evaluating hospital design from an operations management perspective." Health Care Manage Sci 10 (2007): 357–364.

68. Waldrop, R.D. "Don't be put out by throughput in the emergency department." Physician Executive 35 (2009): 38-41.

69. Weiss, S.J., R. Derlet and J. Arndahl. "Estimating the degree of emergency department overcrowding in academic medical centers: results of the National ED Overcrowding Study (NEDOCS." Academic Emergency Medecine 11 (2004): 38-50.

IX. INTERVIEWS

Dr. Moustafa el Mallah (Sheikh Zayed Hospital Manager).

Dr. Hafez Mohamed

Dr. Elia Hanna (Medical Equipment Supplier)

VII. APPENDICES

Appendix A: Hospital Terminologies

Length of Stay (LOS)

According to (Gunal), the performance was being measured as the percentage of patients exceeding the length of stay (LOS) established; which is from the time they arrive the ED to the time they either go home or enter the hospital. The UK Department of Health in 2002said that the LOS target should not be more than 4hrs., then in 2004 they said that only 2% of the patients could surpass the LOS (4 hrs.).

According to the (Position Statement on Emergency Department Overcrowding) done by the Canadian Association of Emergency Physicians, the LOS shouldn't exceed 6 hrs. in 95% cases of levels 1, 2, and 3, and 4hrs. with the same percentage for levels 4 and 5.

According to the Singaporean Ministry of Health (), the median wait times recommended are 20 min. for PAC 2 patients and 30 min. for PAC 3 patients

Triage

It has been mentioned that priority is given to patients according to their clinical need and this is done via triage. Triage is the preliminary stage where a patient is assigned priority according to their clinical needs; it is like a sorting process. In most cases, Triage is performed in a dedicated area of the ED by a skilled nurse or a doctor. In a triage, cases are assessed and sorted according to the patients' need and are usually referred to a waiting area as a result. If minor treatment is required, it could be done in the triage with no further

clinical need. Nevertheless, extreme conditions that need serious treatment go directly to the desired department in the hospital for supplementary care. A triage is considered as an intermediate case in an ED.

Resuscitation (Trauma Center)

Resuscitation is defined as: "Bringing a person back to life after an apparent death or in cases of impending death." (Gale Encyclopedia of Medicine). This area deals with patients having serious illnesses or injuries and has the equipment and staff required for such cases. It is considered as a hot case classification in an ED since it deals with critical conditions of the coming patients. Figure 60 represents an example of a resuscitation room.

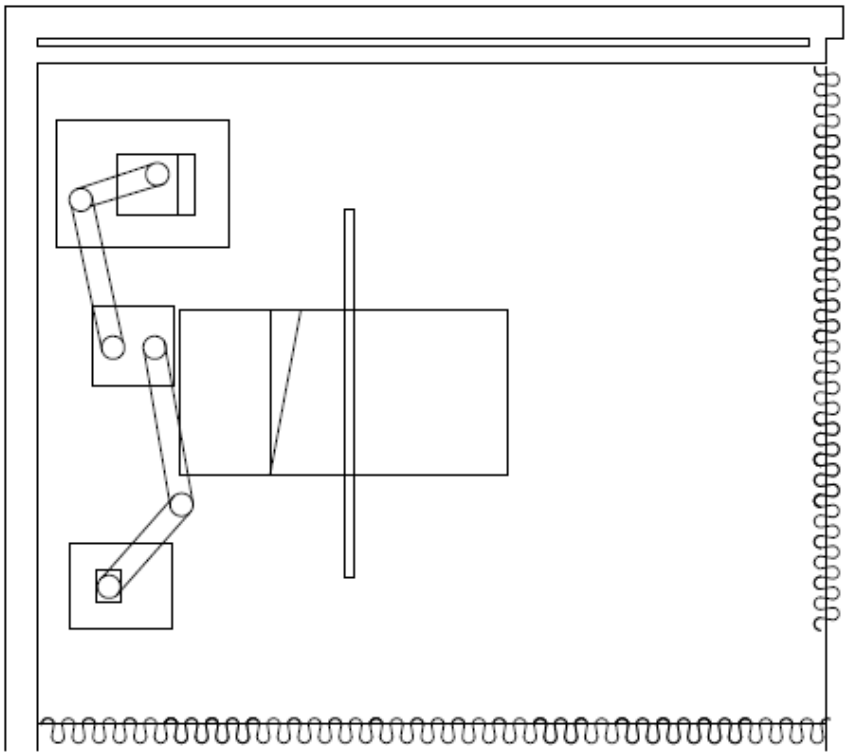
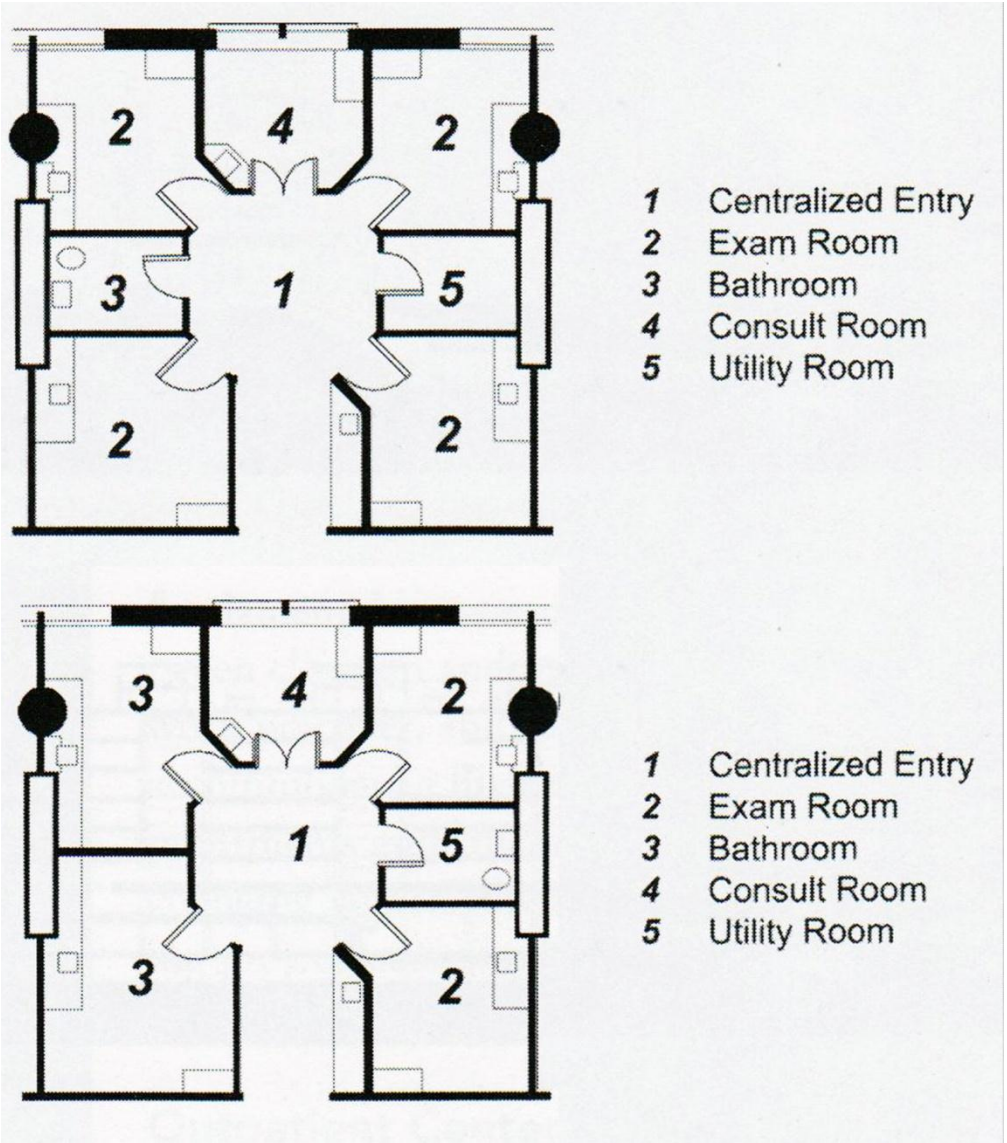
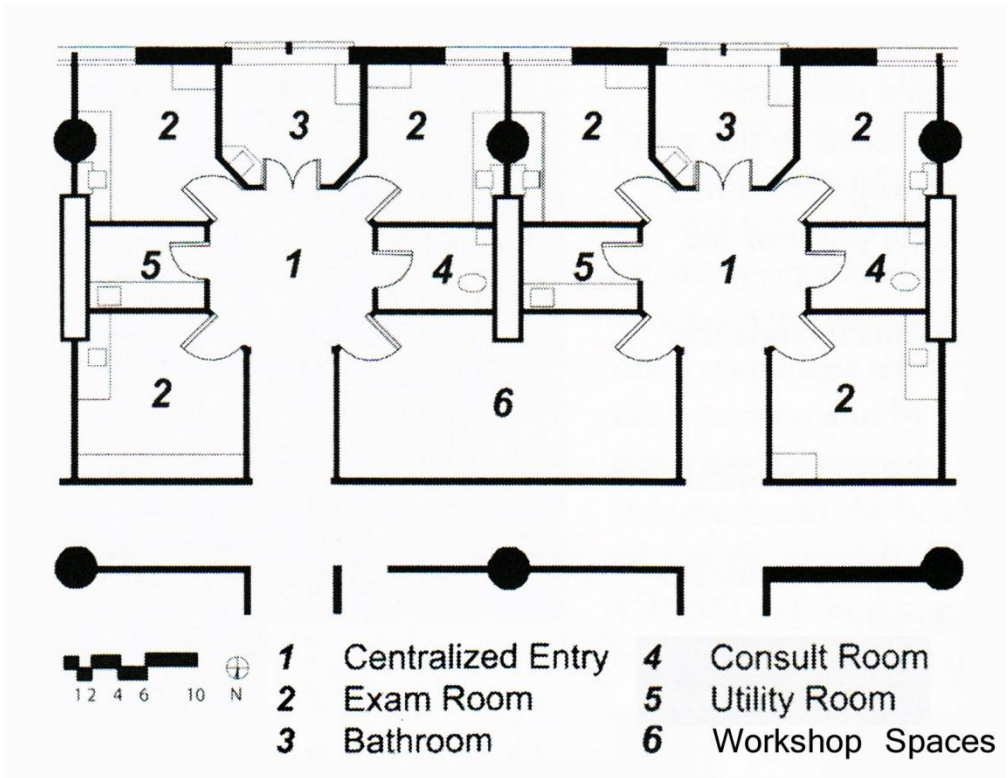


Figure 60: Resuscitation Room in an ED Plan Scale 1:50

Examination Room

In the examination room, the patient undergoes specific examinations and treatments and is considered as one of the cold cases in an ED.

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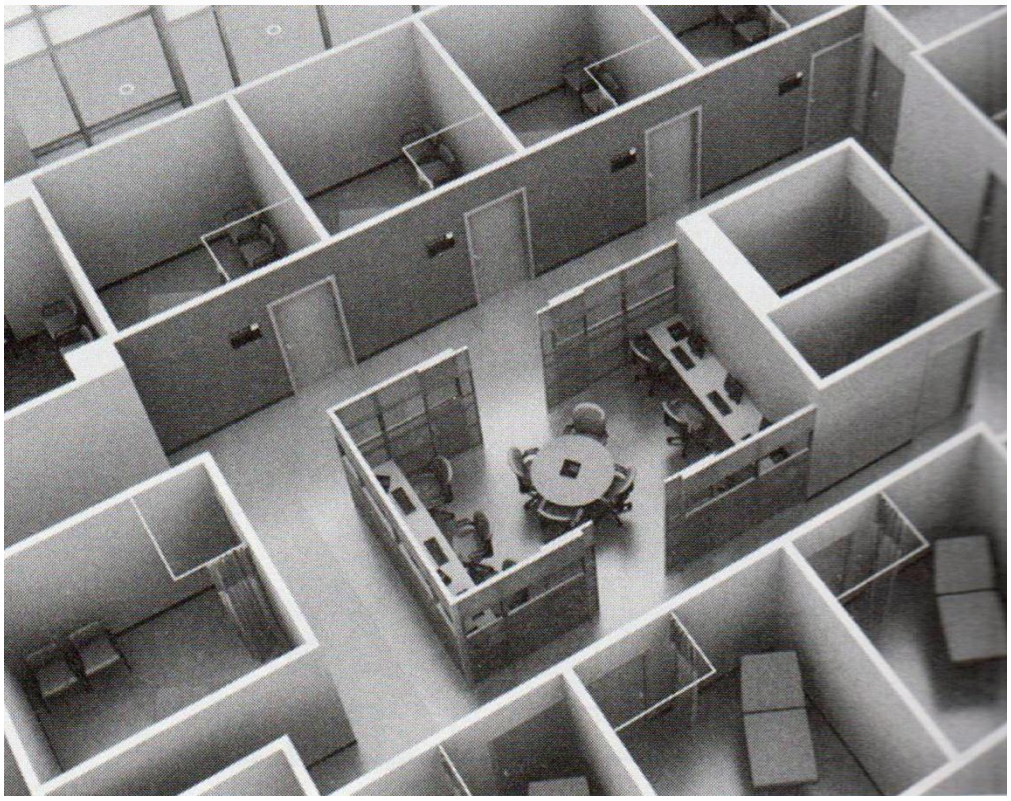
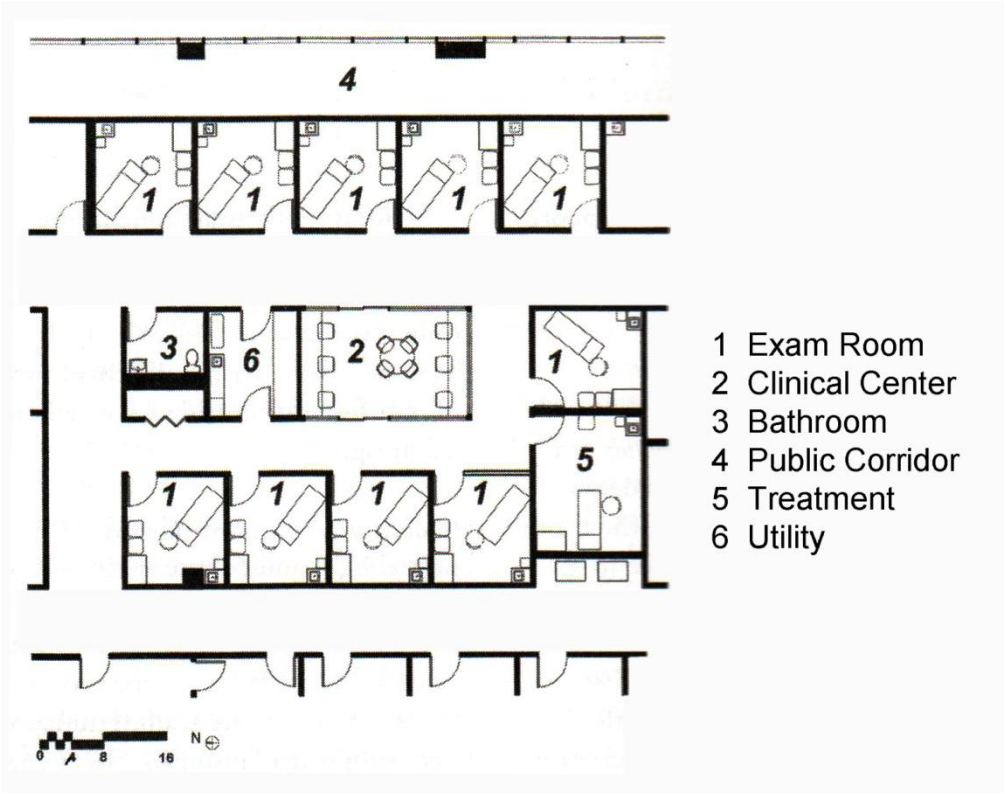
1 Centralized Entry
2 Exam Room
3 Bathroom
4 Consult Room
5 Utility Room
6 Workshop Spaces





Observation Room

The observation room is where the patient is monitored for a certain period of time till physicians make sure the patient's condition is stabilized. Curtains are used between these spaces to allow a wider range of flexibility for the design (cubicles instead of rooms). It should be noted that this room is classified as an intermediate case in an ED.

Casting Room

The casting room is the room in which a patient enters in case if any bone fractures. It is based as an intermediate case and has the highest number of patients that undergo this procedure.

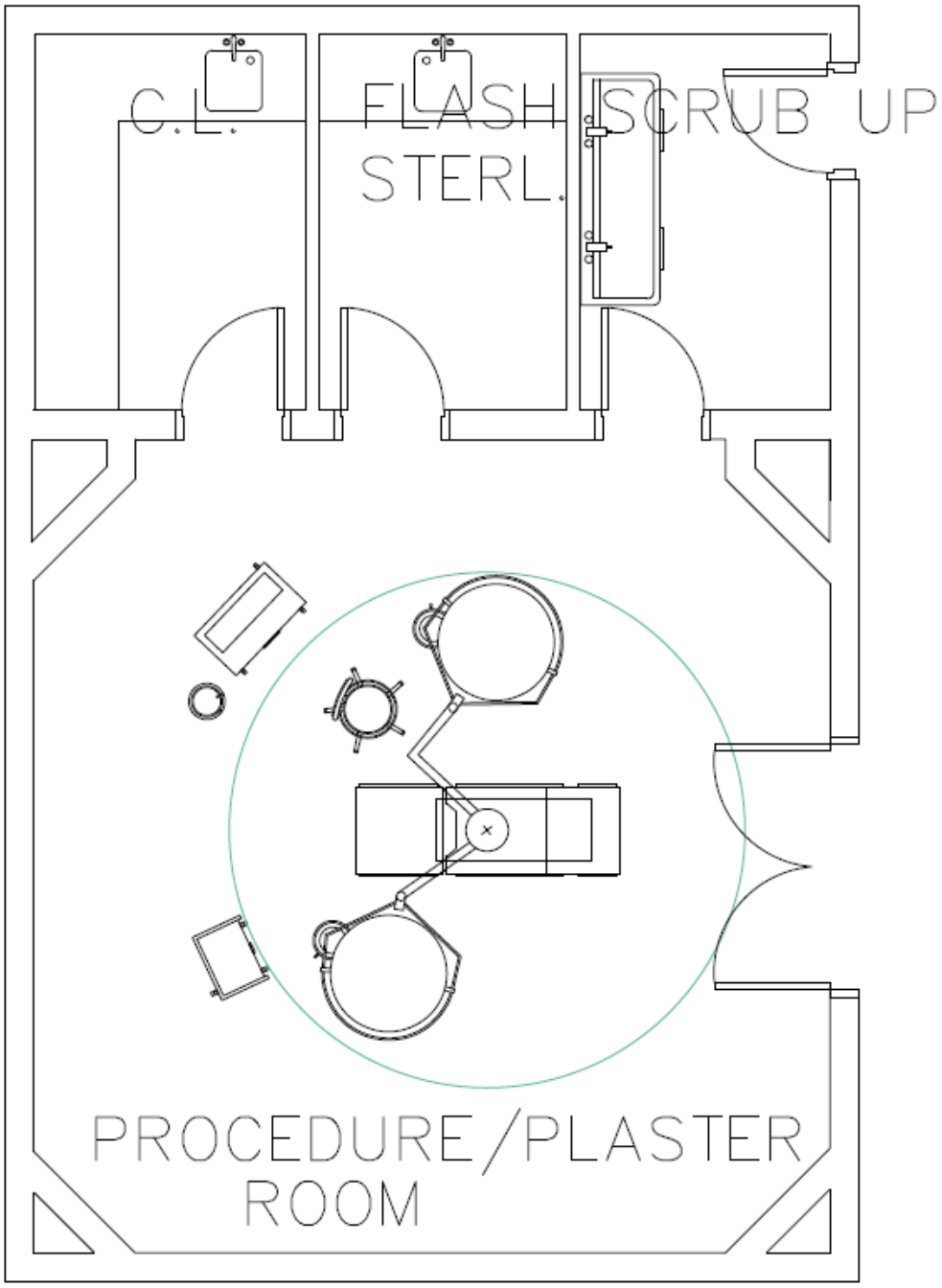


Figure 61: Casting Room Plan in an ED

Gynecology

A gynecology deals with the female health and system of reproduction. It can be represented on a plan as can be seen in Figure 62.

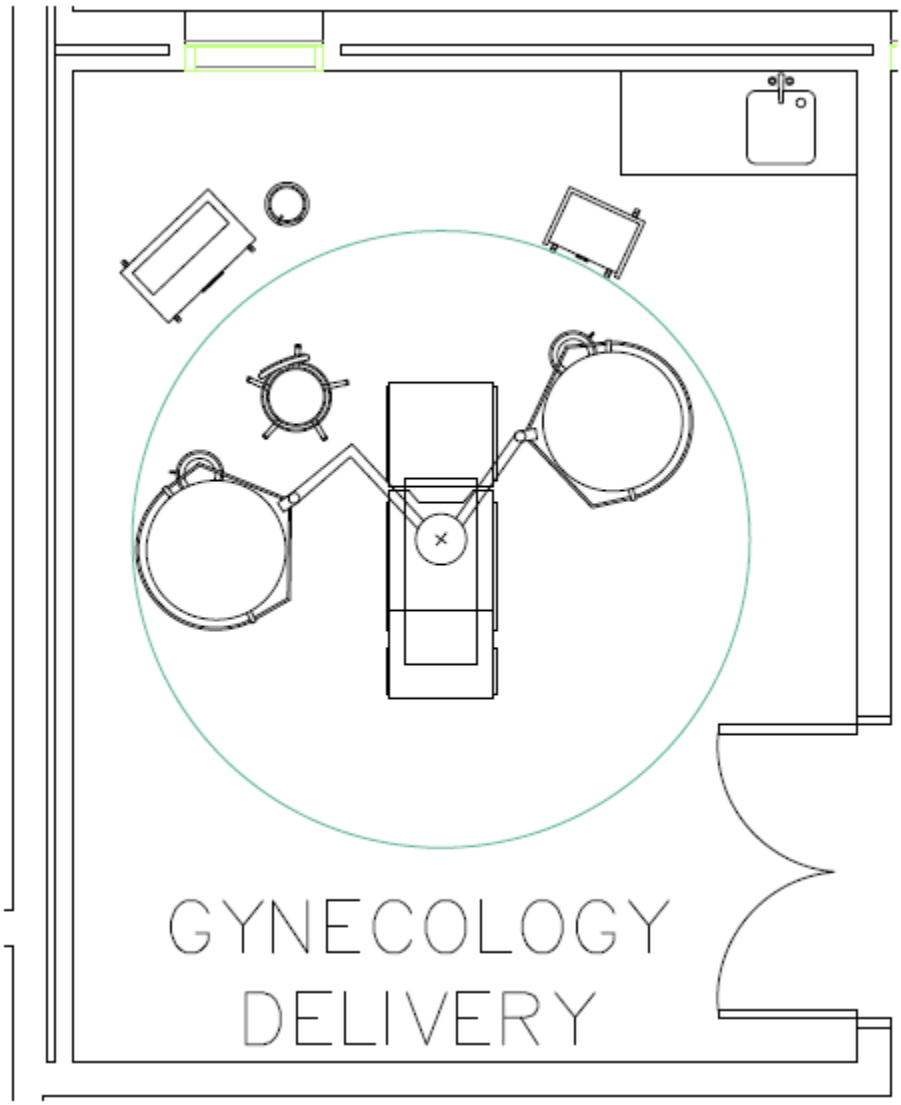
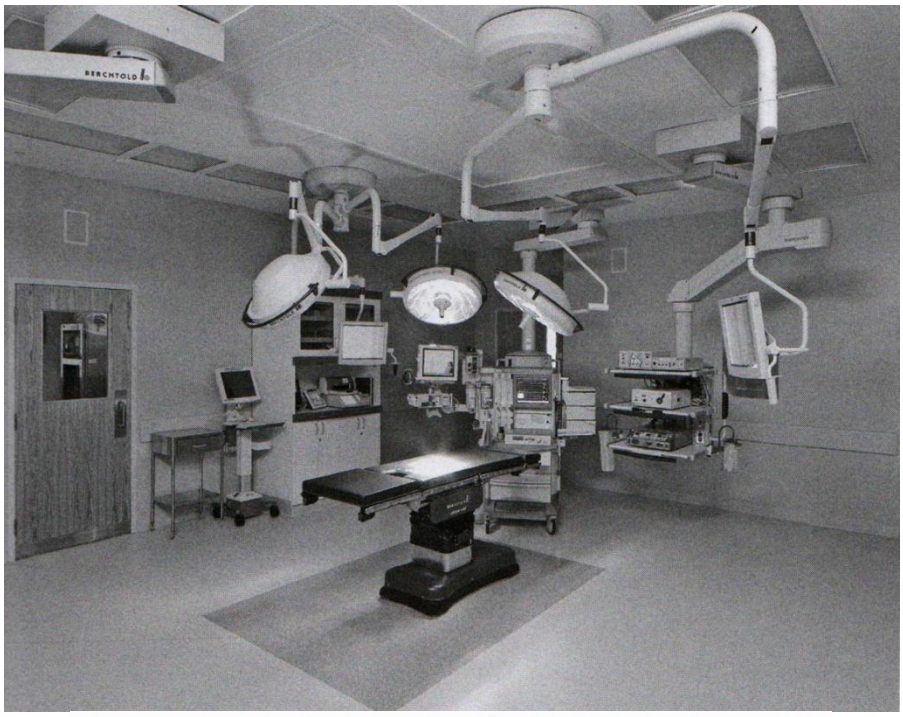
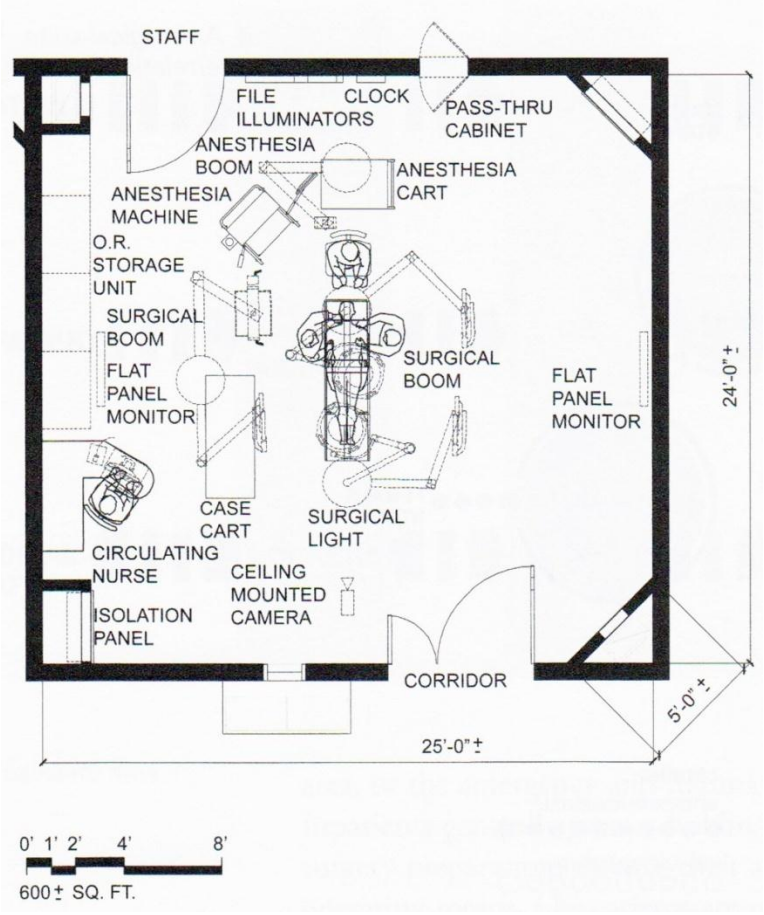


Figure 62: Gynecology plan in an ED Scale 1:50

Operation room





Appendix B: Literature Review

TITLE	YEAR	AUTHOR	Simulation Type	Software	Field	Objective	Resource-related
A simulation analysis of a hospital emergency department	1974	Hannan, E.L., R.J. Giglio and R.S. Sadowski	Other		Re-engineering	New ED with lab and x-ray facilities.	Equipment resource-related (installed lab and X-ray facilities in ED)
Discrete simulation application-scheduling staff for the emergency room	1989	Kumar, A.P. and R. Kapur	Discrete-Event	SIMAN	Quality of Service	Staff scheduling to meet unpredictable workload patterns	used human resources (alternative staff scheduling)
Simulation of a hospital's surgical suite and critical care area	1992	Lowery, J.C.	Other		Costs	Decrease building, equipment and staffing costs	used space as a resource (by varying the no. of beds and rooms)
Mercy Hospital: simulation techniques for ER processes	1992	Pallin, A. and R.P. Kittell	Conceptual		Re-engineering	Improve the ER process	used space as a resource + used human resources
A simulation model for scheduling in the emergency room	1993	Bardi, M.A. and J. Hollingsworth	Process-oriented simulation modelling	SLAM	Efficiency	Develop a generic tool to evaluate policy changes for ED productivity and efficiency improvement	
Using simulation to reduce length of stay in emergency departments	1994	McGuire, F.	Other		Quality of Service	Increase the quality of service by reducing patient wait times.	used space as a + used human resources

TITLE	YEAR	AUTHOR	Simulation Type	Software	Field	Objective	Resource-related
Reducing time in an emergency room via a fast-track	1995	Garcia, M.L., M.A. Centeno, C. Rivera, et al.	Other		Quality of Service	Reduce the excessive wait times for low accuity patients	
Simulating an emergency department 'is as much fun as. . . '.	1995	Kirtland, A., J. Lockwood, K. Poisker, et al.	Other		Quality of Service	Reduce the no of dissatisfied patients	used space as a resource + Used human resources
Quality improvement for the Campbell town Hospital Emergency Service	1995	Liyanage, L. and M. Gale	Other		Quality of Service	Reduce the excessive patient wait times	Used human resources
A simulation model for evaluating personnel schedules in a hospital emergency department	1996	Evans, G.W., T.B. Gor and E. Unger	Discrete-Event	Arena	Quality of Service	Reduce the excessive patient wait times	used human resources (alternative staff scheduling)
An analysis of emergency room wait-time issues via computer simulation.	1996	Blake, J.T. and M.W. Carter	Discrete-Event	SIMAN	Quality of Service	Reduce the excessive wait times for low acuity patients	Used human resources (by changing resident availability)

TITLE	YEAR	AUTHOR	Simulation Type	Software	Field	Objective	Resource-related
Improving the quality of service in an emergency room using simulation-animation and total quality management	1997	Gonzalez, C.J., M. Gonzalez and N.M. Rios	Process-oriented simulation modeling	SLAM (Simulation Language for Alternative Modeling)	Quality of Service	Decrease the overload on ED staff to increase ED efficiency and reduce patient wait times due to the high withdrawal rates	used space as a resource (by varying the no. of beds and rooms) + Used human resources (varying the no. of ED staff available)
Emergency department simulation and determination of optimal attending physician staffing schedules	1999	Rossetti, M.D., G.F. Trzcinski and S.A. Syverud	Discrete-Event	Arena	Efficiency	Increase the efficiency in staff utilization	used human resources (alternative staff scheduling)
Enhancing simulation models for emergency rooms using VBA	1999	Alvarez, A.M. and M.A. Centeno	Discrete-Event	Arena	Costs	Decrease & control rising costs in the operation process	
In-patient flow analysis using ProModel simulation package	2000	Elbeyli, S. and P. Krishnan	Other	ProModel	Quality of Service	Reduce the excessive patient wait times	

TITLE	YEAR	AUTHOR	Simulation Type	Software	Field	Objective	Resource-related
Looking in the wrong place for healthcare improvements	2000	Lane, D.C., C. Monefeldt and J.V. Rosenhead	System Dynamics		Quality of Service	Reduce the excessive patient wait times	used space as a resource (by changing the no. of beds and rooms)
Emergency departments II: Pairing Emergency Severity Index5-level triage data	2003	Mahapatra, S., C.P. Koelling, L. Patvivatsiri, et al.	Other		Costs	Decrease rising costs	
Healthcare process analysis:	2003	Blasak, R.E., D.W. Starks, W.S. Armel, et al	Discrete-Event	Arena	Quality of Service	Reduce the excessive patient wait times	Used human resources
Emergency departments I: the use of simulation to reduce the length of stay in an emergency department.	2003	Samaha, S., W.S. Armel and D.W. Starks	Discrete-Event	Arena	Quality of Service	Reduce the LOS due to the increase in ambulance diversion	Used human resources (varying the no. of ED staff available + resident availability)

TITLE	YEAR	AUTHOR	Simulation Type	Software	Field	Objective	Resource-related
	2003	Baesler, F.F., H.E. Jahnsen, and M. DaCosta	Discrete-Event	Arena	Costs	Increase the corporate customer base without reducing the quality	
Emergency departments II: simulating Six Sigma improvement ideas for a hospital emergency department	2003	Miller, M.J., D.M. Ferrin and J.M. Szymanski	Conceptual	Extend	Costs	Decrease rising costs	
Emergency departments II: a simulation-ILP based tool for scheduling ER staff	2003	Centeno, M.A., R. Giachetti, R. Linn, et al	Mathematical modeling	Arena	Costs	Reduce staffing level without decreasing efficiency	used human resources (alternative staff scheduling)
Functional analysis for operating emergency department of a general hospital	2004	Takakuwa, S. and H. Shiozaki	Discrete-Event	Arena	Re-engineering	Increase the size of ED and separate the ambulance patients from outpatients	used space as a resource + Used human resources + varied in equipment

TITLE	YEAR	AUTHOR	Simulation Type	Software	Field	Objective	Resource-related
A simple and intuitive simulation tool for analyzing emergency department operations	2004	Sinreich, D. and Y.N. Marmor	Discrete-Event		Costs	Decrease & control rising costs in the operation process	
Modelling emergency departments using discrete even simulation techniques	2005	Komashie, A. and A. Mousavi	Discrete-Event	Arena	Quality of Service	Reduce the excessive patient wait times	used space as a resource (by changing the no. of beds and rooms)

TITLE	YEAR	AUTHOR	Simulation Type	Software	Field	Objective
IMPROVING PATIENT FLOW IN A HOSPITAL EMERGENCY DEPARTMENT	Jun-05	Medeiros, D. J., Swenson, E. & DeFlitch, C.	Other	Arena	Re-engineering	Improve the flow of patients to minimize the waiting times.
Evaluating the Design of a family practice healthcare clinic using discrete-event simulation	Jun-05	James R. Swisher & Sheldon H. Jacobson	Discrete-Event Simulation		Quality of Service	change in the recourses to minimize waitning time of patients
Simulation for emergency care process reengineering in hospitals	Jul-05	Shim. Sung & K. Arun	Discrete-Event Simulation	SIMUL8	Quality of Service	change in the emergency care process to reduce waiting time
simulation model for improving the operation of the emergency department of special health care	2006	Ruohonen et al.	Other	MedModel	Quality of Service	change in the recourses to minimize waitning time of patients
Combining DataMining and Discrete Event Simulation for a value-added view of a hospital emergency department	2007	R Ceglowski, L Churilov & J Wasserthiel	simulation & data mining		Quality of Service	Identify bottlenecks in the interface between an ED and a hospital ward
Modelling and Improving Emergency Department Systems using Discrete Event Simulation	Apr-07	Duguay, C. & Chetouane, F.	Discrete-Event Simulation	Arena	Quality of Service	change in the recourse availability to minimize waiting time of patients
Simulation application for resource allocation in facility management processes in hospitals	May-07	S. Vishal et al.	Other	Simphony simulation	Costs	Change in the service management process to reduce costs and work order completion time.

TITLE	YEAR	AUTHOR	Simulation Type	Software	Field	Objective
Evaluating hospital design from an operations management perspective	Jul-07	V. Leti & G. Siebren	Discrete-Event Simulation	MedModel	Re-engineering	prove that Design affects the flow in corridors
A comprehensive simulation for wait time reduction and capacity planning applied in general surgery	Sep-07	T. Peter & T. John	Discrete-Event Simulation	Arena	Quality of Service	Change in the recourses (bed usage & OR time) to minimize waiting time of patients and maximize throughput
Process Modelling of Emergency Department patient flow: effect of patient length of stay on ED diversion	Oct-08	Kolker, A.	Discrete-Event Simulation	Process Model 5.2.0	Quality of Service	Quantitative relationship between ED performance characteristics and patients' length of stay
Improving Emergency Department Patient Flow Through Optimal Fast Track Usage	Oct-08	Peck, J & Kim, S	Discrete-Event Simulation		Re-engineering	Improve the flow of patients to minimize the waiting times.
Design and analysis of a health care clinic for homeless people using simulations	2010	R. Jared et al.	Discrete-Event Simulation	SIMUL8	Quality of Service	Change in the recourses (staffing level) to minimize waiting time of patients and maximize throughput
Increasing Utilization in a hospital operating department using simulation modelling	Sep-10	S. Krisjanis, P. Fredrik & H. Martin	Discrete-Event Simulation	Arena	Re-engineering	Better resource utilization in operation department (operation planning system)
Simulation optimization for an emergency department healthcare unit in Kuwait	Nov-10	M.A. Ahmed, M. A. & Alkhamis, T. A.	simulation & optimization		Quality of Service	1. Optimize the recourses 2. Evaluate the impact of staffing levels on the service efficiency

Appendix C: Sheikh Zayed Data-Base

Number of patients for July

Date	Total No. of Cases	Accident Cases	Medical Cases
1-Jul-2010	70	20	50
2-Jul-2010	42	13	29
3-Jul-2010	60	5	55
4-Jul-2010	63	14	49
5-Jul-2010	68	31	37
6-Jul-2010	67	14	53
7-Jul-2010	52	5	47
8-Jul-2010	43	4	39
9-Jul-2010	60	21	39
10-Jul-2010	43	4	39
11-Jul-2010	44	9	35
12-Jul-2010	49	10	39
13-Jul-2010	42	17	25
14-Jul-2010	50	10	40
15-Jul-2010	53	7	46
16-Jul-2010	59	14	45
17-Jul-2010	59	12	47
18-Jul-2010	67	19	48
19-Jul-2010	69	7	62
20-Jul-2010	44	6	38
21-Jul-2010	65	9	56
22-Jul-2010	62	38	24
23-Jul-2010	53	14	39
24-Jul-2010	68	15	53
25-Jul-2010	52	11	41
26-Jul-2010	50	8	42
27-Jul-2010	49	6	43
28-Jul-2010	62	14	48
29-Jul-2010	66	14	52
30-Jul-2010	51	19	32
31-Jul-2010	52	10	42

Total No.	1734	400	1334

Number of patients for October

Date	Total No. of Cases	Accident Cases	Medical Cases
1-Oct-2010	53	8	45
2-Oct-2010	56	2	54
3-Oct-2010	51	6	45
4-Oct-2010	51	10	41
5-Oct-2010	51	10	41
6-Oct-2010	64	20	44
7-Oct-2010	58	6	52
8-Oct-2010	54	8	46
9-Oct-2010	52	14	38
10-Oct-2010	52	8	44
11-Oct-2010	58	10	48
12-Oct-2010	53	12	41
13-Oct-2010	79	27	52
14-Oct-2010	74	5	69
15-Oct-2010	55	4	51
16-Oct-2010	43	7	36
17-Oct-2010	62	16	46
18-Oct-2010	57	6	51
19-Oct-2010	65	17	48
20-Oct-2010	61	14	47
21-Oct-2010	73	8	65
22-Oct-2010	46	10	36
23-Oct-2010	51	3	48
24-Oct-2010	75	16	59
25-Oct-2010	59	7	52
26-Oct-2010	59	4	55
27-Oct-2010	75	11	64
28-Oct-2010	72	10	62
29-Oct-2010	63	4	59
30-Oct-2010	52	14	38
31-Oct-2010	62	12	50

Total No.	1836	309	1527

Number of patients for December

Date	Total No. of Cases	Accident Cases	Medical Cases
1-Dec-2010	61	10	51
2-Dec-2010	94	10	84
3-Dec-2010	81	10	71
4-Dec-2010	51	8	43
5-Dec-2010	66	15	51
6-Dec-2010	87	8	79
7-Dec-2010	100	9	91
8-Dec-2010	66	7	59
9-Dec-2010	62	11	51
10-Dec-2010	61	3	58
11-Dec-2010	62	12	50
12-Dec-2010	46	10	36
13-Dec-2010	55	12	43
14-Dec-2010	71	19	52
15-Dec-2010	75	11	64
16-Dec-2010	81	12	69
17-Dec-2010	88	4	84
18-Dec-2010	60	11	49
19-Dec-2010	62	8	54
20-Dec-2010	82	8	74
21-Dec-2010	85	15	70
22-Dec-2010	93	14	79
23-Dec-2010	96	17	79
24-Dec-2010	82	10	72
25-Dec-2010	81	12	69
26-Dec-2010	82	14	68
27-Dec-2010	83	7	76
28-Dec-2010	77	22	55
29-Dec-2010	82	17	65
30-Dec-2010	85	9	76
31-Dec-2010	79	7	72

Total No.	2336	342	1994

Case distribution for July

Case	No. of Patients
Died	14
Entered ICU	28
Entered Hospital	125
Operations	47
Gynaecology	35
Resuscitation	18

Case distribution for October

Case	No. of Patients
Died	2
Entered ICU	33
Entered Hospital	87
Operations	49
Gynaecology	34
Resuscitation	24

Case distribution for December

Case	No. of Patients
Died	7
Entered ICU	23
Entered Hospital	93
Operations	65
Gynaecology	40
Resuscitation	0

	July	October	December	Average	Simulation
Died	5.2%	0.9%	3.1%	0.0%	0.0%
Entered ICU	10.5%	14.4%	10.1%	11.7%	15.8815%
Entered Hospital	46.8%	38.0%	40.8%	0.0%	0.0%
Operations	17.6%	21.4%	28.5%	22.5%	30.6459%
Gynaecology	13.1%	14.8%	17.5%	15.2%	20.7%
Resuscitation	6.7%	10.5%	0.0%	5.7%	7.8%
	100.0%	100.0%	100.0%	55.1%	75%
					Note: 25% outpatients

Appendix D: Cost Data-Base

Work Station	EGP
Dirty Linen	11147.04
Clean Linen	4135.84
Delivery Room	388061.1
Doctors' Lounge	32591.04
Examination Room	86965.88
ICU	567163.6
Operation Room	1139320
Triage	57263.04
Ultra Sound	597166.6
Observation Room	192932.2
X-Ray	1289684
Resuscitation	429764.5

Appendix E: Simulation Runs

Base case scenario

This ARENA report represents the base case scenario for the case study which is Sheikh Zayed ED.

Emergency Department

Replications: 1 Time Units: Minutes

Key Performance Indicators

System

	Average
Number Out	89

Emergency Department

Replications: 1 Time Units: Minutes

Entity

Time

VA Time	Average	Half Width	Minimum Value	Maximum Value
Patient	76.3067	(Insufficient)	9.6345	210.39

NVA Time	Average	Half Width	Minimum Value	Maximum Value
Patient	0.00	(Insufficient)	0.00	0.00

Wait Time	Average	Half Width	Minimum Value	Maximum Value
Patient	9.3751	(Insufficient)	0.00	180.83

Transfer Time	Average	Half Width	Minimum Value	Maximum Value
Patient	0.00	(Insufficient)	0.00	0.00

Other Time	Average	Half Width	Minimum Value	Maximum Value
Patient	0.00	(Insufficient)	0.00	0.00

Total Time	Average	Half Width	Minimum Value	Maximum Value
Patient	85.6819	(Insufficient)	9.6345	372.71

Other

Number In	Value
Patient	97.0000

Number Out	Value
Patient	89.0000

WIP	Average	Half Width	Minimum Value	Maximum Value
Patient	5.5367	(Insufficient)	0.00	12.0000

Emergency Department

Replications: 1 Time Units: Minutes

Process

Time per Entity

VA Time Per Entity	Average	Half Width	Minimum Value	Maximum Value
Casting	20.9088	(Insufficient)	10.1751	29.5625
Examination and Treatment	24.3053	(Insufficient)	20.3239	29.9668
Gynecology	36.7566	(Insufficient)	30.4563	44.3925
MiniOperations	62.1407	(Insufficient)	46.4457	78.7441
Observation Room	109.83	(Insufficient)	70.1876	145.00
Reception	7.3098	(Insufficient)	5.1823	9.9933
Resuscitation	7.7320	(Insufficient)	7.0102	8.1716
Triage	5.8298	(Insufficient)	1.0000	10.0000

Wait Time Per Entity	Average	Half Width	Minimum Value	Maximum Value
Casting	4.6296	(Insufficient)	0.00	33.3409
Examination and Treatment	0.00	(Insufficient)	0.00	0.00
Gynecology	1.9399	(Insufficient)	0.00	15.5190
MiniOperations	50.4717	(Insufficient)	0.00	180.83
Observation Room	0.2661	(Insufficient)	0.00	9.8474
Reception	1.1823	(Insufficient)	0.00	13.2580
Resuscitation	0.00	(Insufficient)	0.00	0.00
Triage	0.00	(Insufficient)	0.00	0.00

Total Time Per Entity	Average	Half Width	Minimum Value	Maximum Value
Casting	25.5384	(Insufficient)	10.9451	58.2287
Examination and Treatment	24.3053	(Insufficient)	20.3239	29.9668
Gynecology	38.6964	(Insufficient)	30.4563	59.9116
MiniOperations	112.61	(Insufficient)	46.4457	257.43
Observation Room	110.09	(Insufficient)	70.1876	145.00
Reception	8.4921	(Insufficient)	5.1823	20.1164
Resuscitation	7.7320	(Insufficient)	7.0102	8.1716
Triage	5.8298	(Insufficient)	1.0000	10.0000

Accumulated Time

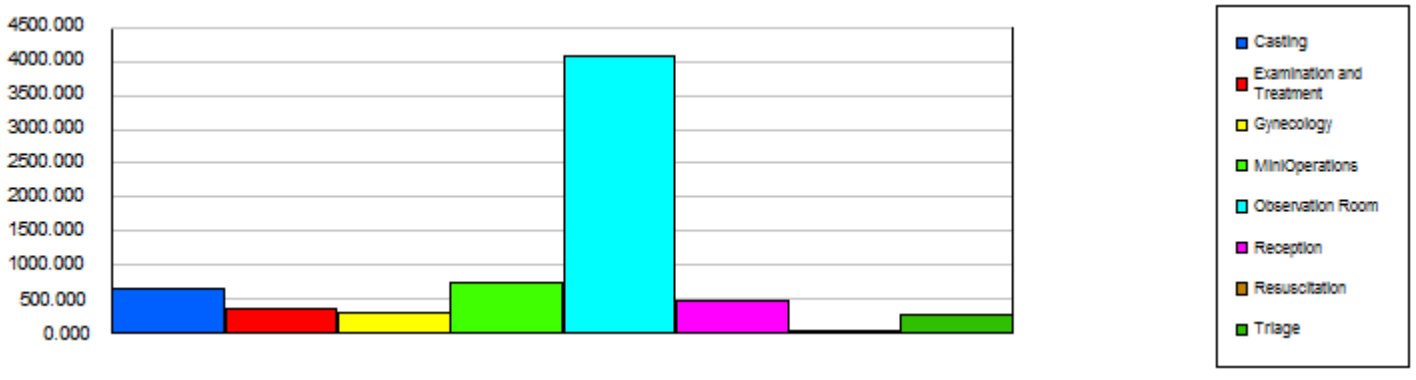
Emergency Department

Replications: 1 Time Units: Minutes

Process

Accumulated Time

Accum VA Time	Value
Casting	648.17
Examination and Treatment	364.58
Gynecology	294.05
MiniOperations	745.69
Observation Room	4063.58
Reception	482.45
Resuscitation	23.1961
Triage	274.00



Emergency Department

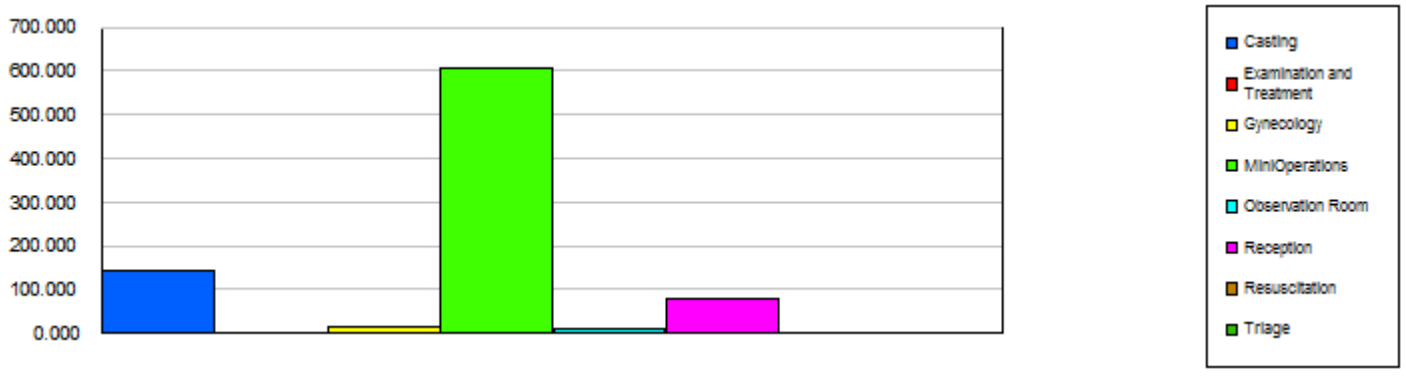
Replications: 1 Time Units: Minutes

Process

Accumulated Time

Accum Wait Time

	Value
Casting	143.52
Examination and Treatment	0.00
Gynecology	15.5190
MiniOperations	605.66
Observation Room	9.8474
Reception	78.0321
Resuscitation	0.00
Triage	0.00



Other

Emergency Department

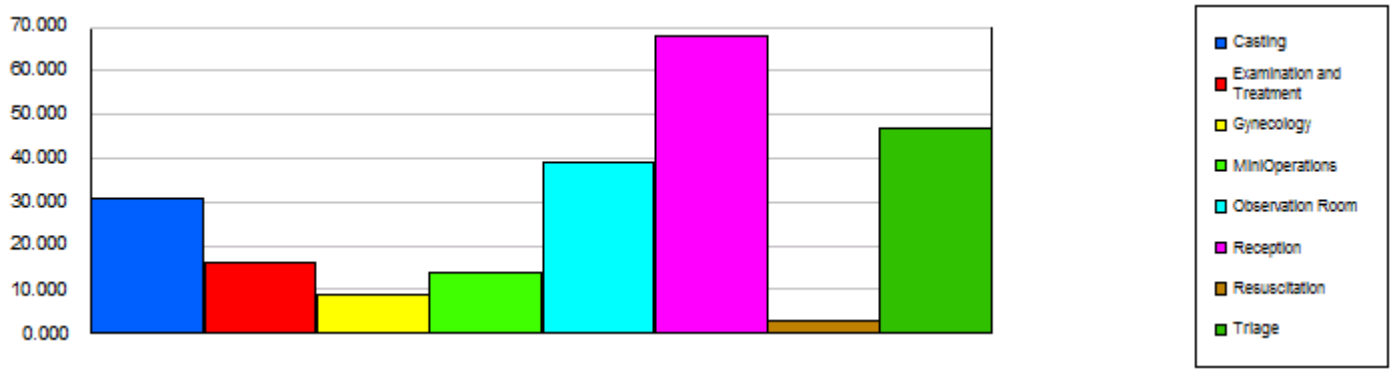
Replications: 1 Time Units: Minutes

Process

Other

Number In

	Value
Casting	31.0000
Examination and Treatment	16.0000
Gynecology	9.0000
MiniOperations	14.0000
Observation Room	39.0000
Reception	68.0000
Resuscitation	3.0000
Triage	47.0000



Number Out

	Value
Casting	31.0000
Examination and Treatment	15.0000
Gynecology	8.0000
MiniOperations	12.0000
Observation Room	37.0000
Reception	66.0000
Resuscitation	3.0000
Triage	47.0000

Emergency Department

Replications: 1 Time Units: Minutes

Queue

Time

Waiting Time	Average	Half Width	Minimum Value	Maximum Value
Casting.Queue	4.6296	(Insufficient)	0.00	33.3409
Examination and Treatment.Queue	0.00	(Insufficient)	0.00	0.00
Gynecology.Queue	1.7243	(Insufficient)	0.00	15.5190
MiniOperations.Queue	46.5892	(Insufficient)	0.00	180.83
Observation Room.Queue	0.2525	(Insufficient)	0.00	9.8474
Reception.Queue	1.1647	(Insufficient)	0.00	13.2580
Resuscitation.Queue	0.00	(Insufficient)	0.00	0.00
Triage.Queue	0.00	(Insufficient)	0.00	0.00

Other

Number Waiting	Average	Half Width	Minimum Value	Maximum Value
Casting.Queue	0.0997	(Insufficient)	0.00	2.0000
Examination and Treatment.Queue	0.00	(Insufficient)	0.00	0.00
Gynecology.Queue	0.01077711	(Insufficient)	0.00	1.0000
MiniOperations.Queue	0.4231	(Insufficient)	0.00	3.0000
Observation Room.Queue	0.00683847	(Insufficient)	0.00	1.0000
Reception.Queue	0.05453628	(Insufficient)	0.00	2.0000
Resuscitation.Queue	0.00	(Insufficient)	0.00	0.00
Triage.Queue	0.00	(Insufficient)	0.00	0.00

Emergency Department

Replications: 1 Time Units: Minutes

Resource

Usage

Instantaneous Utilization	Average	Half Width	Minimum Value	Maximum Value
Cast Room	0.4501	(Insufficient)	0.00	1.0000
Exam Bed	0.05119424	(Insufficient)	0.00	0.6000
Gyn Room	0.2229	(Insufficient)	0.00	1.0000
Observation Bed	0.4849	(Insufficient)	0.00	1.0000
Operation Room	0.5582	(Insufficient)	0.00	1.0000
Receptionist	0.3389	(Insufficient)	0.00	1.0000
Trauma Bed	0.00805420	(Insufficient)	0.00	0.5000
Triage Bed	0.04756944	(Insufficient)	0.00	0.5000

Number Busy	Average	Half Width	Minimum Value	Maximum Value
Cast Room	0.4501	(Insufficient)	0.00	1.0000
Exam Bed	0.2560	(Insufficient)	0.00	3.0000
Gyn Room	0.2229	(Insufficient)	0.00	1.0000
Observation Bed	2.9092	(Insufficient)	0.00	6.0000
Operation Room	0.5582	(Insufficient)	0.00	1.0000
Receptionist	0.3389	(Insufficient)	0.00	1.0000
Trauma Bed	0.01610841	(Insufficient)	0.00	1.0000
Triage Bed	0.1903	(Insufficient)	0.00	2.0000

Number Scheduled	Average	Half Width	Minimum Value	Maximum Value
Cast Room	1.0000	(Insufficient)	1.0000	1.0000
Exam Bed	5.0000	(Insufficient)	5.0000	5.0000
Gyn Room	1.0000	(Insufficient)	1.0000	1.0000
Observation Bed	6.0000	(Insufficient)	6.0000	6.0000
Operation Room	1.0000	(Insufficient)	1.0000	1.0000
Receptionist	1.0000	(Insufficient)	1.0000	1.0000
Trauma Bed	2.0000	(Insufficient)	2.0000	2.0000
Triage Bed	4.0000	(Insufficient)	4.0000	4.0000

Emergency Department

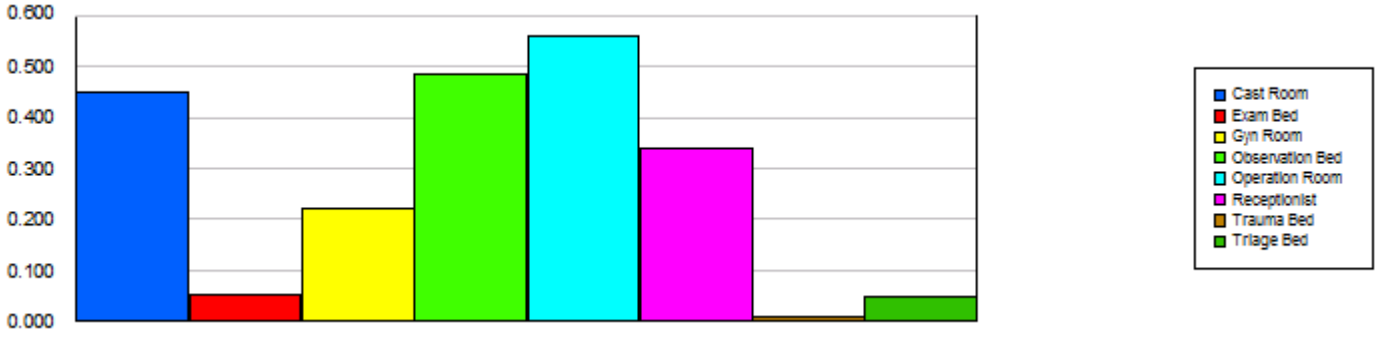
Replications: 1 Time Units: Minutes

Resource

Usage

Scheduled Utilization

	Value
Cast Room	0.4501
Exam Bed	0.05119424
Gyn Room	0.2229
Observation Bed	0.4849
Operation Room	0.5582
Receptionist	0.3389
Trauma Bed	0.00805420
Triage Bed	0.04756944



Emergency Department

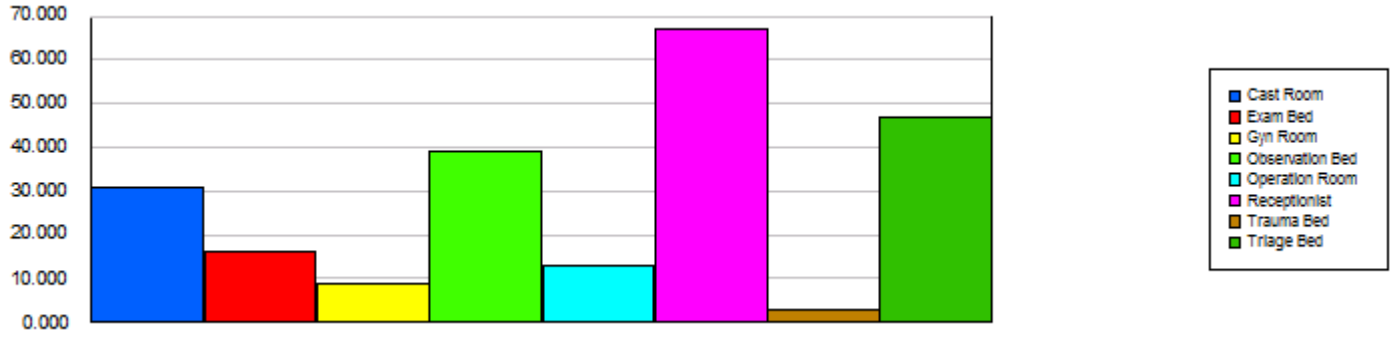
Replications: 1 Time Units: Minutes

Resource

Usage

Total Number Seized

	Value
Cast Room	31.0000
Exam Bed	16.0000
Gyn Room	9.0000
Observation Bed	39.0000
Operation Room	13.0000
Receptionist	67.0000
Trauma Bed	3.0000
Triage Bed	47.0000



Unnamed Project

Replications: 1 Time Units: Minutes

Applying different arrival rates on the base case

The following reports represent the application of different arrival rates on the base case without changing the number of resources of the base case scenario.

Emergency Department

Replications: 1 Time Units: Minutes

Key Performance Indicators

System

	Average
Number Out	117

Emergency Department

Replications: 1 Time Units: Minutes

Entity

Time

VA Time	Average	Half Width	Minimum Value	Maximum Value
Patient	77.5539	(Insufficient)	9.3726	199.38

NVA Time	Average	Half Width	Minimum Value	Maximum Value
Patient	0.00	(Insufficient)	0.00	0.00

Wait Time	Average	Half Width	Minimum Value	Maximum Value
Patient	38.2202	(Insufficient)	0.00	376.21

Transfer Time	Average	Half Width	Minimum Value	Maximum Value
Patient	0.00	(Insufficient)	0.00	0.00

Other Time	Average	Half Width	Minimum Value	Maximum Value
Patient	0.00	(Insufficient)	0.00	0.00

Total Time	Average	Half Width	Minimum Value	Maximum Value
Patient	115.77	(Insufficient)	9.3726	529.73

Other

Number In	Value
Patient	129.00

Number Out	Value
Patient	117.00

WIP	Average	Half Width	Minimum Value	Maximum Value
Patient	10.4627	(Insufficient)	0.00	16.0000

Emergency Department

Replications: 1 Time Units: Minutes

Process

Time per Entity

VA Time Per Entity	Average	Half Width	Minimum Value	Maximum Value
Casting	18.8936	(Insufficient)	10.7766	29.7946
Examination and Treatment	23.6498	(Insufficient)	20.0875	29.9668
Gynecology	35.2577	(Insufficient)	24.0273	44.8763
MiniOperations	68.5579	(Insufficient)	53.2736	87.0493
Observation Room	105.38	(Insufficient)	66.8842	143.52
Reception	7.4282	(Insufficient)	5.0139	9.8606
Resuscitation	9.7015	(Insufficient)	6.7582	13.2738
Triage	6.3500	(Insufficient)	1.0000	14.0000

Wait Time Per Entity	Average	Half Width	Minimum Value	Maximum Value
Casting	8.8705	(Insufficient)	0.00	34.7375
Examination and Treatment	0.00	(Insufficient)	0.00	0.00
Gynecology	7.3538	(Insufficient)	0.00	37.3569
MiniOperations	208.11	(Insufficient)	0.00	376.21
Observation Room	4.7975	(Insufficient)	0.00	54.7642
Reception	0.01471350	(Insufficient)	0.00	1.2801
Resuscitation	0.00	(Insufficient)	0.00	0.00
Triage	0.00	(Insufficient)	0.00	0.00

Total Time Per Entity	Average	Half Width	Minimum Value	Maximum Value
Casting	27.7641	(Insufficient)	10.7766	61.3560
Examination and Treatment	23.6498	(Insufficient)	20.0875	29.9668
Gynecology	42.6115	(Insufficient)	24.0273	82.2331
MiniOperations	276.67	(Insufficient)	75.3597	437.88
Observation Room	110.17	(Insufficient)	66.8842	175.42
Reception	7.4429	(Insufficient)	5.0139	9.8606
Resuscitation	9.7015	(Insufficient)	6.7582	13.2738
Triage	6.3500	(Insufficient)	1.0000	14.0000

Accumulated Time

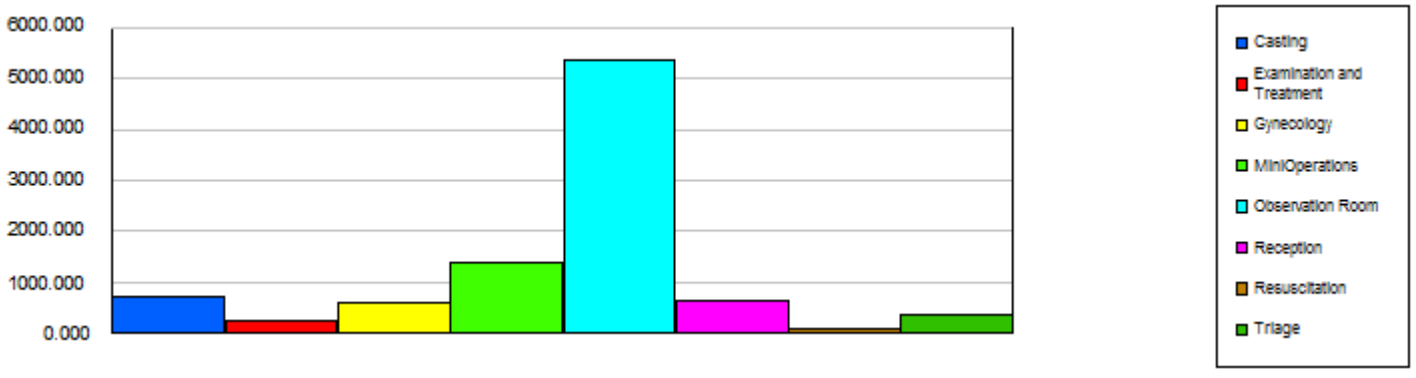
Emergency Department

Replications: 1 Time Units: Minutes

Process

Accumulated Time

Accum VA Time	Value
Casting	699.06
Examination and Treatment	260.15
Gynecology	599.38
MiniOperations	1371.16
Observation Room	5374.21
Reception	646.25
Resuscitation	77.6117
Triage	381.00



Emergency Department

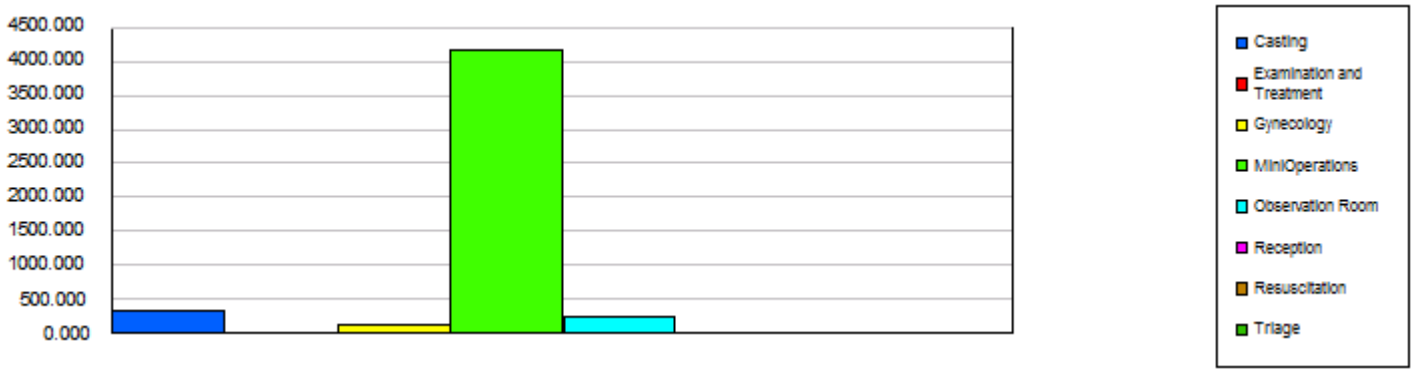
Replications: 1 Time Units: Minutes

Process

Accumulated Time

Accum Wait Time

	Value
Casting	328.21
Examination and Treatment	0.00
Gynecology	125.01
MiniOperations	4162.19
Observation Room	244.67
Reception	1.2801
Resuscitation	0.00
Triage	0.00



Other

Emergency Department

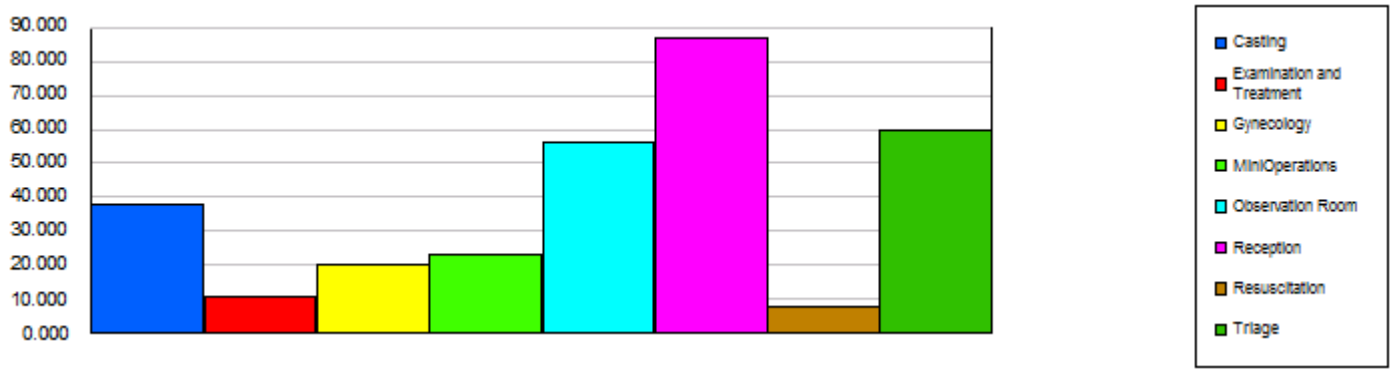
Replications: 1 Time Units: Minutes

Process

Other

Number In

	Value
Casting	38.0000
Examination and Treatment	11.0000
Gynecology	20.0000
MiniOperations	23.0000
Observation Room	56.0000
Reception	87.0000
Resuscitation	8.0000
Triage	60.0000



Number Out

	Value
Casting	37.0000
Examination and Treatment	11.0000
Gynecology	17.0000
MiniOperations	20.0000
Observation Room	51.0000
Reception	87.0000
Resuscitation	8.0000
Triage	60.0000

Emergency Department

Replications: 1 Time Units: Minutes

Queue

Time

Waiting Time	Average	Half Width	Minimum Value	Maximum Value
Casting.Queue	8.6371	(Insufficient)	0.00	34.7375
Examination and Treatment.Queue	0.00	(Insufficient)	0.00	0.00
Gynecology.Queue	9.5812	(Insufficient)	0.00	47.4464
MiniOperations.Queue	211.44	(Insufficient)	0.00	376.21
Observation Room.Queue	4.3691	(Insufficient)	0.00	54.7642
Reception.Queue	0.01471350	(Insufficient)	0.00	1.2801
Resuscitation.Queue	0.00	(Insufficient)	0.00	0.00
Triage.Queue	0.00	(Insufficient)	0.00	0.00

Other

Number Waiting	Average	Half Width	Minimum Value	Maximum Value
Casting.Queue	0.2279	(Insufficient)	0.00	3.0000
Examination and Treatment.Queue	0.00	(Insufficient)	0.00	0.00
Gynecology.Queue	0.1369	(Insufficient)	0.00	2.0000
MiniOperations.Queue	3.1803	(Insufficient)	0.00	6.0000
Observation Room.Queue	0.1699	(Insufficient)	0.00	3.0000
Reception.Queue	0.00088894	(Insufficient)	0.00	1.0000
Resuscitation.Queue	0.00	(Insufficient)	0.00	0.00
Triage.Queue	0.00	(Insufficient)	0.00	0.00

Emergency Department

Replications: 1 Time Units: Minutes

Resource

Usage

Instantaneous Utilization	Average	Half Width	Minimum Value	Maximum Value
Cast Room	0.4969	(Insufficient)	0.00	1.0000
Exam Bed	0.03613170	(Insufficient)	0.00	0.4000
Gyn Room	0.4253	(Insufficient)	0.00	1.0000
Observation Bed	0.6517	(Insufficient)	0.00	1.0000
Operation Room	0.9664	(Insufficient)	0.00	1.0000
Receptionist	0.1496	(Insufficient)	0.00	1.0000
Trauma Bed	0.02694850	(Insufficient)	0.00	0.5000
Triage Bed	0.06614583	(Insufficient)	0.00	0.5000

Number Busy	Average	Half Width	Minimum Value	Maximum Value
Cast Room	0.4969	(Insufficient)	0.00	1.0000
Exam Bed	0.1807	(Insufficient)	0.00	2.0000
Gyn Room	0.4253	(Insufficient)	0.00	1.0000
Observation Bed	3.9102	(Insufficient)	0.00	6.0000
Operation Room	0.9664	(Insufficient)	0.00	1.0000
Receptionist	0.4488	(Insufficient)	0.00	3.0000
Trauma Bed	0.05389701	(Insufficient)	0.00	1.0000
Triage Bed	0.2646	(Insufficient)	0.00	2.0000

Number Scheduled	Average	Half Width	Minimum Value	Maximum Value
Cast Room	1.0000	(Insufficient)	1.0000	1.0000
Exam Bed	5.0000	(Insufficient)	5.0000	5.0000
Gyn Room	1.0000	(Insufficient)	1.0000	1.0000
Observation Bed	6.0000	(Insufficient)	6.0000	6.0000
Operation Room	1.0000	(Insufficient)	1.0000	1.0000
Receptionist	3.0000	(Insufficient)	3.0000	3.0000
Trauma Bed	2.0000	(Insufficient)	2.0000	2.0000
Triage Bed	4.0000	(Insufficient)	4.0000	4.0000

Emergency Department

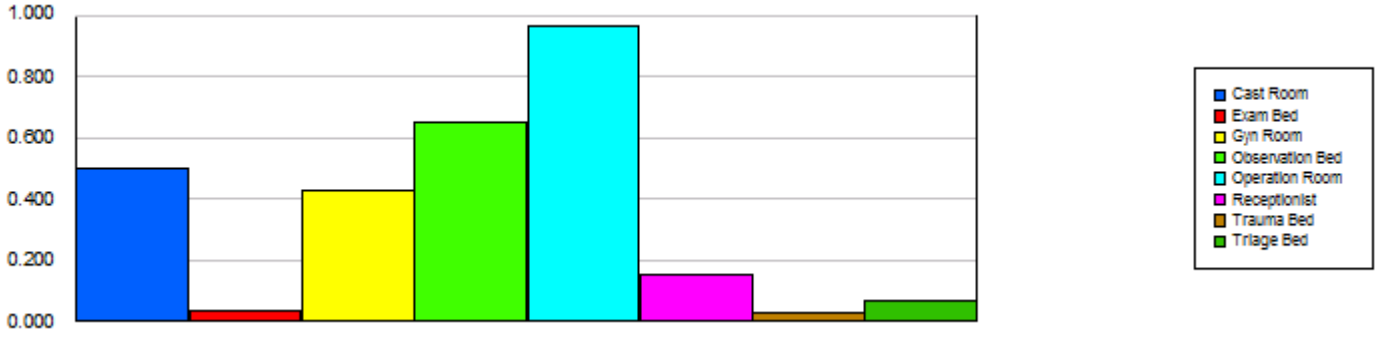
Replications: 1 Time Units: Minutes

Resource

Usage

Scheduled Utilization

	Value
Cast Room	0.4969
Exam Bed	0.03613170
Gyn Room	0.4253
Observation Bed	0.6517
Operation Room	0.9664
Receptionist	0.1496
Trauma Bed	0.02694850
Triage Bed	0.06614583



Emergency Department

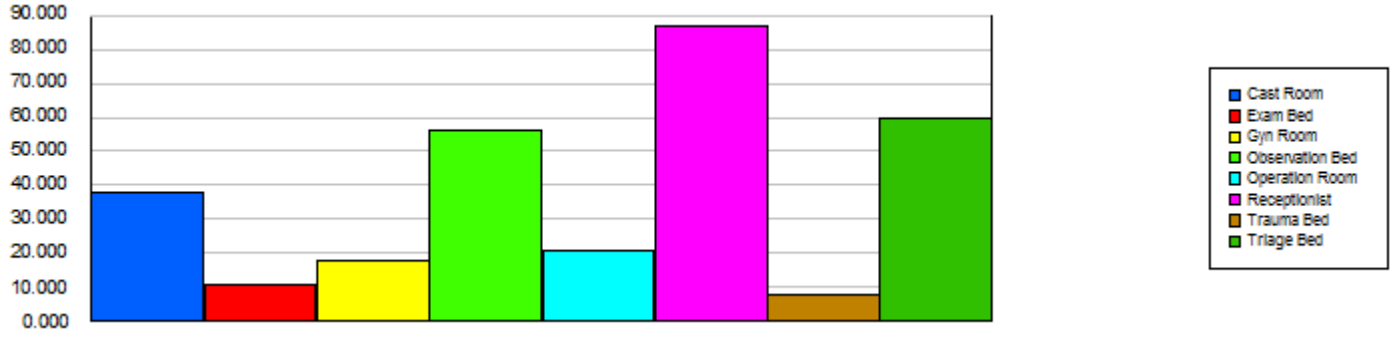
Replications: 1 Time Units: Minutes

Resource

Usage

Total Number Seized

	Value
Cast Room	38.0000
Exam Bed	11.0000
Gyn Room	18.0000
Observation Bed	56.0000
Operation Room	21.0000
Receptionist	87.0000
Trauma Bed	8.0000
Triage Bed	60.0000



Unnamed Project

Replications: 1 Time Units: Minutes

Emergency Department

Replications: 1 Time Units: Minutes

Key Performance Indicators

System

	Average
Number Out	111

Emergency Department

Replications: 1 Time Units: Minutes

Entity

Time

VA Time	Average	Half Width	Minimum Value	Maximum Value
Patient	72.2597	(Insufficient)	9.6345	216.64

NVA Time	Average	Half Width	Minimum Value	Maximum Value
Patient	0.00	(Insufficient)	0.00	0.00

Wait Time	Average	Half Width	Minimum Value	Maximum Value
Patient	20.2940	(Insufficient)	0.00	132.57

Transfer Time	Average	Half Width	Minimum Value	Maximum Value
Patient	0.00	(Insufficient)	0.00	0.00

Other Time	Average	Half Width	Minimum Value	Maximum Value
Patient	0.00	(Insufficient)	0.00	0.00

Total Time	Average	Half Width	Minimum Value	Maximum Value
Patient	92.5537	(Insufficient)	9.8857	295.97

Other

Number In	Value
Patient	117.00

Number Out	Value
Patient	111.00

WIP	Average	Half Width	Minimum Value	Maximum Value
Patient	7.5279	(Insufficient)	0.00	15.0000

Emergency Department

Replications: 1 Time Units: Minutes

Process

Time per Entity

VA Time Per Entity	Average	Half Width	Minimum Value	Maximum Value
Casting	19.7668	(Insufficient)	10.0626	29.6425
Examination and Treatment	23.6989	(Insufficient)	20.1533	29.3565
Gynecology	33.2135	(Insufficient)	24.0016	42.9060
MiniOperations	70.0483	(Insufficient)	54.4363	80.1688
Observation Room	118.57	(Insufficient)	64.1940	147.54
Reception	7.5585	(Insufficient)	5.0325	9.9678
Resuscitation	9.0144	(Insufficient)	6.7582	11.6618
Triage	6.0000	(Insufficient)	3.0000	13.0000

Wait Time Per Entity	Average	Half Width	Minimum Value	Maximum Value
Casting	4.9891	(Insufficient)	0.00	25.3765
Examination and Treatment	0.00	(Insufficient)	0.00	0.00
Gynecology	2.5157	(Insufficient)	0.00	12.9417
MiniOperations	0.00	(Insufficient)	0.00	0.00
Observation Room	38.4746	(Insufficient)	0.00	112.50
Reception	4.9653	(Insufficient)	0.00	38.7350
Resuscitation	0.00	(Insufficient)	0.00	0.00
Triage	0.00	(Insufficient)	0.00	0.00

Total Time Per Entity	Average	Half Width	Minimum Value	Maximum Value
Casting	24.7559	(Insufficient)	10.0626	48.5677
Examination and Treatment	23.6989	(Insufficient)	20.1533	29.3565
Gynecology	35.7291	(Insufficient)	24.0016	55.8477
MiniOperations	70.0483	(Insufficient)	54.4363	80.1688
Observation Room	157.04	(Insufficient)	67.3826	242.52
Reception	12.5238	(Insufficient)	5.1942	43.7675
Resuscitation	9.0144	(Insufficient)	6.7582	11.6618
Triage	6.0000	(Insufficient)	3.0000	13.0000

Accumulated Time

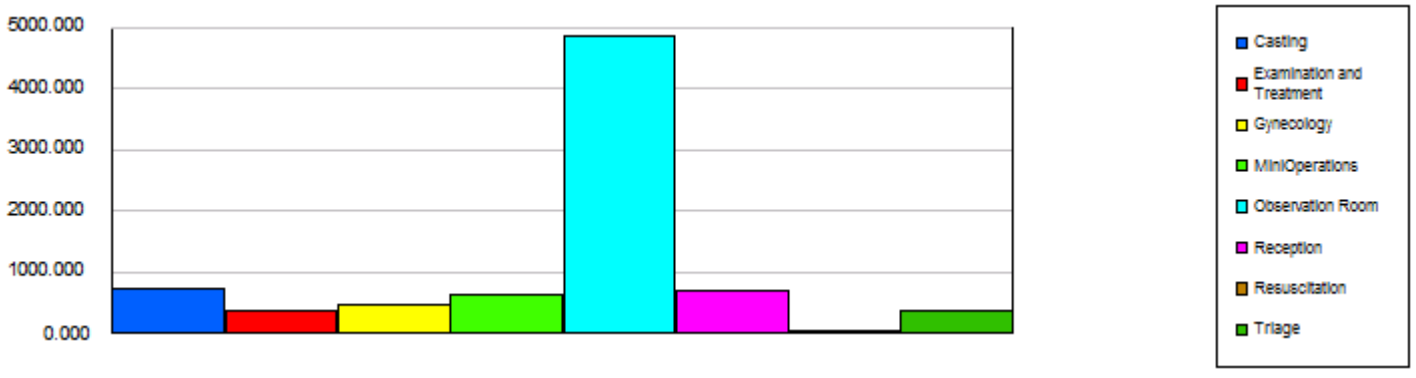
Emergency Department

Replications: 1 Time Units: Minutes

Process

Accumulated Time

Accum VA Time	Value
Casting	731.37
Examination and Treatment	379.18
Gynecology	464.99
MiniOperations	630.43
Observation Room	4861.29
Reception	702.94
Resuscitation	54.0862
Triage	378.00



Emergency Department

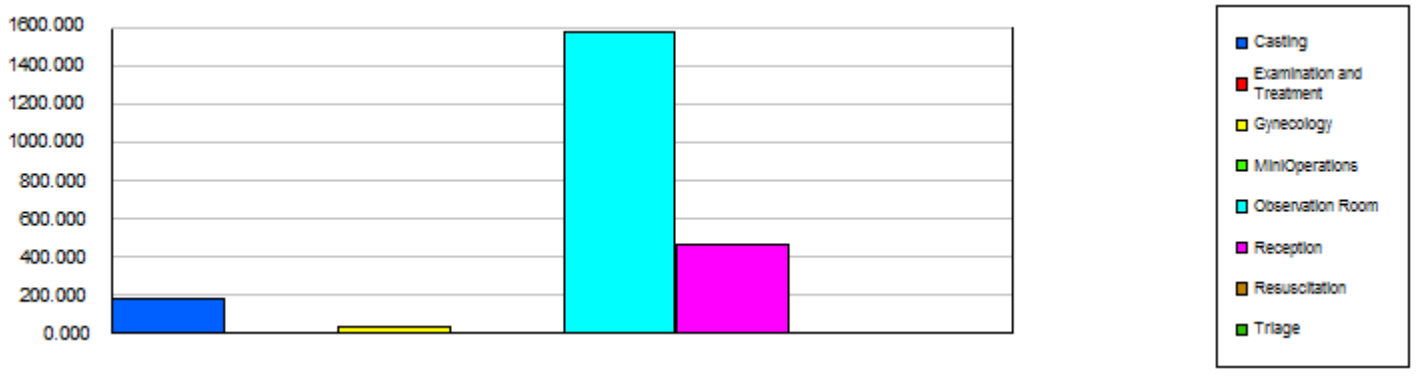
Replications: 1 Time Units: Minutes

Process

Accumulated Time

Accum Wait Time

	Value
Casting	184.60
Examination and Treatment	0.00
Gynecology	35.2195
MiniOperations	0.00
Observation Room	1577.46
Reception	461.78
Resuscitation	0.00
Triage	0.00



Other

Emergency Department

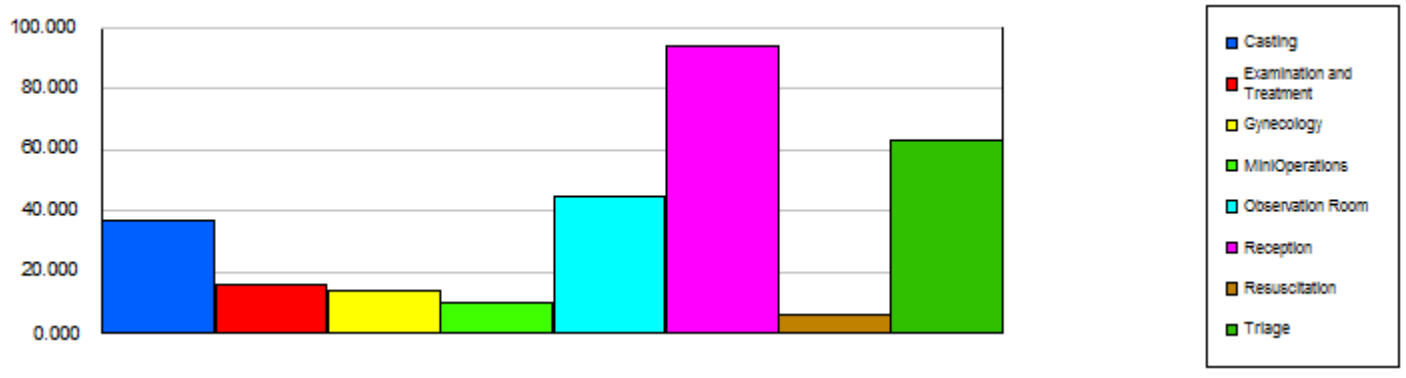
Replications: 1 Time Units: Minutes

Process

Other

Number In

	Value
Casting	37.0000
Examination and Treatment	16.0000
Gynecology	14.0000
MiniOperations	10.0000
Observation Room	45.0000
Reception	94.0000
Resuscitation	6.0000
Triage	63.0000



Number Out

	Value
Casting	37.0000
Examination and Treatment	16.0000
Gynecology	14.0000
MiniOperations	9.0000
Observation Room	41.0000
Reception	93.0000
Resuscitation	6.0000
Triage	63.0000

Emergency Department

Replications: 1 Time Units: Minutes

Queue

Time

Waiting Time	Average	Half Width	Minimum Value	Maximum Value
Casting.Queue	4.9891	(Insufficient)	0.00	25.3765
Examination and Treatment.Queue	0.00	(Insufficient)	0.00	0.00
Gynecology.Queue	2.5157	(Insufficient)	0.00	12.9417
MiniOperations.Queue	0.00	(Insufficient)	0.00	0.00
Observation Room.Queue	39.8501	(Insufficient)	0.00	112.50
Reception.Queue	4.9125	(Insufficient)	0.00	38.7350
Resuscitation.Queue	0.00	(Insufficient)	0.00	0.00
Triage.Queue	0.00	(Insufficient)	0.00	0.00

Other

Number Waiting	Average	Half Width	Minimum Value	Maximum Value
Casting.Queue	0.1282	(Insufficient)	0.00	2.0000
Examination and Treatment.Queue	0.00	(Insufficient)	0.00	0.00
Gynecology.Queue	0.02445801	(Insufficient)	0.00	1.0000
MiniOperations.Queue	0.00	(Insufficient)	0.00	0.00
Observation Room.Queue	1.2453	(Insufficient)	0.00	5.0000
Reception.Queue	0.3207	(Insufficient)	0.00	5.0000
Resuscitation.Queue	0.00	(Insufficient)	0.00	0.00
Triage.Queue	0.00	(Insufficient)	0.00	0.00

Emergency Department

Replications: 1 Time Units: Minutes

Resource

Usage

Instantaneous Utilization	Average	Half Width	Minimum Value	Maximum Value
Cast Room	0.5079	(Insufficient)	0.00	1.0000
Exam Bed	0.1317	(Insufficient)	0.00	1.0000
Gyn Room	0.3229	(Insufficient)	0.00	1.0000
Observation Bed	0.8637	(Insufficient)	0.00	1.0000
Operation Room	0.1569	(Insufficient)	0.00	0.6667
Receptionist	0.4895	(Insufficient)	0.00	1.0000
Trauma Bed	0.03755983	(Insufficient)	0.00	1.0000
Triage Bed	0.1313	(Insufficient)	0.00	1.0000

Number Busy	Average	Half Width	Minimum Value	Maximum Value
Cast Room	0.5079	(Insufficient)	0.00	1.0000
Exam Bed	0.2633	(Insufficient)	0.00	2.0000
Gyn Room	0.3229	(Insufficient)	0.00	1.0000
Observation Bed	3.4549	(Insufficient)	0.00	4.0000
Operation Room	0.4707	(Insufficient)	0.00	2.0000
Receptionist	0.4895	(Insufficient)	0.00	1.0000
Trauma Bed	0.03755983	(Insufficient)	0.00	1.0000
Triage Bed	0.2625	(Insufficient)	0.00	2.0000

Number Scheduled	Average	Half Width	Minimum Value	Maximum Value
Cast Room	1.0000	(Insufficient)	1.0000	1.0000
Exam Bed	2.0000	(Insufficient)	2.0000	2.0000
Gyn Room	1.0000	(Insufficient)	1.0000	1.0000
Observation Bed	4.0000	(Insufficient)	4.0000	4.0000
Operation Room	3.0000	(Insufficient)	3.0000	3.0000
Receptionist	1.0000	(Insufficient)	1.0000	1.0000
Trauma Bed	1.0000	(Insufficient)	1.0000	1.0000
Triage Bed	2.0000	(Insufficient)	2.0000	2.0000

Emergency Department

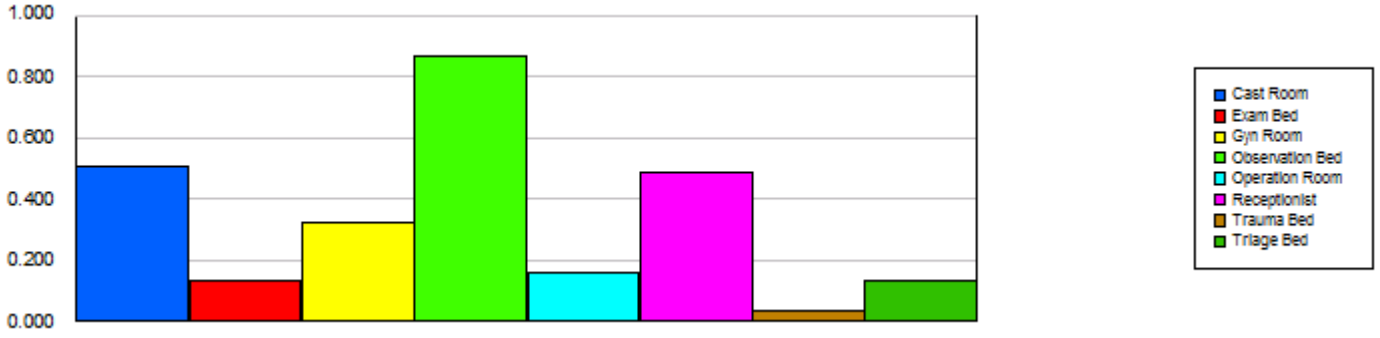
Replications: 1 Time Units: Minutes

Resource

Usage

Scheduled Utilization

	Value
Cast Room	0.5079
Exam Bed	0.1317
Gyn Room	0.3229
Observation Bed	0.8637
Operation Room	0.1569
Receptionist	0.4895
Trauma Bed	0.03755983
Triage Bed	0.1313



Emergency Department

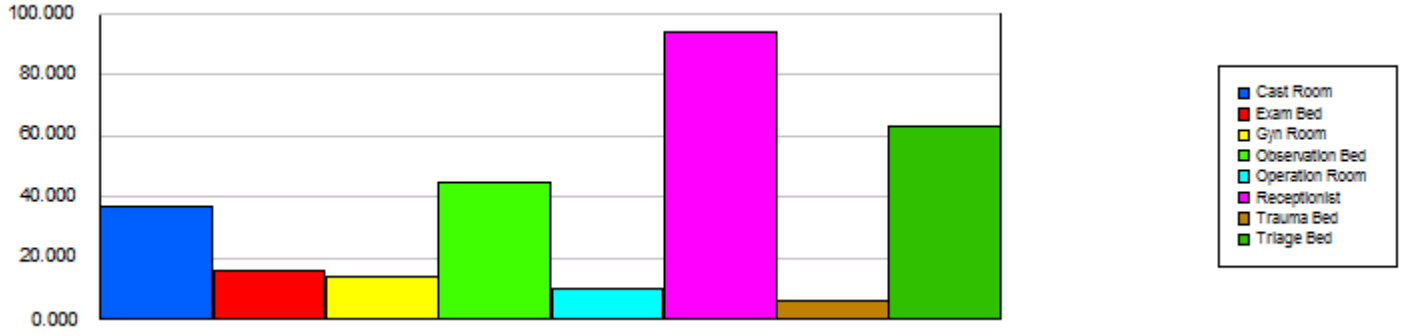
Replications: 1 Time Units: Minutes

Resource

Usage

Total Number Seized

	Value
Cast Room	37.0000
Exam Bed	16.0000
Gyn Room	14.0000
Observation Bed	45.0000
Operation Room	10.0000
Receptionist	94.0000
Trauma Bed	6.0000
Triage Bed	63.0000



Unnamed Project

Replications: 1 Time Units: Minutes

Emergency Department

Replications: 1 Time Units: Minutes

Key Performance Indicators

System

	Average
Number Out	103

Emergency Department

Replications: 1 Time Units: Minutes

Entity

Time

VA Time	Average	Half Width	Minimum Value	Maximum Value
Patient	67.0273	(Insufficient)	9.8906	225.50

NVA Time	Average	Half Width	Minimum Value	Maximum Value
Patient	0.00	(Insufficient)	0.00	0.00

Wait Time	Average	Half Width	Minimum Value	Maximum Value
Patient	46.3602	(Insufficient)	0.00	263.50

Transfer Time	Average	Half Width	Minimum Value	Maximum Value
Patient	0.00	(Insufficient)	0.00	0.00

Other Time	Average	Half Width	Minimum Value	Maximum Value
Patient	0.00	(Insufficient)	0.00	0.00

Total Time	Average	Half Width	Minimum Value	Maximum Value
Patient	113.39	(Insufficient)	9.8906	442.34

Other

Number In	Value
Patient	124.00

Number Out	Value
Patient	103.00

WIP	Average	Half Width	Minimum Value	Maximum Value
Patient	11.7388	(Insufficient)	0.00	23.0000

Emergency Department

Replications: 1 Time Units: Minutes

Process

Time per Entity

VA Time Per Entity	Average	Half Width	Minimum Value	Maximum Value
Casting	18.9677	(Insufficient)	10.0651	29.2555
Examination and Treatment	24.8919	(Insufficient)	21.2934	29.0615
Gynecology	34.0664	(Insufficient)	25.0653	41.5326
MiniOperations	65.2985	(Insufficient)	46.4457	83.4664
Observation Room	110.56	(Insufficient)	65.3171	145.00
Reception	7.4542	(Insufficient)	5.0438	9.9933
Resuscitation	10.2596	(Insufficient)	7.6370	13.2738
Triage	6.2745	(Insufficient)	1.0000	14.0000

Wait Time Per Entity	Average	Half Width	Minimum Value	Maximum Value
Casting	10.1098	(Insufficient)	0.00	47.8417
Examination and Treatment	2.8936	(Insufficient)	0.00	17.4642
Gynecology	2.7836	(Insufficient)	0.00	10.6760
MiniOperations	4.8126	(Insufficient)	0.00	53.5468
Observation Room	117.39	(Insufficient)	0.00	258.48
Reception	2.7442	(Insufficient)	0.00	23.5926
Resuscitation	0.00	(Insufficient)	0.00	0.00
Triage	0.00	(Insufficient)	0.00	0.00

Total Time Per Entity	Average	Half Width	Minimum Value	Maximum Value
Casting	29.0775	(Insufficient)	10.0651	74.2395
Examination and Treatment	27.7855	(Insufficient)	21.2934	44.0727
Gynecology	36.8500	(Insufficient)	25.0653	47.5828
MiniOperations	70.1110	(Insufficient)	46.4457	113.70
Observation Room	227.94	(Insufficient)	96.4362	384.07
Reception	10.1984	(Insufficient)	5.1823	32.0166
Resuscitation	10.2596	(Insufficient)	7.6370	13.2738
Triage	6.2745	(Insufficient)	1.0000	14.0000

Accumulated Time

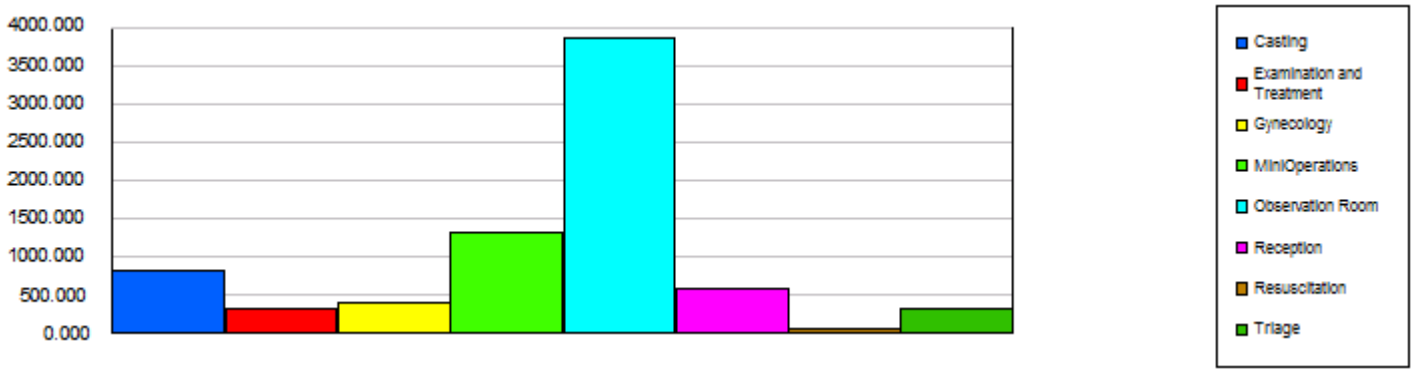
Emergency Department

Replications: 1 Time Units: Minutes

Process

Accumulated Time

Accum VA Time	Value
Casting	815.61
Examination and Treatment	323.59
Gynecology	408.80
MiniOperations	1305.97
Observation Room	3869.51
Reception	581.42
Resuscitation	61.5577
Triage	320.00



Emergency Department

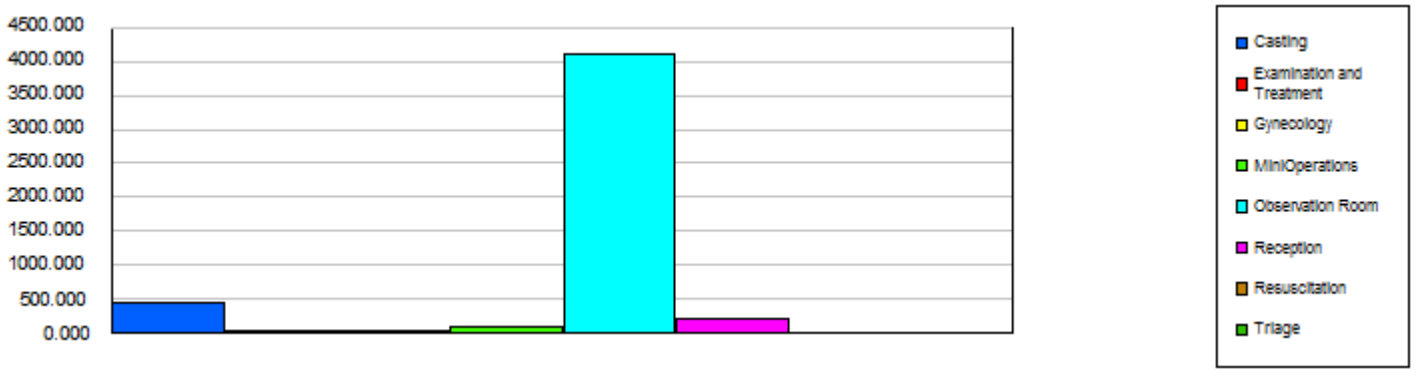
Replications: 1 Time Units: Minutes

Process

Accumulated Time

Accum Wait Time

	Value
Casting	434.72
Examination and Treatment	37.6167
Gynecology	33.4033
MiniOperations	96.2512
Observation Room	4108.49
Reception	214.05
Resuscitation	0.00
Triage	0.00



Other

Emergency Department

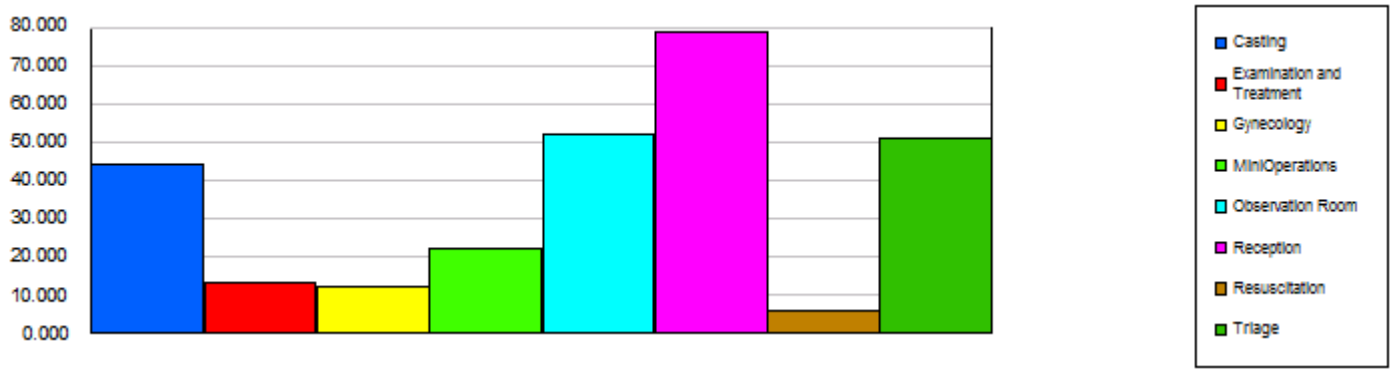
Replications: 1 Time Units: Minutes

Process

Other

Number In

	Value
Casting	44.0000
Examination and Treatment	13.0000
Gynecology	12.0000
MiniOperations	22.0000
Observation Room	52.0000
Reception	79.0000
Resuscitation	6.0000
Triage	51.0000



Number Out

	Value
Casting	43.0000
Examination and Treatment	13.0000
Gynecology	12.0000
MiniOperations	20.0000
Observation Room	35.0000
Reception	78.0000
Resuscitation	6.0000
Triage	51.0000

Emergency Department

Replications: 1 Time Units: Minutes

Queue

Time

Waiting Time	Average	Half Width	Minimum Value	Maximum Value
Casting.Queue	10.5919	(Insufficient)	0.00	47.8417
Examination and Treatment.Queue	2.8936	(Insufficient)	0.00	17.4642
Gynecology.Queue	2.7836	(Insufficient)	0.00	10.6760
MiniOperations.Queue	4.3751	(Insufficient)	0.00	53.5468
Observation Room.Queue	132.51	(Insufficient)	0.00	315.03
Reception.Queue	2.7095	(Insufficient)	0.00	23.5926
Resuscitation.Queue	0.00	(Insufficient)	0.00	0.00
Triage.Queue	0.00	(Insufficient)	0.00	0.00

Other

Number Waiting	Average	Half Width	Minimum Value	Maximum Value
Casting.Queue	0.3236	(Insufficient)	0.00	3.0000
Examination and Treatment.Queue	0.02612272	(Insufficient)	0.00	1.0000
Gynecology.Queue	0.02319674	(Insufficient)	0.00	1.0000
MiniOperations.Queue	0.06684108	(Insufficient)	0.00	1.0000
Observation Room.Queue	5.6016	(Insufficient)	0.00	16.0000
Reception.Queue	0.1486	(Insufficient)	0.00	3.0000
Resuscitation.Queue	0.00	(Insufficient)	0.00	0.00
Triage.Queue	0.00	(Insufficient)	0.00	0.00

Emergency Department

Replications: 1 Time Units: Minutes

Resource

Usage

Instantaneous Utilization	Average	Half Width	Minimum Value	Maximum Value
Cast Room	0.5716	(Insufficient)	0.00	1.0000
Exam Bed	0.2247	(Insufficient)	0.00	1.0000
Gyn Room	0.2839	(Insufficient)	0.00	1.0000
Observation Bed	0.9417	(Insufficient)	0.00	1.0000
Operation Room	0.4861	(Insufficient)	0.00	1.0000
Receptionist	0.4061	(Insufficient)	0.00	1.0000
Trauma Bed	0.02137419	(Insufficient)	0.00	0.5000
Triage Bed	0.07407407	(Insufficient)	0.00	0.6667

Number Busy	Average	Half Width	Minimum Value	Maximum Value
Cast Room	0.5716	(Insufficient)	0.00	1.0000
Exam Bed	0.2247	(Insufficient)	0.00	1.0000
Gyn Room	0.2839	(Insufficient)	0.00	1.0000
Observation Bed	2.8252	(Insufficient)	0.00	3.0000
Operation Room	0.9723	(Insufficient)	0.00	2.0000
Receptionist	0.4061	(Insufficient)	0.00	1.0000
Trauma Bed	0.04274839	(Insufficient)	0.00	1.0000
Triage Bed	0.2222	(Insufficient)	0.00	2.0000

Number Scheduled	Average	Half Width	Minimum Value	Maximum Value
Cast Room	1.0000	(Insufficient)	1.0000	1.0000
Exam Bed	1.0000	(Insufficient)	1.0000	1.0000
Gyn Room	1.0000	(Insufficient)	1.0000	1.0000
Observation Bed	3.0000	(Insufficient)	3.0000	3.0000
Operation Room	2.0000	(Insufficient)	2.0000	2.0000
Receptionist	1.0000	(Insufficient)	1.0000	1.0000
Trauma Bed	2.0000	(Insufficient)	2.0000	2.0000
Triage Bed	3.0000	(Insufficient)	3.0000	3.0000

Emergency Department

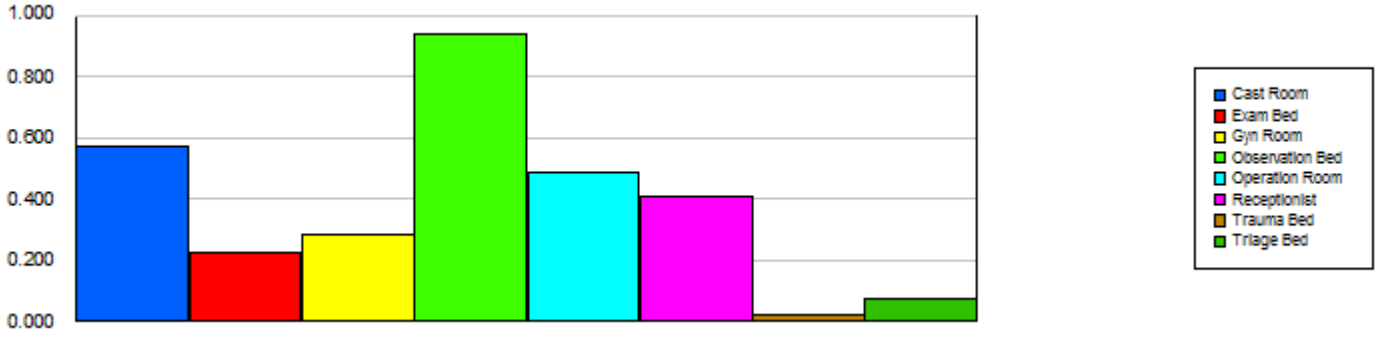
Replications: 1 Time Units: Minutes

Resource

Usage

Scheduled Utilization

	Value
Cast Room	0.5716
Exam Bed	0.2247
Gyn Room	0.2839
Observation Bed	0.9417
Operation Room	0.4861
Receptionist	0.4061
Trauma Bed	0.02137419
Triage Bed	0.07407407



Emergency Department

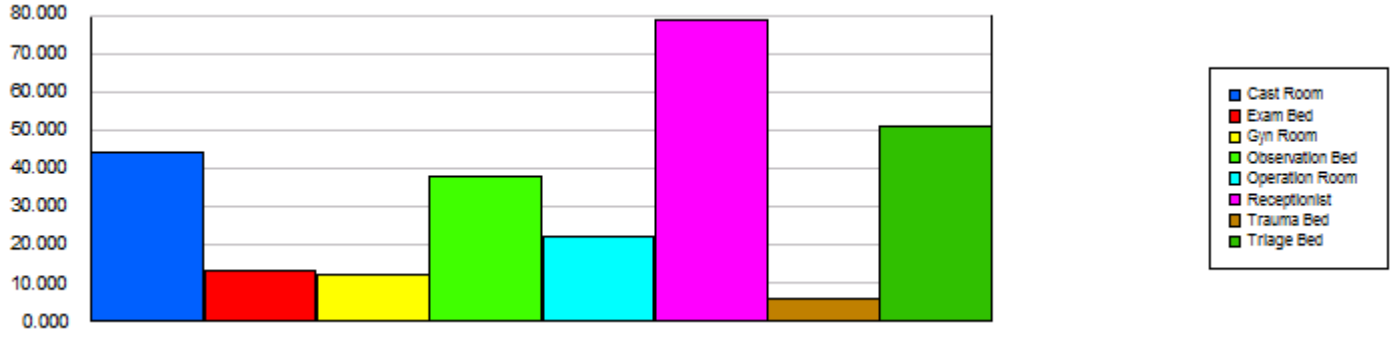
Replications: 1 Time Units: Minutes

Resource

Usage

Total Number Seized

	Value
Cast Room	44.0000
Exam Bed	13.0000
Gyn Room	12.0000
Observation Bed	38.0000
Operation Room	22.0000
Receptionist	79.0000
Trauma Bed	6.0000
Triage Bed	51.0000



Unnamed Project

Replications: 1 Time Units: Minutes

Applying different arrival rates and number of resources

Emergency Department

Replications: 1 Time Units: Minutes

Key Performance Indicators

System

	Average
Number Out	202

Emergency Department

Replications: 1 Time Units: Minutes

Entity

Time

VA Time	Average	Half Width	Minimum Value	Maximum Value
Patient	65.3509	(Insufficient)	7.0658	212.70

NVA Time	Average	Half Width	Minimum Value	Maximum Value
Patient	0.00	(Insufficient)	0.00	0.00

Wait Time	Average	Half Width	Minimum Value	Maximum Value
Patient	83.6154	(Insufficient)	0.00	737.68

Transfer Time	Average	Half Width	Minimum Value	Maximum Value
Patient	0.00	(Insufficient)	0.00	0.00

Other Time	Average	Half Width	Minimum Value	Maximum Value
Patient	0.00	(Insufficient)	0.00	0.00

Total Time	Average	Half Width	Minimum Value	Maximum Value
Patient	148.97	(Insufficient)	10.1552	881.50

Other

Number In	Value
Patient	238.00

Number Out	Value
Patient	202.00

WIP	Average	Half Width	Minimum Value	Maximum Value
Patient	26.2209	(Correlated)	0.00	40.0000

Emergency Department

Replications: 1 Time Units: Minutes

Process

Time per Entity

VA Time Per Entity	Average	Half Width	Minimum Value	Maximum Value
Casting	20.5627	(Insufficient)	10.1301	29.9732
Examination and Treatment	24.7225	(Insufficient)	20.1838	29.5813
Gynecology	34.6373	(Insufficient)	26.9470	45.6490
MiniOperations	66.2881	(Insufficient)	48.6019	82.4037
Observation Room	106.41	(Insufficient)	64.1940	148.04
Reception	7.4736	(Insufficient)	5.0139	9.9709
Resuscitation	8.6489	(Insufficient)	6.8865	11.3940
Triage	6.0000	(Insufficient)	1.0000	14.0000

Wait Time Per Entity	Average	Half Width	Minimum Value	Maximum Value
Casting	43.4683	(Insufficient)	0.00	116.24
Examination and Treatment	9.6325	(Insufficient)	0.00	50.4476
Gynecology	3.0382	(Insufficient)	0.00	28.5966
MiniOperations	331.78	(Insufficient)	0.00	595.04
Observation Room	89.9294	(Insufficient)	0.00	160.11
Reception	12.2454	(Insufficient)	0.00	44.7945
Resuscitation	0.1643	(Insufficient)	0.00	1.3914
Triage	0.5458	(Insufficient)	0.00	9.3542

Total Time Per Entity	Average	Half Width	Minimum Value	Maximum Value
Casting	64.0310	(Insufficient)	10.2858	141.11
Examination and Treatment	34.3550	(Insufficient)	20.6546	75.5957
Gynecology	37.6755	(Insufficient)	27.5169	63.6608
MiniOperations	398.06	(Insufficient)	75.9283	648.93
Observation Room	196.34	(Insufficient)	76.9150	279.42
Reception	19.7190	(Insufficient)	5.0139	50.0542
Resuscitation	8.8132	(Insufficient)	6.8865	12.7855
Triage	6.5458	(Insufficient)	1.5307	18.5901

Accumulated Time

Emergency Department

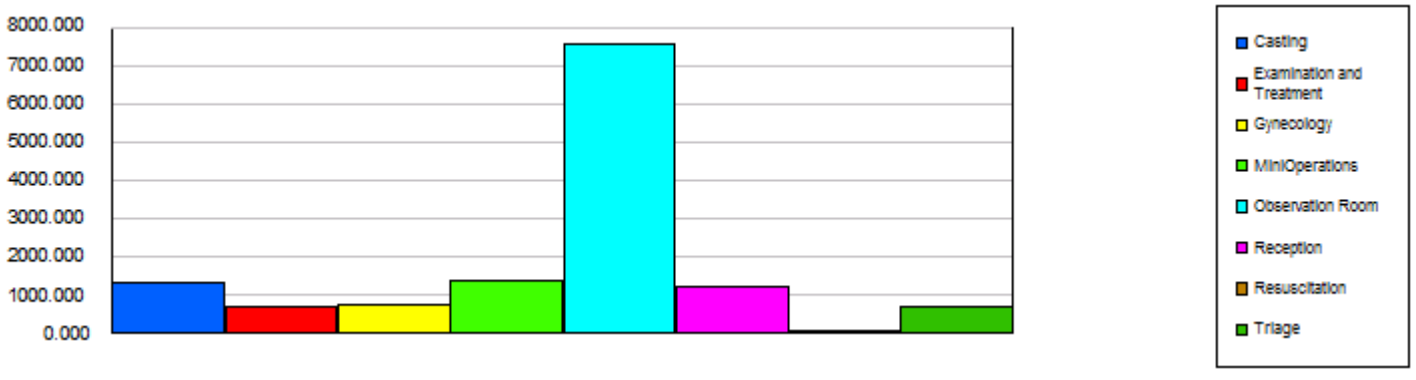
Replications: 1 Time Units: Minutes

Process

Accumulated Time

Accum VA Time

	Value
Casting	1316.01
Examination and Treatment	692.23
Gynecology	762.02
MiniOperations	1392.05
Observation Room	7555.17
Reception	1218.19
Resuscitation	77.8397
Triage	714.00



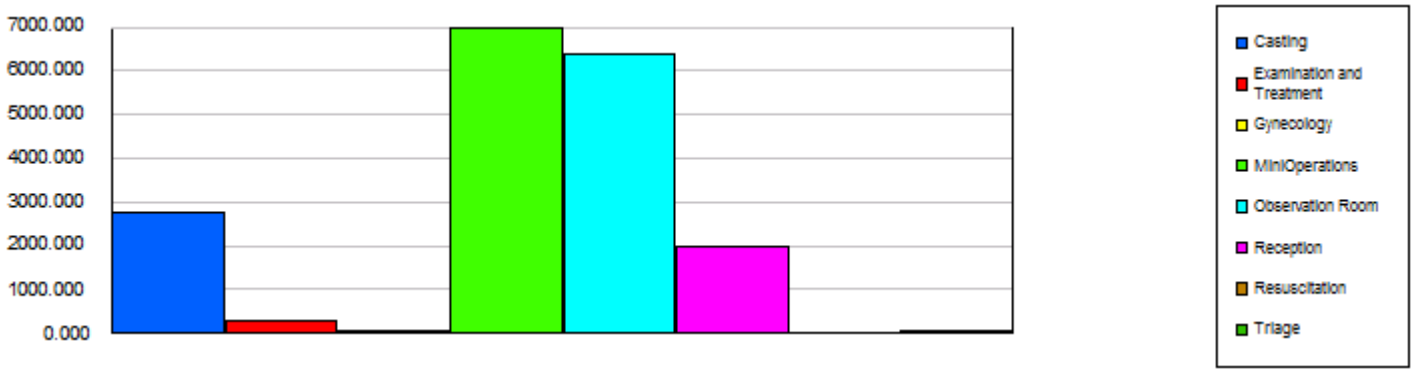
Emergency Department

Replications: 1 Time Units: Minutes

Process

Accumulated Time

Accum Wait Time	Value
Casting	2781.97
Examination and Treatment	269.71
Gynecology	66.8401
MiniOperations	6967.31
Observation Room	6384.99
Reception	1996.01
Resuscitation	1.4786
Triage	64.9531



Other

Emergency Department

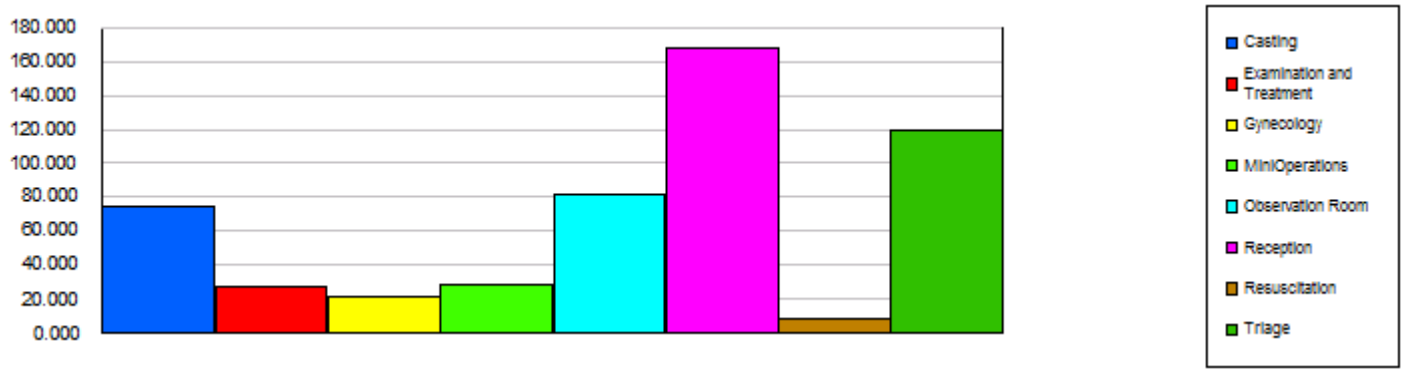
Replications: 1 Time Units: Minutes

Process

Other

Number In

	Value
Casting	75.0000
Examination and Treatment	28.0000
Gynecology	22.0000
MiniOperations	29.0000
Observation Room	82.0000
Reception	168.00
Resuscitation	9.0000
Triage	120.00



Number Out

	Value
Casting	64.0000
Examination and Treatment	28.0000
Gynecology	22.0000
MiniOperations	21.0000
Observation Room	71.0000
Reception	163.00
Resuscitation	9.0000
Triage	119.00

Emergency Department

Replications: 1 Time Units: Minutes

Queue

Time

Waiting Time	Average	Half Width	Minimum Value	Maximum Value
Casting.Queue	44.2664	(Insufficient)	0.00	116.24
Examination and Treatment.Queue	9.6325	(Insufficient)	0.00	50.4476
Gynecology.Queue	3.0382	(Insufficient)	0.00	28.5966
MiniOperations.Queue	342.91	(Insufficient)	0.00	595.04
Observation Room.Queue	91.8565	(Insufficient)	0.00	160.11
Reception.Queue	12.3283	(Insufficient)	0.00	44.7945
Resuscitation.Queue	0.1643	(Insufficient)	0.00	1.3914
Triage.Queue	0.5413	(Insufficient)	0.00	9.3542

Other

Number Waiting	Average	Half Width	Minimum Value	Maximum Value
Casting.Queue	2.5191	(Insufficient)	0.00	10.0000
Examination and Treatment.Queue	0.1873	(Insufficient)	0.00	2.0000
Gynecology.Queue	0.04641673	(Insufficient)	0.00	1.0000
MiniOperations.Queue	7.0867	(Insufficient)	0.00	12.0000
Observation Room.Queue	5.0676	(Insufficient)	0.00	10.0000
Reception.Queue	1.4289	(Insufficient)	0.00	6.0000
Resuscitation.Queue	0.00102684	(Insufficient)	0.00	1.0000
Triage.Queue	0.04510635	(Insufficient)	0.00	2.0000

Emergency Department

Replications: 1 Time Units: Minutes

Resource

Usage

Instantaneous Utilization	Average	Half Width	Minimum Value	Maximum Value
Cast Room	0.9317	(Insufficient)	0.00	1.0000
Exam Bed	0.4807	(Insufficient)	0.00	1.0000
Gyn Room	0.5292	(Insufficient)	0.00	1.0000
Observation Bed	0.9161	(Insufficient)	0.00	1.0000
Operation Room	0.9983	(Insufficient)	0.00	1.0000
Receptionist	0.8492	(Insufficient)	0.00	1.0000
Trauma Bed	0.05405536	(Insufficient)	0.00	1.0000
Triage Bed	0.4990	(Insufficient)	0.00	1.0000

Number Busy	Average	Half Width	Minimum Value	Maximum Value
Cast Room	0.9317	(Insufficient)	0.00	1.0000
Exam Bed	0.4807	(Insufficient)	0.00	1.0000
Gyn Room	0.5292	(Insufficient)	0.00	1.0000
Observation Bed	5.4966	(Insufficient)	0.00	6.0000
Operation Room	0.9983	(Insufficient)	0.00	1.0000
Receptionist	0.8492	(Insufficient)	0.00	1.0000
Trauma Bed	0.05405536	(Insufficient)	0.00	1.0000
Triage Bed	0.4990	(Insufficient)	0.00	1.0000

Number Scheduled	Average	Half Width	Minimum Value	Maximum Value
Cast Room	1.0000	(Insufficient)	1.0000	1.0000
Exam Bed	1.0000	(Insufficient)	1.0000	1.0000
Gyn Room	1.0000	(Insufficient)	1.0000	1.0000
Observation Bed	6.0000	(Insufficient)	6.0000	6.0000
Operation Room	1.0000	(Insufficient)	1.0000	1.0000
Receptionist	1.0000	(Insufficient)	1.0000	1.0000
Trauma Bed	1.0000	(Insufficient)	1.0000	1.0000
Triage Bed	1.0000	(Insufficient)	1.0000	1.0000

Emergency Department

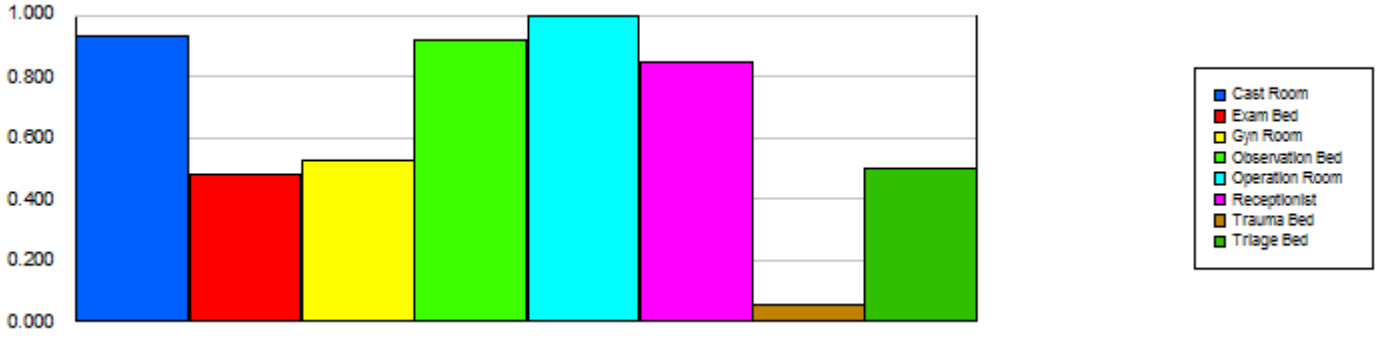
Replications: 1 Time Units: Minutes

Resource

Usage

Scheduled Utilization

	Value
Cast Room	0.9317
Exam Bed	0.4807
Gyn Room	0.5292
Observation Bed	0.9161
Operation Room	0.9983
Receptionist	0.8492
Trauma Bed	0.05405536
Triage Bed	0.4990



Emergency Department

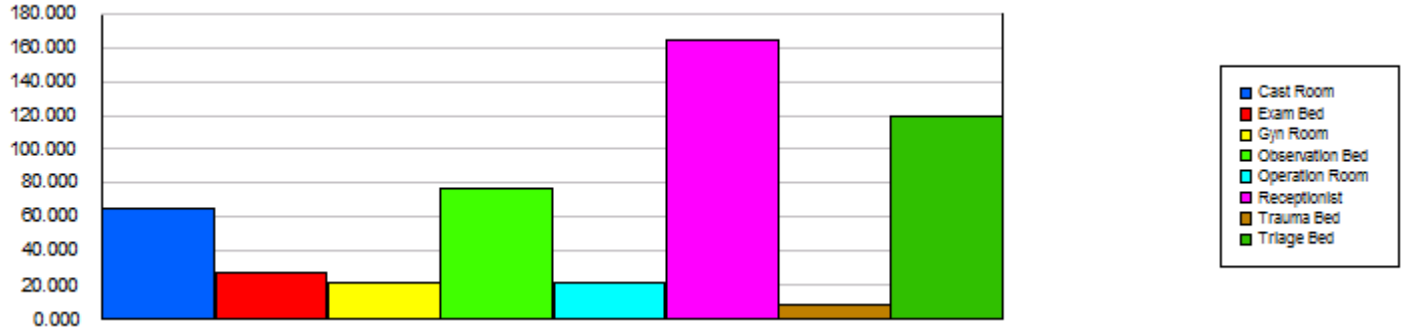
Replications: 1 Time Units: Minutes

Resource

Usage

Total Number Seized

	Value
Cast Room	65.0000
Exam Bed	28.0000
Gyn Room	22.0000
Observation Bed	77.0000
Operation Room	22.0000
Receptionist	164.00
Trauma Bed	9.0000
Triage Bed	120.00



Unnamed Project

Replications: 1 Time Units: Minutes

Unnamed Project

Replications: 1 Time Units: Minutes

Key Performance Indicators

System

	Average
Number Out	219

Unnamed Project

Replications: 1 Time Units: Minutes

Entity

Time

VA Time	Average	Half Width	Minimum Value	Maximum Value
Patient	76.8496	(Insufficient)	9.2501	217.61

NVA Time	Average	Half Width	Minimum Value	Maximum Value
Patient	0.00	(Insufficient)	0.00	0.00

Wait Time	Average	Half Width	Minimum Value	Maximum Value
Patient	12.2969	(Insufficient)	0.00	180.83

Transfer Time	Average	Half Width	Minimum Value	Maximum Value
Patient	0.00	(Insufficient)	0.00	0.00

Other Time	Average	Half Width	Minimum Value	Maximum Value
Patient	0.00	(Insufficient)	0.00	0.00

Total Time	Average	Half Width	Minimum Value	Maximum Value
Patient	89.1464	(Insufficient)	9.2501	372.71

Other

Number In	Value
Patient	226.00

Number Out	Value
Patient	219.00

WIP	Average	Half Width	Minimum Value	Maximum Value
Patient	6.9289	(Correlated)	0.00	19.0000

Unnamed Project

Replications: 1 Time Units: Minutes

Process

Time per Entity

VA Time Per Entity	Average	Half Width	Minimum Value	Maximum Value
Casting	19.7314	(Insufficient)	10.1524	29.5625
Examination and Treatment	24.8513	(Insufficient)	20.3239	29.9668
Gynecology	35.7421	(Insufficient)	25.7306	44.3925
MiniOperations	65.1770	(Insufficient)	46.4457	80.3970
Observation Room	109.95	(Insufficient)	70.1876	145.00
Reception	7.5628	(Insufficient)	5.0356	9.9933
Resuscitation	9.7495	(Insufficient)	6.8865	13.1523
Triage	6.1463	(Insufficient)	1.0000	14.0000

Wait Time Per Entity	Average	Half Width	Minimum Value	Maximum Value
Casting	7.0114	(Insufficient)	0.00	41.3816
Examination and Treatment	0.00	(Insufficient)	0.00	0.00
Gynecology	8.2005	(Insufficient)	0.00	58.8582
MiniOperations	29.9471	(Insufficient)	0.00	180.83
Observation Room	9.0728	(Insufficient)	0.00	89.9671
Reception	2.9855	(Insufficient)	0.00	25.1128
Resuscitation	0.00	(Insufficient)	0.00	0.00
Triage	0.00	(Insufficient)	0.00	0.00

Total Time Per Entity	Average	Half Width	Minimum Value	Maximum Value
Casting	26.7428	(Insufficient)	10.1524	63.0337
Examination and Treatment	24.8513	(Insufficient)	20.3239	29.9668
Gynecology	43.9426	(Insufficient)	30.4563	84.5888
MiniOperations	95.1242	(Insufficient)	46.4457	257.43
Observation Room	119.02	(Insufficient)	70.1876	214.69
Reception	10.5483	(Insufficient)	5.1823	31.2894
Resuscitation	9.7495	(Insufficient)	6.8865	13.1523
Triage	6.1463	(Insufficient)	1.0000	14.0000

Accumulated Time

Unnamed Project

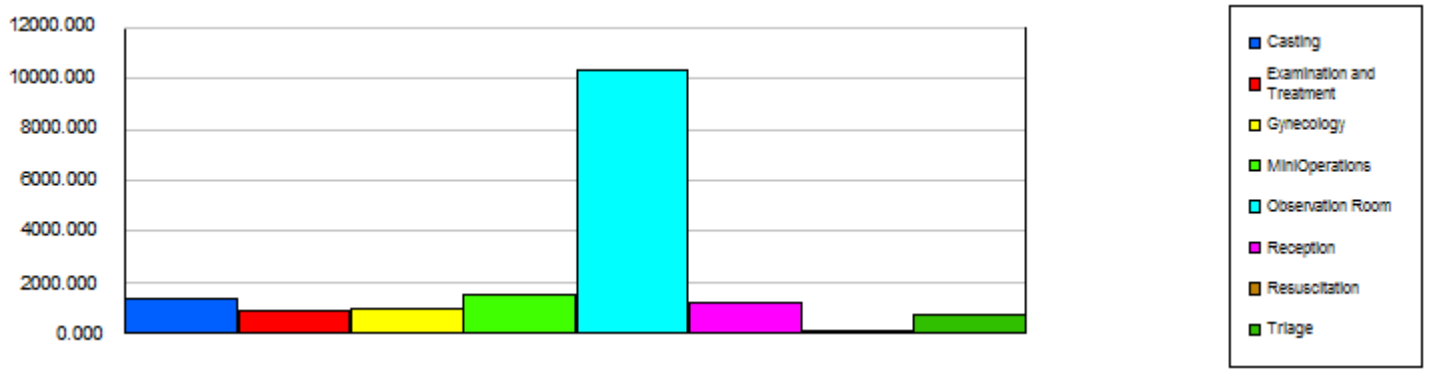
Replications: 1 Time Units: Minutes

Process

Accumulated Time

Accum VA Time

	Value
Casting	1341.74
Examination and Treatment	869.80
Gynecology	929.29
MiniOperations	1499.07
Observation Room	10335.42
Reception	1210.05
Resuscitation	97.4951
Triage	756.00



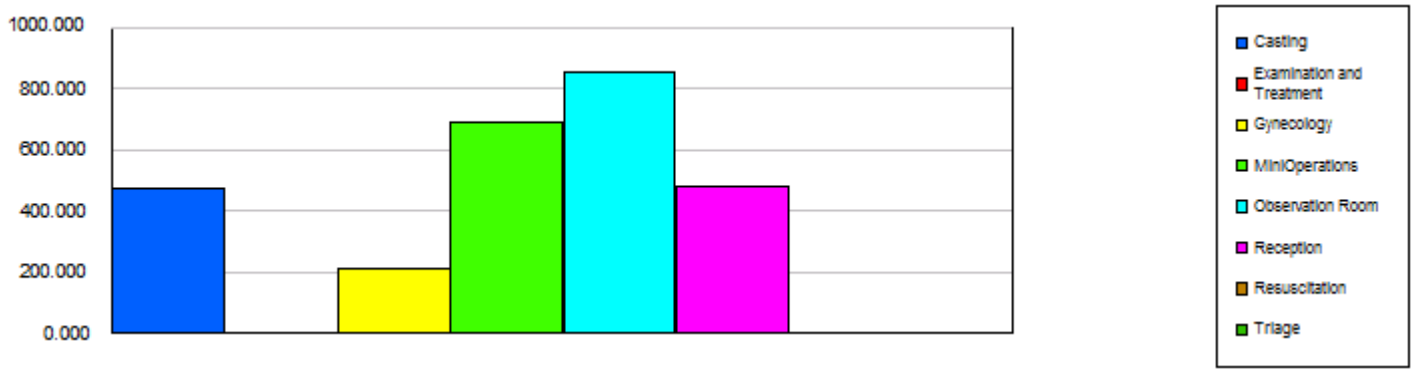
Unnamed Project

Replications: 1 Time Units: Minutes

Process

Accumulated Time

Accum Wait Time	Value
Casting	476.77
Examination and Treatment	0.00
Gynecology	213.21
MiniOperations	688.78
Observation Room	852.84
Reception	477.68
Resuscitation	0.00
Triage	0.00



Other

Unnamed Project

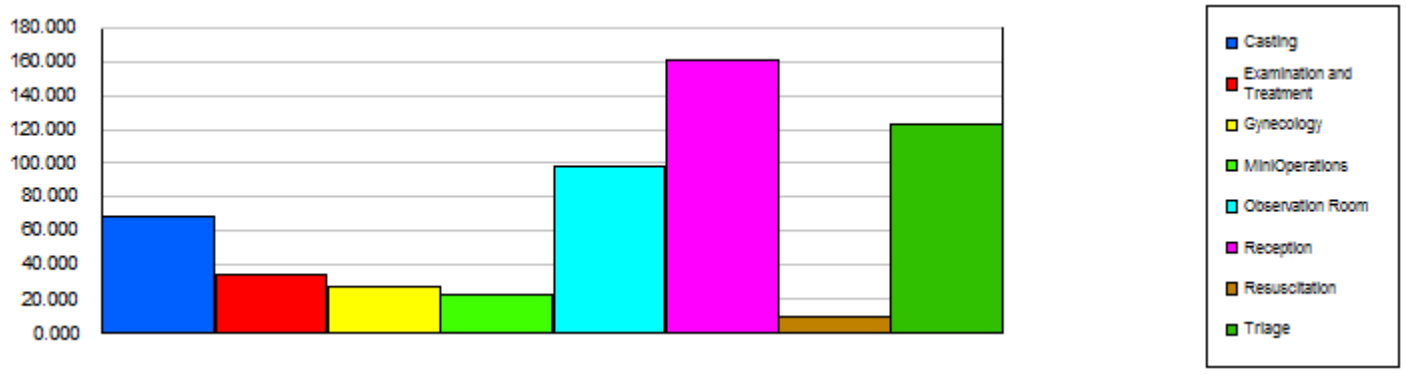
Replications: 1 Time Units: Minutes

Process

Other

Number In

	Value
Casting	69.0000
Examination and Treatment	35.0000
Gynecology	27.0000
MiniOperations	23.0000
Observation Room	98.0000
Reception	161.00
Resuscitation	10.0000
Triage	123.00



Number Out

	Value
Casting	68.0000
Examination and Treatment	35.0000
Gynecology	26.0000
MiniOperations	23.0000
Observation Room	94.0000
Reception	160.00
Resuscitation	10.0000
Triage	123.00

Unnamed Project

Replications: 1 Time Units: Minutes

Queue

Time

Waiting Time	Average	Half Width	Minimum Value	Maximum Value
Casting.Queue	6.9098	(Insufficient)	0.00	41.3816
Examination and Treatment.Queue	0.00	(Insufficient)	0.00	0.00
Gynecology.Queue	8.2656	(Insufficient)	0.00	58.8582
MiniOperations.Queue	29.9471	(Insufficient)	0.00	180.83
Observation Room.Queue	8.7025	(Insufficient)	0.00	89.9671
Reception.Queue	2.9669	(Insufficient)	0.00	25.1128
Resuscitation.Queue	0.00	(Insufficient)	0.00	0.00
Triage.Queue	0.00	(Insufficient)	0.00	0.00

Other

Number Waiting	Average	Half Width	Minimum Value	Maximum Value
Casting.Queue	0.1655	(Insufficient)	0.00	3.0000
Examination and Treatment.Queue	0.00	(Insufficient)	0.00	0.00
Gynecology.Queue	0.07749010	(Insufficient)	0.00	2.0000
MiniOperations.Queue	0.2392	(Insufficient)	0.00	3.0000
Observation Room.Queue	0.2961	(Insufficient)	0.00	5.0000
Reception.Queue	0.1659	(Insufficient)	0.00	4.0000
Resuscitation.Queue	0.00	(Insufficient)	0.00	0.00
Triage.Queue	0.00	(Insufficient)	0.00	0.00

Unnamed Project

Replications: 1 Time Units: Minutes

Resource

Usage

Instantaneous Utilization	Average	Half Width	Minimum Value	Maximum Value
Cast Room	0.4680	(Insufficient)	0.00	1.0000
Exam Bed	0.06040252	(Insufficient)	0.00	0.6000
Gyn Room	0.3307	(Insufficient)	0.00	1.0000
Observation Bed	0.6076	(Insufficient)	0.00	1.0000
Operation Room	0.5205	(Insufficient)	0.00	1.0000
Receptionist	0.4216	(Insufficient)	0.00	1.0000
Trauma Bed	0.01692624	(Insufficient)	0.00	0.5000
Triage Bed	0.06562500	(Insufficient)	0.00	0.5000

Number Busy	Average	Half Width	Minimum Value	Maximum Value
Cast Room	0.4680	(Insufficient)	0.00	1.0000
Exam Bed	0.3020	(Insufficient)	0.00	3.0000
Gyn Room	0.3307	(Insufficient)	0.00	1.0000
Observation Bed	3.6455	(Insufficient)	0.00	6.0000
Operation Room	0.5205	(Insufficient)	0.00	1.0000
Receptionist	0.4216	(Insufficient)	0.00	1.0000
Trauma Bed	0.03385248	(Insufficient)	0.00	1.0000
Triage Bed	0.2625	(Insufficient)	0.00	2.0000

Number Scheduled	Average	Half Width	Minimum Value	Maximum Value
Cast Room	1.0000	(Insufficient)	1.0000	1.0000
Exam Bed	5.0000	(Insufficient)	5.0000	5.0000
Gyn Room	1.0000	(Insufficient)	1.0000	1.0000
Observation Bed	6.0000	(Insufficient)	6.0000	6.0000
Operation Room	1.0000	(Insufficient)	1.0000	1.0000
Receptionist	1.0000	(Insufficient)	1.0000	1.0000
Trauma Bed	2.0000	(Insufficient)	2.0000	2.0000
Triage Bed	4.0000	(Insufficient)	4.0000	4.0000

Unnamed Project

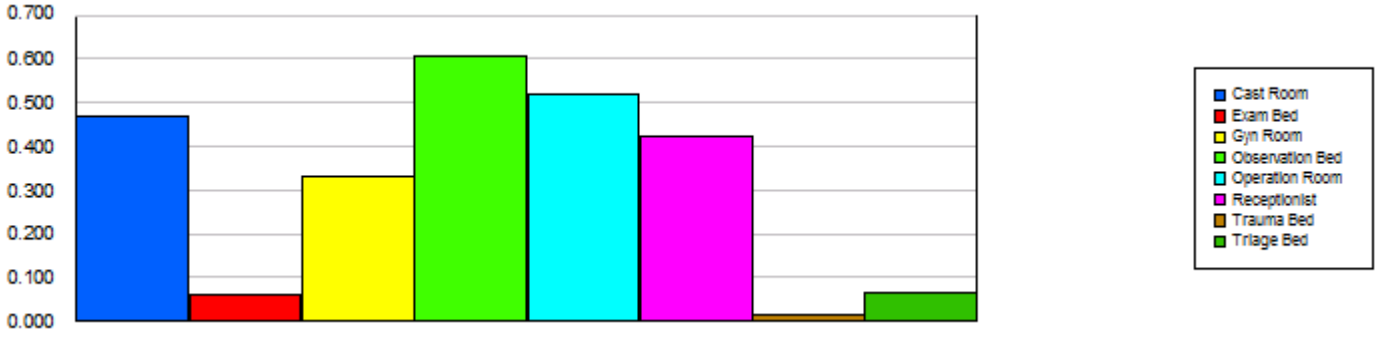
Replications: 1 Time Units: Minutes

Resource

Usage

Scheduled Utilization

	Value
Cast Room	0.4680
Exam Bed	0.06040252
Gyn Room	0.3307
Observation Bed	0.6076
Operation Room	0.5205
Receptionist	0.4216
Trauma Bed	0.01692624
Triage Bed	0.06562500



Unnamed Project

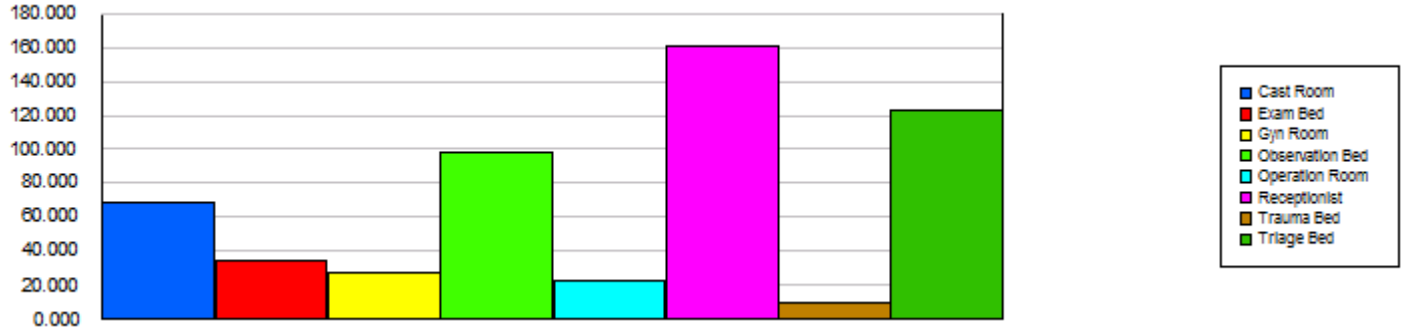
Replications: 1 Time Units: Minutes

Resource

Usage

Total Number Seized

	Value
Cast Room	69.0000
Exam Bed	35.0000
Gyn Room	27.0000
Observation Bed	98.0000
Operation Room	23.0000
Receptionist	161.00
Trauma Bed	10.0000
Triage Bed	123.00



Emergency Department

Replications: 1 Time Units: Minutes

Key Performance Indicators

System

	Average
Number Out	96

Emergency Department

Replications: 1 Time Units: Minutes

Entity

Time

VA Time	Average	Half Width	Minimum Value	Maximum Value
Patient	77.3941	(Insufficient)	7.8685	202.36

NVA Time	Average	Half Width	Minimum Value	Maximum Value
Patient	0.00	(Insufficient)	0.00	0.00

Wait Time	Average	Half Width	Minimum Value	Maximum Value
Patient	5.9457	(Insufficient)	0.00	67.1985

Transfer Time	Average	Half Width	Minimum Value	Maximum Value
Patient	0.00	(Insufficient)	0.00	0.00

Other Time	Average	Half Width	Minimum Value	Maximum Value
Patient	0.00	(Insufficient)	0.00	0.00

Total Time	Average	Half Width	Minimum Value	Maximum Value
Patient	83.3398	(Insufficient)	7.8685	230.27

Other

Number In	Value
Patient	103.00

Number Out	Value
Patient	96.0000

WIP	Average	Half Width	Minimum Value	Maximum Value
Patient	5.9641	(Insufficient)	0.00	12.0000

Emergency Department

Replications: 1 Time Units: Minutes

Process

Time per Entity

VA Time Per Entity	Average	Half Width	Minimum Value	Maximum Value
Casting	20.0584	(Insufficient)	10.1751	29.5625
Examination and Treatment	23.0605	(Insufficient)	20.2701	29.9355
Gynecology	36.3040	(Insufficient)	30.3872	42.0219
MiniOperations	60.4965	(Insufficient)	46.4457	75.9283
Observation Room	110.25	(Insufficient)	67.7640	137.32
Reception	7.2505	(Insufficient)	5.2293	9.9933
Resuscitation	8.7873	(Insufficient)	7.5729	11.0759
Triage	6.0000	(Insufficient)	1.0000	14.0000

Wait Time Per Entity	Average	Half Width	Minimum Value	Maximum Value
Casting	6.4826	(Insufficient)	0.00	41.8329
Examination and Treatment	2.7399	(Insufficient)	0.00	20.5042
Gynecology	4.9828	(Insufficient)	0.00	23.4602
MiniOperations	23.9918	(Insufficient)	0.00	108.56
Observation Room	1.0994	(Insufficient)	0.00	22.1573
Reception	1.0744	(Insufficient)	0.00	8.9112
Resuscitation	0.8196	(Insufficient)	0.00	5.7375
Triage	0.1354	(Insufficient)	0.00	3.3286

Total Time Per Entity	Average	Half Width	Minimum Value	Maximum Value
Casting	26.5410	(Insufficient)	10.9857	61.2927
Examination and Treatment	25.8003	(Insufficient)	20.3239	40.7744
Gynecology	41.2867	(Insufficient)	30.3872	58.7931
MiniOperations	84.4883	(Insufficient)	46.4457	171.91
Observation Room	111.35	(Insufficient)	67.7640	137.32
Reception	8.3248	(Insufficient)	5.2293	15.6643
Resuscitation	9.6069	(Insufficient)	7.5729	16.8134
Triage	6.1354	(Insufficient)	1.0000	14.0000

Accumulated Time

Emergency Department

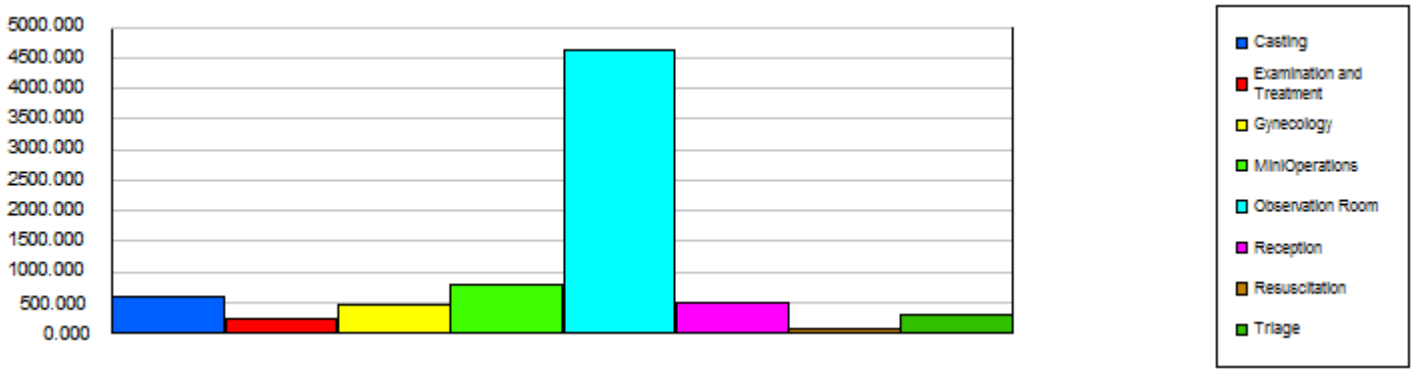
Replications: 1 Time Units: Minutes

Process

Accumulated Time

Accum VA Time

	Value
Casting	601.75
Examination and Treatment	230.60
Gynecology	471.95
MiniOperations	786.45
Observation Room	4630.60
Reception	507.53
Resuscitation	61.5110
Triage	294.00



Emergency Department

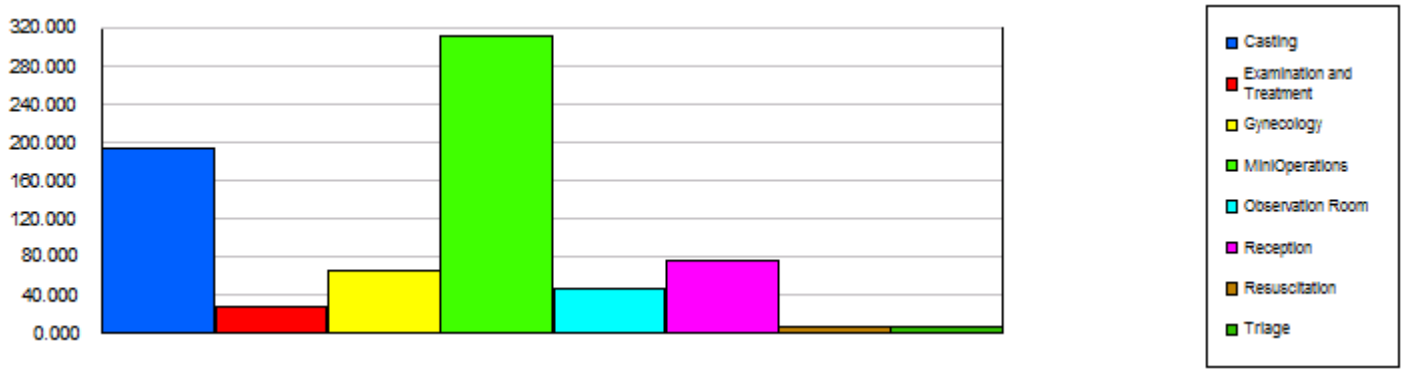
Replications: 1 Time Units: Minutes

Process

Accumulated Time

Accum Wait Time

	Value
Casting	194.48
Examination and Treatment	27.3988
Gynecology	64.7760
MiniOperations	311.89
Observation Room	46.1761
Reception	75.2068
Resuscitation	5.7375
Triage	6.6336



Other

Emergency Department

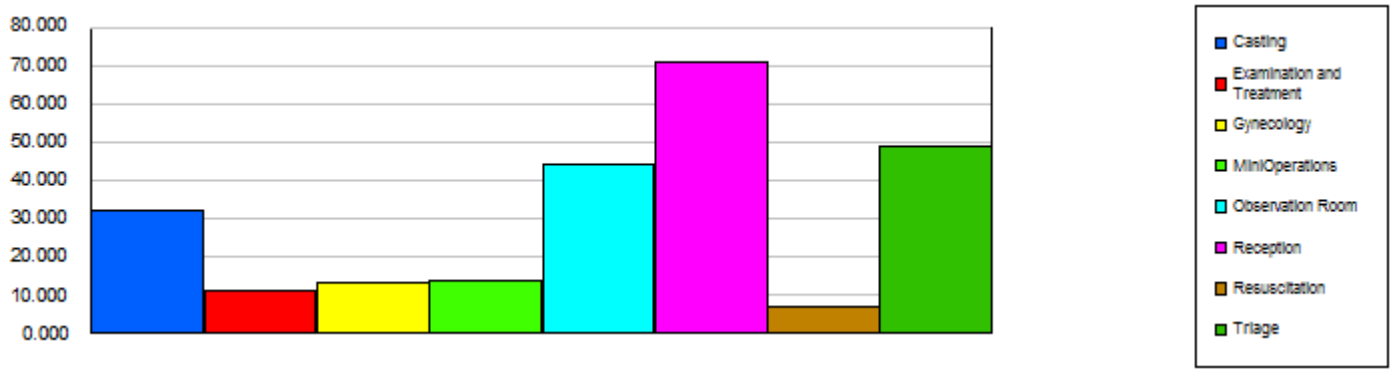
Replications: 1 Time Units: Minutes

Process

Other

Number In

	Value
Casting	32.0000
Examination and Treatment	11.0000
Gynecology	13.0000
MiniOperations	14.0000
Observation Room	44.0000
Reception	71.0000
Resuscitation	7.0000
Triage	49.0000



Number Out

	Value
Casting	30.0000
Examination and Treatment	10.0000
Gynecology	13.0000
MiniOperations	13.0000
Observation Room	42.0000
Reception	70.0000
Resuscitation	7.0000
Triage	49.0000

Emergency Department

Replications: 1 Time Units: Minutes

Queue

Time

Waiting Time	Average	Half Width	Minimum Value	Maximum Value
Casting.Queue	6.2735	(Insufficient)	0.00	41.8329
Examination and Treatment.Queue	2.4908	(Insufficient)	0.00	20.5042
Gynecology.Queue	4.9828	(Insufficient)	0.00	23.4602
MiniOperations.Queue	33.8374	(Insufficient)	0.00	161.83
Observation Room.Queue	1.0495	(Insufficient)	0.00	22.1573
Reception.Queue	1.0593	(Insufficient)	0.00	8.9112
Resuscitation.Queue	0.8196	(Insufficient)	0.00	5.7375
Triage.Queue	0.1354	(Insufficient)	0.00	3.3286

Other

Number Waiting	Average	Half Width	Minimum Value	Maximum Value
Casting.Queue	0.1370	(Insufficient)	0.00	2.0000
Examination and Treatment.Queue	0.01902696	(Insufficient)	0.00	1.0000
Gynecology.Queue	0.04498331	(Insufficient)	0.00	1.0000
MiniOperations.Queue	0.3290	(Insufficient)	0.00	3.0000
Observation Room.Queue	0.03206677	(Insufficient)	0.00	2.0000
Reception.Queue	0.05222692	(Insufficient)	0.00	2.0000
Resuscitation.Queue	0.00398435	(Insufficient)	0.00	1.0000
Triage.Queue	0.00460668	(Insufficient)	0.00	1.0000

Emergency Department

Replications: 1 Time Units: Minutes

Resource

Usage

Instantaneous Utilization	Average	Half Width	Minimum Value	Maximum Value
Cast Room	0.4247	(Insufficient)	0.00	1.0000
Exam Bed	0.1692	(Insufficient)	0.00	1.0000
Gyn Room	0.3277	(Insufficient)	0.00	1.0000
Observation Bed	0.5448	(Insufficient)	0.00	1.0000
Operation Room	0.5506	(Insufficient)	0.00	1.0000
Receptionist	0.3537	(Insufficient)	0.00	1.0000
Trauma Bed	0.04271595	(Insufficient)	0.00	1.0000
Triage Bed	0.2042	(Insufficient)	0.00	1.0000

Number Busy	Average	Half Width	Minimum Value	Maximum Value
Cast Room	0.4247	(Insufficient)	0.00	1.0000
Exam Bed	0.1692	(Insufficient)	0.00	1.0000
Gyn Room	0.3277	(Insufficient)	0.00	1.0000
Observation Bed	3.2685	(Insufficient)	0.00	6.0000
Operation Room	0.5506	(Insufficient)	0.00	1.0000
Receptionist	0.3537	(Insufficient)	0.00	1.0000
Trauma Bed	0.04271595	(Insufficient)	0.00	1.0000
Triage Bed	0.2042	(Insufficient)	0.00	1.0000

Number Scheduled	Average	Half Width	Minimum Value	Maximum Value
Cast Room	1.0000	(Insufficient)	1.0000	1.0000
Exam Bed	1.0000	(Insufficient)	1.0000	1.0000
Gyn Room	1.0000	(Insufficient)	1.0000	1.0000
Observation Bed	6.0000	(Insufficient)	6.0000	6.0000
Operation Room	1.0000	(Insufficient)	1.0000	1.0000
Receptionist	1.0000	(Insufficient)	1.0000	1.0000
Trauma Bed	1.0000	(Insufficient)	1.0000	1.0000
Triage Bed	1.0000	(Insufficient)	1.0000	1.0000

Emergency Department

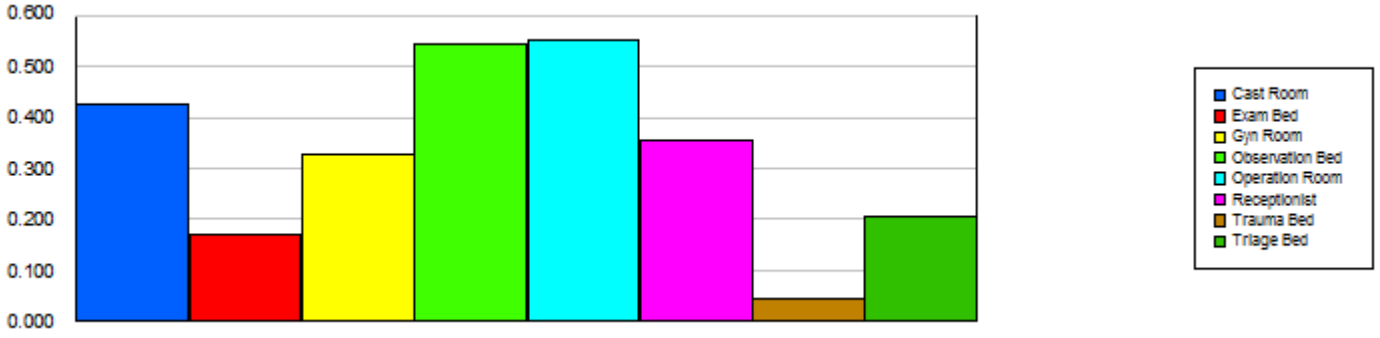
Replications: 1 Time Units: Minutes

Resource

Usage

Scheduled Utilization

	Value
Cast Room	0.4247
Exam Bed	0.1692
Gyn Room	0.3277
Observation Bed	0.5448
Operation Room	0.5506
Receptionist	0.3537
Trauma Bed	0.04271595
Triage Bed	0.2042



Emergency Department

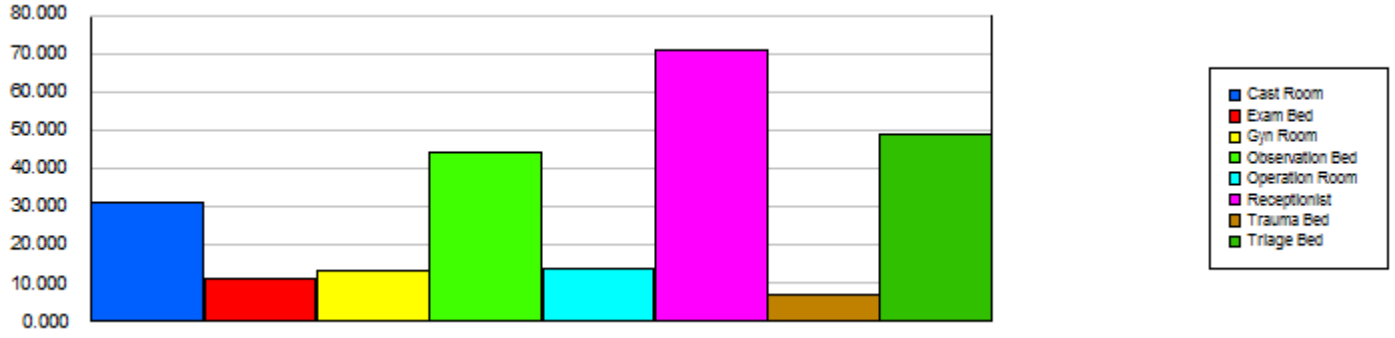
Replications: 1 Time Units: Minutes

Resource

Usage

Total Number Seized

	Value
Cast Room	31.0000
Exam Bed	11.0000
Gyn Room	13.0000
Observation Bed	44.0000
Operation Room	14.0000
Receptionist	71.0000
Trauma Bed	7.0000
Triage Bed	49.0000



Unnamed Project

Replications: 1 Time Units: Minutes

Emergency Department

Replications: 1 Time Units: Minutes

Key Performance Indicators

System

	Average
Number Out	97

Emergency Department

Replications: 1 Time Units: Minutes

Entity

Time

VA Time	Average	Half Width	Minimum Value	Maximum Value
Patient	85.0929	(Insufficient)	9.6523	204.23

NVA Time	Average	Half Width	Minimum Value	Maximum Value
Patient	0.00	(Insufficient)	0.00	0.00

Wait Time	Average	Half Width	Minimum Value	Maximum Value
Patient	9.4733	(Insufficient)	0.00	109.99

Transfer Time	Average	Half Width	Minimum Value	Maximum Value
Patient	0.00	(Insufficient)	0.00	0.00

Other Time	Average	Half Width	Minimum Value	Maximum Value
Patient	0.00	(Insufficient)	0.00	0.00

Total Time	Average	Half Width	Minimum Value	Maximum Value
Patient	94.5662	(Insufficient)	10.6759	313.75

Other

Number In	Value
Patient	102.00

Number Out	Value
Patient	97.0000

WIP	Average	Half Width	Minimum Value	Maximum Value
Patient	6.7249	(Insufficient)	0.00	13.0000

Emergency Department

Replications: 1 Time Units: Minutes

Process

Time per Entity

VA Time Per Entity	Average	Half Width	Minimum Value	Maximum Value
Casting	19.9584	(Insufficient)	10.9451	29.6723
Examination and Treatment	26.2332	(Insufficient)	21.8097	29.9668
Gynecology	33.6398	(Insufficient)	28.7321	44.7789
MiniOperations	63.6393	(Insufficient)	52.9946	80.6328
Observation Room	112.79	(Insufficient)	66.8753	144.99
Reception	7.2807	(Insufficient)	5.1548	9.9709
Resuscitation	9.5060	(Insufficient)	7.4934	13.0440
Triage	6.5577	(Insufficient)	1.0000	12.0000

Wait Time Per Entity	Average	Half Width	Minimum Value	Maximum Value
Casting	5.3134	(Insufficient)	0.00	34.9629
Examination and Treatment	0.7714	(Insufficient)	0.00	10.0286
Gynecology	4.7824	(Insufficient)	0.00	39.2287
MiniOperations	34.8423	(Insufficient)	0.00	109.99
Observation Room	1.6661	(Insufficient)	0.00	38.8417
Reception	2.7130	(Insufficient)	0.00	16.5569
Resuscitation	0.00	(Insufficient)	0.00	0.00
Triage	0.1769	(Insufficient)	0.00	2.7622

Total Time Per Entity	Average	Half Width	Minimum Value	Maximum Value
Casting	25.2718	(Insufficient)	10.9451	55.5592
Examination and Treatment	27.0046	(Insufficient)	21.8097	39.1644
Gynecology	38.4222	(Insufficient)	28.7321	77.6068
MiniOperations	98.4816	(Insufficient)	55.4766	172.43
Observation Room	114.46	(Insufficient)	66.8753	156.55
Reception	9.9937	(Insufficient)	5.1548	24.6636
Resuscitation	9.5060	(Insufficient)	7.4934	13.0440
Triage	6.7346	(Insufficient)	1.0000	12.0000

Accumulated Time

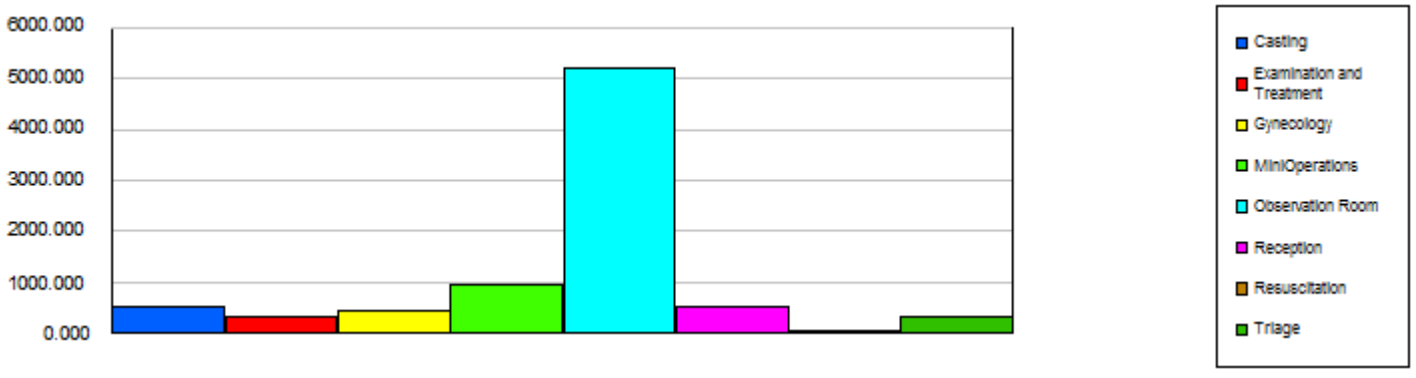
Emergency Department

Replications: 1 Time Units: Minutes

Process

Accumulated Time

Accum VA Time	Value
Casting	538.88
Examination and Treatment	341.03
Gynecology	437.32
MiniOperations	954.59
Observation Room	5188.57
Reception	509.65
Resuscitation	66.5419
Triage	341.00



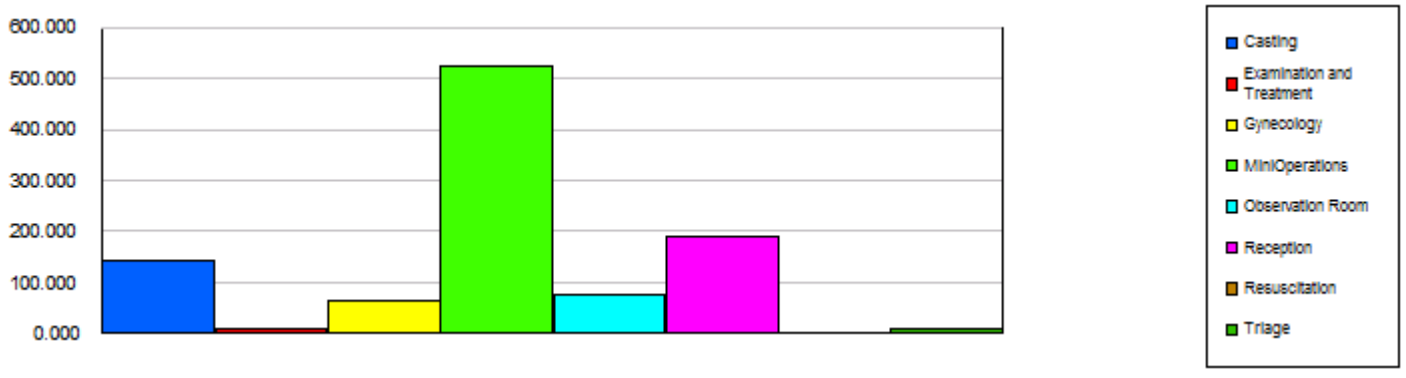
Emergency Department

Replications: 1 Time Units: Minutes

Process

Accumulated Time

Accum Wait Time	Value
Casting	143.46
Examination and Treatment	10.0286
Gynecology	62.1716
MiniOperations	522.63
Observation Room	76.6428
Reception	189.91
Resuscitation	0.00
Triage	9.2013



Other

Emergency Department

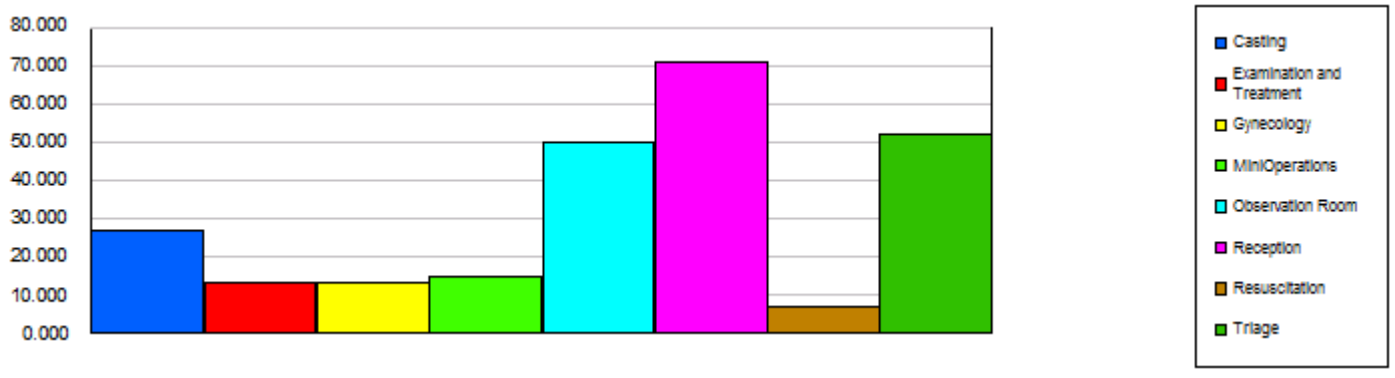
Replications: 1 Time Units: Minutes

Process

Other

Number In

	Value
Casting	27.0000
Examination and Treatment	13.0000
Gynecology	13.0000
MiniOperations	15.0000
Observation Room	50.0000
Reception	71.0000
Resuscitation	7.0000
Triage	52.0000



Number Out

	Value
Casting	27.0000
Examination and Treatment	13.0000
Gynecology	13.0000
MiniOperations	15.0000
Observation Room	46.0000
Reception	70.0000
Resuscitation	7.0000
Triage	52.0000

Emergency Department

Replications: 1 Time Units: Minutes

Queue

Time

Waiting Time	Average	Half Width	Minimum Value	Maximum Value
Casting.Queue	5.3134	(Insufficient)	0.00	34.9629
Examination and Treatment.Queue	0.7714	(Insufficient)	0.00	10.0286
Gynecology.Queue	4.7824	(Insufficient)	0.00	39.2287
MiniOperations.Queue	34.8423	(Insufficient)	0.00	109.99
Observation Room.Queue	1.5329	(Insufficient)	0.00	38.8417
Reception.Queue	2.6748	(Insufficient)	0.00	16.5569
Resuscitation.Queue	0.00	(Insufficient)	0.00	0.00
Triage.Queue	0.1769	(Insufficient)	0.00	2.7622

Other

Number Waiting	Average	Half Width	Minimum Value	Maximum Value
Casting.Queue	0.0996	(Insufficient)	0.00	2.0000
Examination and Treatment.Queue	0.00696428	(Insufficient)	0.00	1.0000
Gynecology.Queue	0.04317475	(Insufficient)	0.00	1.0000
MiniOperations.Queue	0.3629	(Insufficient)	0.00	2.0000
Observation Room.Queue	0.05322418	(Insufficient)	0.00	2.0000
Reception.Queue	0.1319	(Insufficient)	0.00	3.0000
Resuscitation.Queue	0.00	(Insufficient)	0.00	0.00
Triage.Queue	0.00638976	(Insufficient)	0.00	1.0000

Emergency Department

Replications: 1 Time Units: Minutes

Resource

Usage

Instantaneous Utilization	Average	Half Width	Minimum Value	Maximum Value
Cast Room	0.3742	(Insufficient)	0.00	1.0000
Exam Bed	0.2368	(Insufficient)	0.00	1.0000
Gyn Room	0.3037	(Insufficient)	0.00	1.0000
Observation Bed	0.6339	(Insufficient)	0.00	1.0000
Operation Room	0.6629	(Insufficient)	0.00	1.0000
Receptionist	0.3568	(Insufficient)	0.00	1.0000
Trauma Bed	0.04620967	(Insufficient)	0.00	1.0000
Triage Bed	0.2368	(Insufficient)	0.00	1.0000

Number Busy	Average	Half Width	Minimum Value	Maximum Value
Cast Room	0.3742	(Insufficient)	0.00	1.0000
Exam Bed	0.2368	(Insufficient)	0.00	1.0000
Gyn Room	0.3037	(Insufficient)	0.00	1.0000
Observation Bed	3.8033	(Insufficient)	0.00	6.0000
Operation Room	0.6629	(Insufficient)	0.00	1.0000
Receptionist	0.3568	(Insufficient)	0.00	1.0000
Trauma Bed	0.04620967	(Insufficient)	0.00	1.0000
Triage Bed	0.2368	(Insufficient)	0.00	1.0000

Number Scheduled	Average	Half Width	Minimum Value	Maximum Value
Cast Room	1.0000	(Insufficient)	1.0000	1.0000
Exam Bed	1.0000	(Insufficient)	1.0000	1.0000
Gyn Room	1.0000	(Insufficient)	1.0000	1.0000
Observation Bed	6.0000	(Insufficient)	6.0000	6.0000
Operation Room	1.0000	(Insufficient)	1.0000	1.0000
Receptionist	1.0000	(Insufficient)	1.0000	1.0000
Trauma Bed	1.0000	(Insufficient)	1.0000	1.0000
Triage Bed	1.0000	(Insufficient)	1.0000	1.0000

Emergency Department

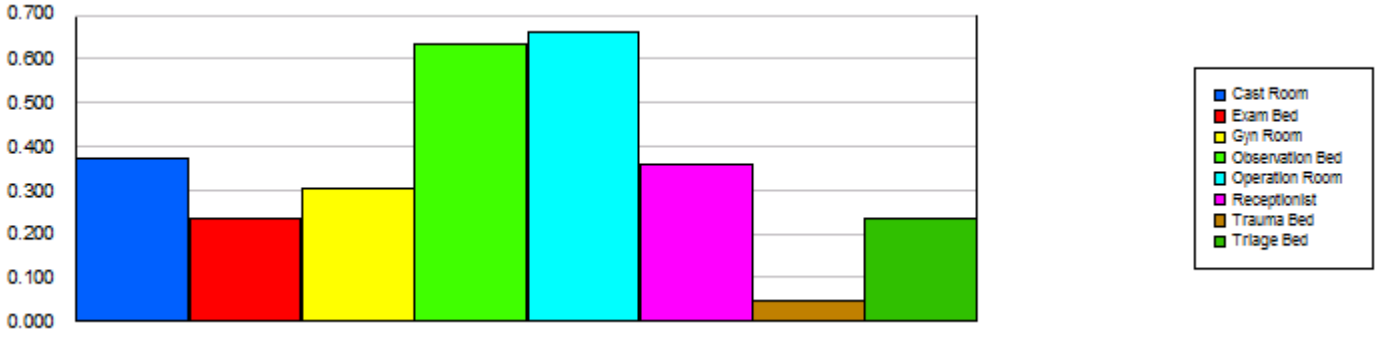
Replications: 1 Time Units: Minutes

Resource

Usage

Scheduled Utilization

	Value
Cast Room	0.3742
Exam Bed	0.2368
Gyn Room	0.3037
Observation Bed	0.6339
Operation Room	0.6629
Receptionist	0.3568
Trauma Bed	0.04620967
Triage Bed	0.2368



Emergency Department

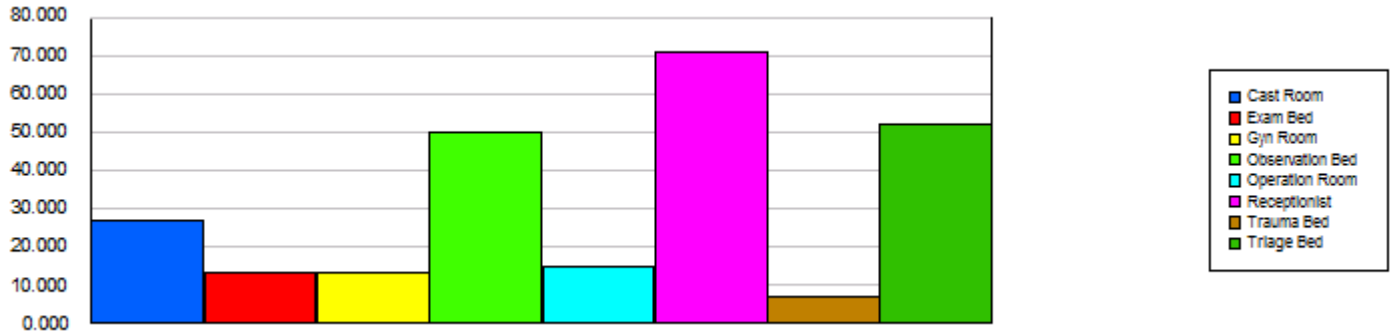
Replications: 1 Time Units: Minutes

Resource

Usage

Total Number Seized

	Value
Cast Room	27.0000
Exam Bed	13.0000
Gyn Room	13.0000
Observation Bed	50.0000
Operation Room	15.0000
Receptionist	71.0000
Trauma Bed	7.0000
Triage Bed	52.0000



Unnamed Project

Replications: 1 Time Units: Minutes

Appendix F: Regression Models

Appendix G: Optimization Model

Appendix H: Optimization Reports

Worksheet: [Optimization Several Runs.xlsx]Optimization
Report Created: 1/3/2012 9:17:29 PM
Result: Solver cannot improve the current solution. All Constraints are satisfied.
Solver Engine
Engine: Evolutionary
Solution Time: 43.54 Seconds.
Iterations: 0 Subproblems: 19685
Solver Options
Max Time 1000 sec, Iterations 1000, Precision 0.000001
Convergence 0.0001, Population Size 100, Random Seed 0, Mutation Rate 0.075, Time w/o Improve 30 sec, Require Bounds
Max Subproblems Unlimited, Max Integer Sols Unlimited, Integer Tolerance 5%, Assume NonNegative

Objective Cell (Min)

Cell	Name	Original Value	Final Value
$D$4	Arrival Rate	0.00	0.00

Variable Cells

Cell	Name	Original Value	Final Value	Integer
$F$3	AR C Res	1.00	1.20	Contin
$H$3	AR E Res	5.14	5.46	Contin
$J$3	AR G Res	1.00	2.04	Contin
$L$3	AR Ob Res	6.18	1.95	Contin
$N$3	AR Op Res	1.00	1.80	Contin
$P$3	AR R Res	1.01	1.93	Contin
$R$3	AR Re Res	4.29	5.41	Contin
$T$3	AR T Res	5.60	4.40	Contin

Constraints

Cell	Name	Cell Value	Formula	Status	Slack
$B$7	AREA	417.60	$B$7<=$D$7	Not Binding	582.3956837
$D$3	AR Arrival Rate	12.99	$D$3=$B$3	Binding	0
$B$9	WT	120.18	$B$9<=$D$9	Not Binding	119.816276
$B$8	COST	5,268,285	$B$8<=$D$8	Not Binding	4731715.171
$D$3	AR Arrival Rate	12.99	$D$3>=0	Not Binding	12.99
$T$3	AR T Res	4.40	$T$3<=$T$5	Not Binding	4.596455263

$R$3	AR Re Res	5.41	$R$3>=1	Not Binding	4.41
$T$3	AR T Res	4.40	$T$3>=1	Not Binding	3.40
$R$3	AR Re Res	5.41	$R$3<=$R$5	Not Binding	3.592616178
$P$3	AR R Res	1.93	$P$3>=1	Not Binding	0.93
$P$3	AR R Res	1.93	$P$3<=$P$5	Not Binding	1.073457156
$N$3	AR Op Res	1.80	$N$3>=1	Not Binding	0.80
$N$3	AR Op Res	1.80	$N$3<=$N$5	Not Binding	0.203376892
$J$3	AR G Res	2.04	$J$3<=$J$5	Not Binding	0.955314408
$L$3	AR Ob Res	1.95	$L$3<=$L$5	Not Binding	7.047725115
$J$3	AR G Res	2.04	$J$3>=1	Not Binding	1.04
$L$3	AR Ob Res	1.95	$L$3>=1	Not Binding	0.95
$H$3	AR E Res	5.46	$H$3<=$H$5	Not Binding	3.54403763
$H$3	AR E Res	5.46	$H$3>=1	Not Binding	4.46
$F$3	AR C Res	1.20	$F$3>=1	Not Binding	0.20
$F$3	AR C Res	1.20	$F$3<=$F$5	Not Binding	1.798840894

Microsoft Excel 14.0 Population Report
Worksheet: [Optimization Several Runs.xlsx]Optimization
Report Created: 1/3/2012 9:08:11 PM

Variable Cells

Cell	Name	Best Value	Mean Value	Standard Deviation	Maximum Value	Minimum Value
$F$3	AR C Res	2.45	2.45	0.000874735	2.453200476	2.448244298
$H$3	AR E Res	5.19	5.19	0.000143289	5.187533756	5.185931958
$J$3	AR G Res	2.11	2.11	0.002585732	2.112403801	2.095481947
$L$3	AR Ob Res	1.00	1.01	0.045221175	1.439094789	1
$N$3	AR Op Res	2.00	2.00	0.000500113	2	1.995303914
$P$3	AR R Res	1.07	1.05	0.023850157	1.142200017	1
$R$3	AR Re Res	4.83	4.83	0.000136058	4.832242675	4.831654459
$T$3	AR T Res	1.00	1.03	0.059434518	1.595179445	1

Constraints

Cell	Name	Best Value	Mean Value	Standard Deviation	Maximum Value	Minimum Value
$B$7	AREA	412.88	413.26	1.155143962	424.2344514	412.6709205
$D$3	AR Arrival Rate	13.99	13.99	0.002425689	14.00194346	13.98503564
$B$9	WT	131.27	131.14	1.036350941	131.2874943	121.2003713
$B$8	COST	5,078,884	5,082,371	11886.77747	5195459.979	5076569.199
$D$3	AR Arrival Rate	13.99	13.99	0.002425689	14.00194346	13.98503564

Microsoft Excel 14.0 Answer Report
Worksheet: [Optimization Several Runs.xlsx]Optimization
Report Created: 1/3/2012 9:08:11 PM
Result: Solver has converged to the current solution. All Constraints are satisfied.
Solver Engine
Engine: Evolutionary
Solution Time: 11.388 Seconds.
Iterations: 0 Subproblems: 5780
Solver Options
Max Time 1000 sec, Iterations 1000, Precision 0.000001
Convergence 0.0001, Population Size 100, Random Seed 0, Mutation Rate 0.075, Time w/o Improve 30 sec, Require Bounds
Max Subproblems Unlimited, Max Integer Sols Unlimited, Integer Tolerance 5%, Assume NonNegative

Objective Cell (Min)

Cell	Name	Original Value	Final Value
$D$4	Arrival Rate	0.00	0.00

Variable Cells

Cell	Name	Original Value	Final Value	Integer
$F$3	AR C Res	2.46	2.45	Contin
$H$3	AR E Res	5.19	5.19	Contin
$J$3	AR G Res	2.11	2.11	Contin
$L$3	AR Ob Res	1.89	1.00	Contin
$N$3	AR Op Res	2.00	2.00	Contin
$P$3	AR R Res	1.27	1.07	Contin
$R$3	AR Re Res	4.84	4.83	Contin
$T$3	AR T Res	2.19	1.00	Contin

Constraints

Cell	Name	Cell Value	Formula	Status	Slack
$B$7	AREA	412.88	$B$7<=$D$7	Not Binding	587.1230013
$D$3	AR Arrival Rate	13.99	$D$3>=0	Not Binding	13.99
$B$9	WT	131.27	$B$9<=$D$9	Not Binding	108.734292
$B$8	COST	5,078,884	$B$8<=$D$8	Not Binding	4921116.366
$D$3	AR Arrival Rate	13.99	$D$3=$B$3	Binding	0
$T$3	AR T Res	1.00	$T$3>=1	Not Binding	0.00
$R$3	AR Re Res	4.83	$R$3>=1	Not Binding	3.83
$T$3	AR T Res	1.00	$T$3<=$T$5	Not Binding	7.997834024

$R$3	AR Re Res	4.83	$R$3<=$R$5	Not Binding	4.168196144
$P$3	AR R Res	1.07	$P$3>=1	Not Binding	0.07
$P$3	AR R Res	1.07	$P$3<=$P$5	Not Binding	1.933557627
$F$3	AR C Res	2.45	$F$3<=$F$5	Not Binding	0.547461215
$F$3	AR C Res	2.45	$F$3>=1	Not Binding	1.45
$H$3	AR E Res	5.19	$H$3<=$H$5	Not Binding	3.813119982
$L$3	AR Ob Res	1.00	$L$3>=1	Not Binding	0.00
$J$3	AR G Res	2.11	$J$3>=1	Not Binding	1.11
$J$3	AR G Res	2.11	$J$3<=$J$5	Not Binding	0.894085243
$N$3	AR Op Res	2.00	$N$3<=$N$5	Not Binding	0.002059837
$N$3	AR Op Res	2.00	$N$3>=1	Not Binding	1.00
$H$3	AR E Res	5.19	$H$3>=1	Not Binding	4.19
$L$3	AR Ob Res	1.00	$L$3<=$L$5	Not Binding	7.99895464

Microsoft Excel 14.0 Population Report
Worksheet: [Optimization Several Runs.xlsx]Optimization
Report Created: 1/3/2012 9:13:53 PM

Variable Cells

Cell	Name	Best Value	Mean Value	Standard Deviation	Maximum Value	Minimum Value
$F$3	AR C Res	1.00	1.01	0.034771377	1.307843512	1
$H$3	AR E Res	5.14	5.14	0.001729187	5.135818562	5.120390632
$J$3	AR G Res	1.00	1.01	0.005045076	1.048684955	1.002997239
$L$3	AR Ob Res	6.18	6.18	0.006704213	6.185741511	6.125598242
$N$3	AR Op Res	1.00	1.00	0.00935063	1.082536657	1
$P$3	AR R Res	1.01	1.01	0.03095195	1.289369722	1
$R$3	AR Re Res	4.29	4.29	0.002874217	4.292694525	4.266918716
$T$3	AR T Res	5.60	5.59	0.094062824	5.607110077	4.770261784

Constraints

Cell	Name	Best Value	Mean Value	Standard Deviation	Maximum Value	Minimum Value
$B$8	COST	4,529,426	4,531,212	8348.130154	4601585.884	4529230.341
$D$3	AR Arrival Rate	14.98	14.98	0.002446713	15.00572832	14.98393424
$D$3	AR Arrival Rate	14.98	14.98	0.002446713	15.00572832	14.98393424
$B$9	WT	34.94	34.91	0.210956498	34.94385999	33.09385262
$B$7	AREA	371.12	371.31	0.727350241	377.3870602	371.119013

Microsoft Excel 14.0 Answer Report
Worksheet: [Optimization Several Runs.xlsx]Optimization
Report Created: 1/3/2012 9:13:53 PM
Result: Solver cannot improve the current solution. All Constraints are satisfied.
Solver Engine

Engine: Evolutionary
Solution Time: 53.43 Seconds.
Iterations: 0 Subproblems: 40477

Solver Options

Max Time 1000 sec, Iterations 1000, Precision 0.000001
Convergence 0.0001, Population Size 100, Random Seed 0, Mutation Rate 0.075, Time w/o Improve 30 sec, Require Bounds
Max Subproblems Unlimited, Max Integer Sols Unlimited, Integer Tolerance 5%, Assume NonNegative

Objective Cell (Min)

Cell	Name	Original Value	Final Value
$D$4	Arrival Rate	0.00	0.00

Variable Cells

Cell	Name	Original Value	Final Value	Integer
$F$3	AR C Res	2.45	1.00	Contin
$H$3	AR E Res	5.19	5.14	Contin
$J$3	AR G Res	2.11	1.00	Contin
$L$3	AR Ob Res	1.00	6.18	Contin
$N$3	AR Op Res	2.00	1.00	Contin
$P$3	AR R Res	1.07	1.01	Contin
$R$3	AR Re Res	4.83	4.29	Contin
$T$3	AR T Res	1.00	5.60	Contin

Constraints

Cell	Name	Cell Value	Formula	Status	Slack
$B$8	COST	4,529,426	$B$8<=$D$8	Not Binding	5470573.873
$D$3	AR Arrival Rate	14.98	$D$3>=0	Not Binding	14.98
$D$3	AR Arrival Rate	14.98	$D$3=$B$3	Binding	0
$B$9	WT	34.94	$B$9<=$D$9	Not Binding	205.0596313
$B$7	AREA	371.12	$B$7<=$D$7	Not Binding	628.880132
$F$3	AR C Res	1.00	$F$3<=$F$5	Not Binding	2
$F$3	AR C Res	1.00	$F$3>=1	Binding	0.00

$H$3	AR E Res	5.14	$H$3>=1	Not Binding	4.14
$H$3	AR E Res	5.14	$H$3<=$H$5	Not Binding	3.864290285
$L$3	AR Ob Res	6.18	$L$3>=1	Not Binding	5.18
$J$3	AR G Res	1.00	$J$3>=1	Not Binding	0.00
$L$3	AR Ob Res	6.18	$L$3<=$L$5	Not Binding	2.815643902
$J$3	AR G Res	1.00	$J$3<=$J$5	Not Binding	1.995707349
$N$3	AR Op Res	1.00	$N$3<=$N$5	Not Binding	0.999926143
$N$3	AR Op Res	1.00	$N$3>=1	Not Binding	0.00
$P$3	AR R Res	1.01	$P$3<=$P$5	Not Binding	1.992896914
$P$3	AR R Res	1.01	$P$3>=1	Not Binding	0.01
$R$3	AR Re Res	4.29	$R$3<=$R$5	Not Binding	4.707817631
$T$3	AR T Res	5.60	$T$3>=1	Not Binding	4.60
$R$3	AR Re Res	4.29	$R$3>=1	Not Binding	3.29
$T$3	AR T Res	5.60	$T$3<=$T$5	Not Binding	3.39764845