ANALYSIS OF PATIENT FLOW USING HYBRID MODELING APPROACH

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Approval

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Acknowledgment

I pay my gratitude to Allah almighty for blessing me a lot and without His guidance I couldn't complete this task. I would like to dedicate my thesis to my Parents

I would specially like to thank my Supervisor Dr. Imran Mahmood who gave me true direction, grabbed my hand and also encourage me at every stage of thesis. Without my supervisor's help I would not be able to complete my work. It is an honor for me to work with Dr. Imran Mahmood. He is a nice and graceful person. I offer my tribute to the place of knowledge i.e. National University of Science and Technology (NUST).

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List of Abbreviation

ABM	Agent based Modeling
DES	Discrete Event System
M&S	Modeling and simulation
IDE	Integrated Development Environment
LOS	Length of Services
R&D	Research and Development
OPD	Out Patient Department
IHI	Institute of Healthcare Improvement

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Abstract

The most important agenda of health care organizations is to provide quality service with specific number of resources and maintain an efficient patient flow.

Maximizing and optimizing the throughput of patient flow for quality care is most important objective of healthcare systems. It impacts the patient safety, quality of services and finance of healthcare institutions. Healthcare institutions deals with patient arrival and flow of patients to several departments for physician's assessment, lab tests etc. For decades' healthcare institutions are facing crowded emergency departments due to lack of focus on healthcare administration. Delayed activities can affect the patient care like staff shortage, delayed surgeries, long waiting queues and diverted ambulances.

To address these challenges this research analyzes the patient flow for better optimization and maximizing the patient flow throughput. In our research model rate of patient's arrival changes over time. Hybrid modeling is suitable modeling paradigm when agents have dynamically associated with other agents and are geographically spread. For the proof of concept hybrid model approach which combines Agent based modeling and Discrete Event modeling is used.

Keywords: *Patient Flow, Analysis of patient flow, Hybrid Modeling, Patient Arrival Testing, simulation and healthcare, scheduling*

Chapter 1
Introduction

This chapter provides the opening and general information of the research to provide a clear understanding about this thesis. It also covers the problem statement along with solution statement.

Efficient patient flow management and providing Quality services having specified number of resources has become most important agenda of healthcare originations. In hospitals demand and supply imbalance occurs very often. Most of the hospitals are failing in this domain. Improper management of patient flow is leading to financial issues as well, as a survey shows 15% of patients leave the hospital without getting services due to overcrowded emergency departments and long waiting times.

Proper and efficient management of patient flow can maximize the patient flow by providing quality services under limited budget and resources.

Patient arrival rate has potential impact on economy and patient flow system efficiency. It can also reduce the imbalance between demand and capacity. [1]

To address all these challenges this research will simulate the optimization of efficient patient flow using Hybrid modeling approach in Anylogic. Patient flow throughput can be increased by reducing patient length of stay and it can be achieved by managing patient flow using factors which have positive impact on

Institute of healthcare improvement has developed a series for analysis and optimization of patient to help healthcare organizations to improve their patient flow. This program offers new perspective of efficient patient flow through all stages of healthcare environment. IHI also offered a model for evaluating the patient flow, testing improvement factors and challenges and measuring output.

High utilization rate of resources causes increased waiting time for incoming patients and increase in rejection process or diverting patients. Hospital can afford higher utilization rates when greater proportion of scheduled patient in incoming flow is having invariable demand. Hospitals should keep utilization rate low when there is great proportion of unscheduled or invariable patients so diverting the patients and rejection process could be minimized. Resources should be managed so that they could be provided to unpredictable arrivals.

In emergency departments patient flow should be primarily focused because that category of patients need urgent care without facing waiting rooms and long queues. Number of resources in emergency departments should also be sufficient so that deadlock in patient flow could be avoided or minimized. Most of the healthcare organizations are facing the patient flow problem now a day. Patient flow can be affected majorly because of two reasons 1. At the time of Natural disasters 2. Lack of available resources [3].

This could be directly relating to variation in patient arrivals. At the time of natural disasters patients flow increase drastically and it becomes almost impossible to make the patient flow smooth. For the solution of this, planning before time is best suggested factor through which patient flow can be controlled up to a very large scale. More tasks a process have, there are more chances of effect of quality of services.

If number of tasks are reduced of a process more chances it would be of improving patient flow. Longer waiting times and queues become the reason of amplification in patient flow. This amplification results in mismatch of demand and capacity. Seriously ill patients are prioritized and services are given on urgent bases. This limits the remaining resources for less seriously ill patients, who have to face long delay for getting services. Hospitals must have appropriate number of staff and services providers to meet the projected and critical demand. In the regard of staff physician's lab technicians, middle level services providers and nurses are equally important. To handle variations in patient arrival and providing high quality services resources including staff and equipment should be radially available keeping in view the projected and critical demand. In emergency departments not all the patients need to be admitted and need bed. Beds can also be treated as resources. The process of segmentation helps in diverting patients to proper direction for getting their type of services. In emergency department some patients need urgent treatment and then discharged, these kinds of patients don't need bed. If more patients are directed towards bed in emergency department then it means, we are increasing demand without increasing resources and capacity. Less serious patients should be kept moving without occupying beds. The more patients occupy bed more resources tend to limit. As we have discussed earlier staff, physician and nurses are also resources.

1.1 Challenge

Huge volume of literature showed that Healthcare management and patient flow issues are increasing day by day.

Insufficiency of data and lack of evolution in simulation of healthcare are becoming major issues.

Delayed activities of healthcare due to poor management results in congestion, crowded emergency departments and economy issues for healthcare organizations. [2]

1.2 Problem Statement

All the information and objectives/ constraints that define the problem are called problem domain in the engineering terms. The goals which have to be achieved, the context of the problem and all the rules which define the functions are included in the problem domain. The environment in which the solution has to operate is represented by the problem domain.

1.3 Solution Domain

Modeling and Simulation (M&S) is a technique in which we can model real world scenarios as we cannot afford to find right solution by experimenting with real world objects. Building, destroying or making changes may be too expensive, dangerous or impossible. In modeling and simulation, we can even commit mistakes which, if done in real life scenarios can give devastating results. We can undo things, go back and forth in time, basically it provides a risk-free world where we can find our direction from problem to its solution

1.4 Solution Statement

The information that is used to define the proposed or expected solution of the system is called solution domain. The concepts, laws, techniques, software architects, algorithms and recommended ideas and practices which help in finding the solution of the problem are included in the solution domain.

The solution statement is defined based on the approach proposed: "Developing a model of hospital in Anylogic which can analyze patient flow by simulating and streaming activities of healthcare using hybrid modeling approach".

1.5 Key Contributions

We propose a hybrid agent-based and discrete event modeling for simulation and analysis framework that encompasses (i) model patient, states of a patient and resources (nurses) as agents, because there can be different kind of resources in our scenario staff, labs and healthcare equipment can be considered as resources (ii) model the delays and services taken by patients, patients movement towards different departments in hospital (such as Orthopedics, General Surgery, ENT, Plastic surgery, Neuro etc.) in discrete event modeling systems, as patient is considered an entity in the healthcare environment. In DES we used process modeling library for modeling different process of healthcare through which a patient goes through. (iii) Developed front end using Anylogic for showing different states of patient at different stages of healthcare environment.

1.6 Research Impact

Our proposed framework is for maximum throughput and optimized patient flow. Developers must have domain knowledge of hybrid modeling approach in order to take advantage of more than one modeling technique. It will help in modeling the nonlinear behavior of complex system over time such as in natural disasters number of unscheduled patients increase exponentially.

1.7 Thesis Organization

Rest of the thesis is organized in following chapters

1.7.1 Chapter 2: Background

Chapter 2 provides brief overview of patients flow and the factors which have positive negative impact on patient's flow.

How we can optimize the patients flow in best possible ways. Moreover, few preliminary concepts, used in methodology chapter, have also been discussed.

1.7.2 Chapter 3: Literature

This chapter explains the work done so far related to patient flow, optimization of patients flows and hybrid modeling approaches in healthcare environments. The formulation of the thesis and the novelty of the thesis lie in identifying the research

gap from the literature already published. The identification of the direction of research is also one of the sanctions of literature.

1.7.3 Chapter 4: Methodology

Our proposed simulation and analysis framework have been presented in this chapter. Moreover, the tool used for the development of framework and built-in libraries of the tool used for developing the model, are presented here. Furthermore, the input parameters required to drive the framework are also presented in this section.

1.7.4 Chapter 5: Simulation and Results

The functionality of our proposed framework is described in this section. The inputs which the framework requires and the output which our framework provides, the simulation of our frame work and the visualizations which our framework provides are all presented in this chapter.

1.7.5 Chapter 6: Conclusion and Future work

The work accomplished in this thesis has been concluded in this last chapter. Moreover, the chapter also describes the future directions which can be done ahead to this work.

Chapter 2
Background

In this chapter we discuss the information about the topic which is being studied. It describes the definitions and concepts of model components and model composability to get understanding about this thesis.

2.1 Patient Flow

Movements of patients through healthcare organizations is called patient flow [3]. It includes medical care, hospital internal systems and physical resources that a patient need from the phase of admission to the phase of discharge keeping in view the quality services and patient satisfaction. Patient flow is becoming the critical issue of administration and process management in healthcare facilities.

Figure 1: Patient Flow

2.2 Optimization of Patient Flow

Optimizing patient flow circumscribed the instantaneously adequate and effective fullfillness of patient care services by moving patients through healthcare path ways while keeping in view patient safety and satisfaction [4]. To optimize patient flow, it is necessary to keep balance between demand and capacity of resources as per rate of admissions.

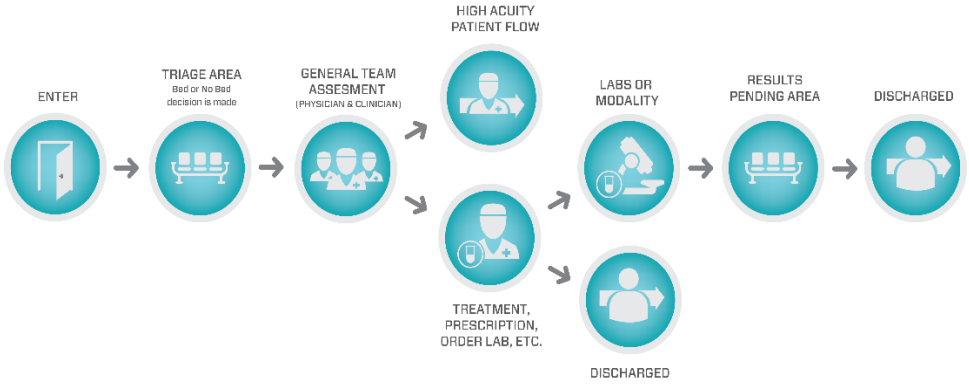


Figure 2: Optimization Of Patient Flow

2.3 Patient Flow Simulation Models

Patent flow simulation approaches describe the way how simulated individuals will perform in an environment. Three patient flow simulation modeling approaches have been discussed below. [5]

2.4 Flow-Based Approach

In this approach population is considered as a whole (homogenous entities) and abstracts from individual's characteristics and behavior. This approach is mainly used to simulate the population in healthcare environments to analyze the patient' flow in complex situations such as in emergency departments. [5]

2.4.1 Entity-Based Approach

Individuals are modeled as homogenous entities using entity-based approach. This approach also incorporates social, psychological and global/local laws which affects the motion of entities in physical world.

2.4.2 Agent-Based Approach

Agent-based approach enables simulation of autonomous entities in interacting environment. Entities modeled using this approach are intelligent and communicate with each other. Agents can react to the situation on their own and make decisions according to the set of rules. Using this approach, modelers are given complete freedom to simulate attributes and behavior of each individual.

2.5 Factors that Affect the patient care

Research on reasons of failure in patient flow management came across many negative factors which influences the patient flow planning on very large scale. As these problems become the reason for long delay in provision of patient care services. Factors can be visualized in the following graph and are discussed below in the accompanying sections. [6]

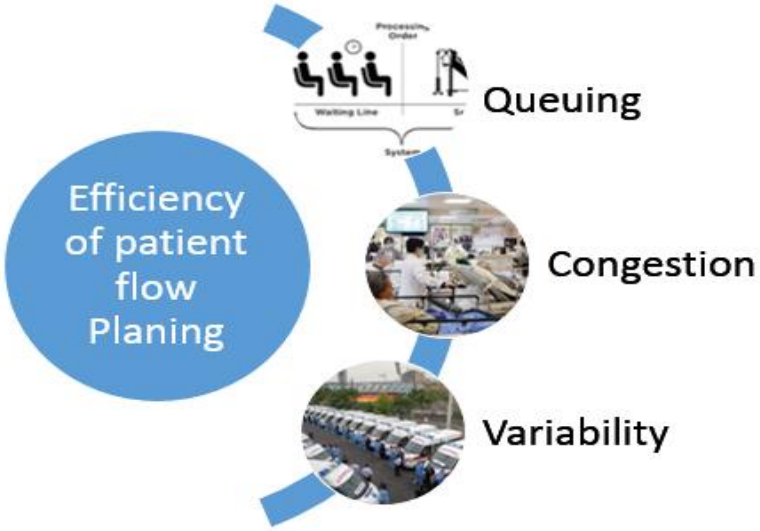


Figure 3: Factors that Affect the Patient care

2.5.1 Queuing

The system having patient movement have series of queues. If more than one person is waiting for getting services, then we have queue. To solve such problems which cause queuing and results in long waiting times most of the researches used queuing theory and gave mathematical solutions by finding relations between random arrivals and available resources. Most of suffering of queuing can be seen in healthcare environments where patients have to wait too long for getting services.

The problem arises when the increase is not proportionally but exponentially. [7]

2.5.2 Congestion

Congestion in the system occurs when imbalance between demand and capacity congestion can also be described as relation between the number of persons who are getting services and those who are waiting in queue. There may be many factors which

could lead to congestion in system, longer waiting time and increased rate of patient arrival can cause congestion in system. Patients who are new to the environment may also stuck in hustle and bustle for getting healthcare services earlier which is also a reason for creating congestion.

Congestion can be measured by finding the count of patients getting the services with what frequency and number of patients waiting in queue for getting services. [8]

2.6 Factors that can lead to improved Patient flow

For improved and efficient patient flow planning if some aspects are considered, they may prove a positive step to attain patient's satisfaction and will increase the market value of healthcare organizations. Factors that can lead to improve patient flow are showed and discussed below. [7]

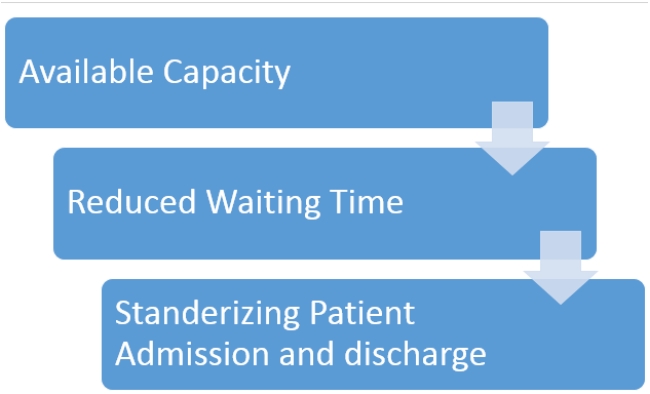


Figure 4: Factors that improve patient flow

2.6.1 Available capacity planning

Planning about available capacity requires the balance between the demand and resources. Keeping track of patient arrival and discharge rate can help in this regard. None of the resources should be consumed after the need is full. Free and allocated resources should be reported instantaneously so that delay factor could be reduced while assigning any resource to patient. Resource allocation should be on priority bases. This will have a positive impact on emergency patients who need resource allocation without delay [7].

2.6.2 Reduced waiting time

Patient Waiting time is the time when a patient enters in the system for getting services to the point when patient is being served. Patient spend a lot of time for getting healthcare services, reducing waiting time specially in emergency departments becoming need of the hour to attain patient satisfaction and market value of health organizations. Long waiting time for patients affect the efficiency of hospitals to a great extent. It is necessary to keep an eye in scheduling the healthcare activities such that the focus should be on patients not on services providers. At the same time healthcare organizations should make sure the availability of service provider at every work station when patient arrive. A study on Uganda healthcare patient flow performance showed that 80% of patient flow can be improved by providing attendants at each work station timely [10].

2.6.3 Standardizing Patients Arrival and Discharge

In order to achieve excellence in healthcare management should keep track of patient arrival and patient discharge count. This approach can be proved so helpful in keeping balance between demand and capacity. If management have proper record for number of patients who visit the hospital everyday it would be suggested how much service providers and resources should be available at work stations for patient care. This factor is considered a core factor in achieving optimal and smooth patient flow in healthcare organizations, as controlling this factor one of the best things can be achieved that is proper allocation of resources which would lead to reduce patient waiting time as well.

2.6.4 Variation in patient Arrival Rate

Variation in patient arrival rate is also one of the biggest reasons for lack of availability of timely patient care services. Variation in patient arrival are observed mostly at the time of accidents or natural disasters. This factor largely affects the provision of resources. Patient flow planning most come across failure at such kind of situations. [7]

2.7 Anylogic

Anylogic is a versatile simulation tool with graphical interface that allows modeler to quickly model complex environments. Anylogic Simulation environment provides

both a user-friendly Integrated Development Environment (IDE) as well as an efficient simulation engine that allows the modelers to quickly create and simulate high fidelity models of complex systems. It supports different modelling techniques such as Discrete Event, Agent Based and System Dynamics. We can develop complex hybrid models with the combination of discrete event, agent-based and system dynamics. Anylogic provides user-friendly interface, Java-based development environment and a set of multipurpose component libraries, which all together help to robust the modelling process. It also facilitates modeler to integrate simulations with external environments.

2.8 Agent Based Modeling

Agent base modeling is becoming very important modeling paradigm in application area specially in which human behavior is involved. Agent based modeling analyze capture and model human behavior in detail. In agent-based modeling agents are main components of Anylogic model. Agents may be any representative of the system it may be person, company, tangible/ non-tangible thing, vehicles or anything which is playing vital role in model as a building block of that model. Agents have attributes, variables and states [11]. Agent based modelling is preferred when agents are in dynamic relation with other agents and are separated spatially or geographically [12]. Variability of systems across applied domains is result of increasing number of quality software platforms for agent-based systems [13]. Agent based modeling is suitable paradigm when the system involves changing probabilities of arrival of agents over time.

Figure 5: Agent base Model

2.9 Discrete Event Modeling

Discrete event system modeling involves entities which can exist in spatial or aspatial environments. DES is basically process oriented modeling. In discrete event systems we deal with entities, which doesn't pass messages but can receive messages. But after modification entities can be enabled to receive messages [14].DES systems are used when entities came across clinical or conceptual modeling [15] .DES can be well understood in domain of operational research. It also has strong link with development of software and algorithms [16] [17].

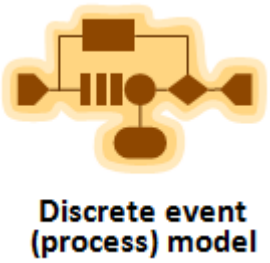


Figure 6: Discrete Event Model

2.10 Hybrid Modeling

Researchers of simulation found it long that most of the real-world problems cannot fall in the domain of single modeling paradigm. To achieve excellency and for better results in simulation of real-world problems researchers came across cross modeling approaches. This field is comparatively new in the world of simulation modeling [18].

Most of the publications in hybrid modeling domain up till now are theoretical rather than describing applications which clearly show that this is relatively new field and becoming attractive research domain for researchers.

Researchers are now leaning down toward hybrid modeling approach for getting the privileges of both modeling techniques for better and optimized results. In optimizing patient flow scenario hybrid modeling takes account of all characteristics which are directly or indirectly involved in healthcare activities. According to Athanasiadis et al. models developed using hybrid paradigm are more accurate and precise as compared to a model developed using a single paradigm. In our observation, either most of the existing simulation models focus on agent-based modeling or on Discrete event modeling, but not on both. We, therefore, propose a hybrid model based on the

combination of ABM and DES [19] . A comprehensive table is shown of publications on hybrid modeling which shows that this field is becoming popular, application work on this and publications are towards increasing trend.

Year	Publications	Year	Publications	Year	Publications
2014	3	2008	5	2002	3
2013	10	2007	3	2001	3
2012	4	2006	3	2000	0
2011	5	2005	0	1999	1
2010	4	2004	0		
2009	3	2003	2		

Table 1 : Publications on Hybrid Modeling

2.11 Simulation Role in Analysis of Patient Flow

Healthcare data has been analyzed with statistic techniques and less frequently mathematical techniques for improvement of management of healthcare systems issues.

Analyzed patterns of healthcare activity cannot provide the complete picture of issues that healthcare management is facing for the decades.

Simulating the real-world models provide an opportunity to explore complex systems and give solutions without disturbing the real system activities.It also avoids the difficulty in development of complex mathematical solutions.

Chapter 3
Literature Review

This chapter helps in explaining how related the work with that of others is Moreover, it contributes in the understanding and development of the area of research.

Error! Reference source not found. summarizes the literature work into separate categories whereas details of these papers are described later.

Author (s)	Category	Paper Description	Key Features
[3]	Patient Flow	Describes that crowding and waiting time in emergency departments are inevitable factors which effect patient flow to a great extent.	Analysis of 60 hospitals of United Kingdom has been done by institute of healthcare to figure out the influential factors on patient flow.
[7]		Explains how safety and quality of healthcare services can be improved.	Managing patient flow is key to improve quality and services of healthcare units.
[19]		Explains why patient flow is important.	This guideline discusses 10 major areas which could be helpful in improving patient flow.
[20]		Explains how demand and capacity of a hospital effect Patient flow	Simulation has been done to analyze how patient flow can be improved.
[8]	Analysis of Patient Flow	Analysis of patient flow is basically evaluation of internal factors.	Relationship between capacity and decision are discussed in this research.
[21]		Explains Performance measures for better facility of patients.	Research is based on data of local patient care facility.
[22]		Explains what is utilization rate of each unit.	Methodology of facility is illustrated using modeling approach.
[11]	Agent Based Modeling	This study aims to explain why agent-based approach is used in modeling.	Explains Advantages, Principles and implementation of agent-based modeling.

[25]		Discuss how modeling approaches the systems that contain large number of active objects	Explains how different modeling approaches correspond with agent-based modeling which focuses on physical design and systems.
[26]		Agent based model of emergency department is formed which depicts the behavior of individual agent which populate the system.	Explains general components of emergency department model.
[12]	**Hybrid Modeling**	Discuss how modeling approaches the systems that contain large number of active objects	Explains how different modeling approaches correspond with agent base modeling which focuses on physical design and systems.
[23]		Discuss how hybrid models could be developed in a single paradigm	This study focuss on the improvement of Emergency Modeling Systems, using hybrid modeling approach.
[26]		This paper discuss a model based on hybrid modeling approach.	It explains Agent based modeling and discrete event model development to simulate the emergency department of hospital.

Table 2: Literature Review

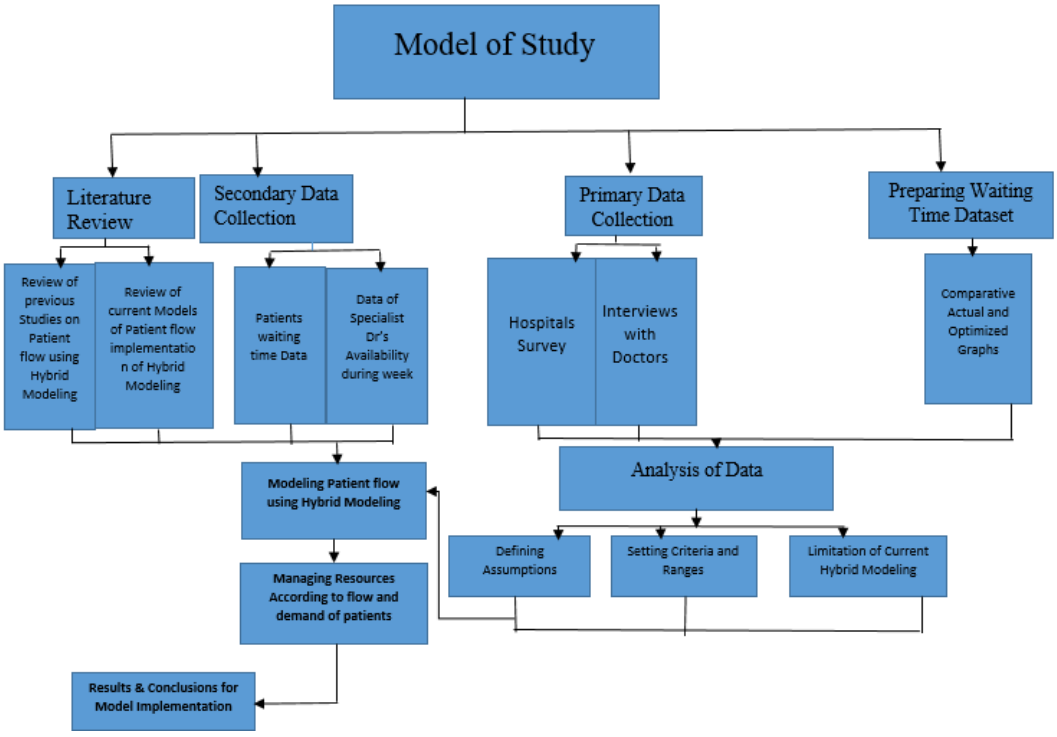


Figure 7: Research Methodology flow developed to conduct the proposed research work

3.1 Patient Flow

Patient flow is the time which patients spend in hospital from the point of entrance to the point of exit from hospital including the services time. More and more of hospitals are now focusing in betterment of the patient flow area in hospitals [7].Patient flow is number of persons passing through specific area per unit time to get services at their earliest. Most of the healthcare organizations are facing the patient flow problem now a day. Patient flow can be affected majorly because of two reasons 1. At the time of Natural disasters 2. Lack of available resources [3].

This could be directly relating to variation in patient arrivals. At the time of natural disasters patients flow increase drastically and it becomes almost impossible to make the patient flow smooth.

For the solution of this, planning before time is best suggested factor through which patient flow can be controlled up to a very large scale.

If patients get treatment on specified time this could also minimize the patient flow problem as waiting time for next patient would be reduced [1].

There are many factors which have positive effects on achieving best and smooth patient flow and some factors which needs to be considered as precautions for reducing the arising problem of patient flow in healthcare organizations.

Patient flow can also be out of control when there is imbalance between demand and capacity.

If more patients arrive than the available rooms capacity in hospital or there are a smaller number of resources to serve the patients, then long network of queues are observed.

In emergency departments patient flow should be primarily focused because that category of patients' needs urgent care without facing waiting rooms and long queues.

Number of resources in emergency departments should also be sufficient so that deadlock in patient flow could be avoided or minimized [20].

More tasks a process have, there are more chances of effect of quality of services.

If number of tasks are reduced of a process more chances it would be of improving patient flow. Longer waiting times and queues become the reason of amplification in patient flow. This amplification results in mismatch of demand and capacity. Seriously

ill patients are prioritized and services are given on urgent bases. This limits the remaining resources for less seriously ill patients, who have to face long delay for getting services.

Time analysis at anaSouth Warwickshire showed interdependency of their local hospital system.

Improper scheduling can also result in imbalance patient flow. This improper scheduling of operation theaters could have negative effects. For example, if elective surgeries are scheduled earlier at week then patients could have more resources to recover and this will eventually limit staff and support services of post-operative unit.

The basic origin of patient flow problem are emergency departments. The flow is amplified when non-critical patients turn their sides towards emergency department for primary and quick healthcare services. For improved patient flow automated approach is being popular, use of telehealth software can help in this regard up to great extent. This patient flow software can automate the process of patient arrivals and data gathering for analysis. Through automated processes patients who need information about appointment or other question can be managed on calls or online portals. Many researchers are working on the factors which could lead to minimize the delays in healthcare systems due to which patient flow affects.

The smooth patient flow is like flowing of water which means patients' needs are fulfilled at point of services within specified time and with minimum delay.

Good patient flow and minimal delay represents the efficiency of healthcare system; it represents that patients are quickly served as they move through different stages of healthcare environment [24].

3.2 Analysis of Patient Flow

Analysis of patient flow is basically evaluation of internal factors that influence the flow of patients and become reasons of overcrowded emergency departments. [8]
Institute of healthcare improvement has developed a series for analysis and optimization of patients to help healthcare organizations to improve their patient flow. This program offers new perspective of efficient patient flow through all stages of healthcare environment. IHI also offered a model for evaluating the patient flow, testing improvement factors and challenges and measuring output. [21] [26]

Analysis of patient flow in healthcare institutes show that it can be controlled in a better way if certain factors are considered [25]. Discharged patients should be discharge at early morning so that the space for new coming patient could be made available. Most of the admitted patients stay in hospital for 24 hours or for four days [26]. Very few patients stay for months in hospital.

Make a backlog of patient's arrival and discharge as well as of available resources and services provider for 24 hours.

Keeping in view this backlog of patients and healthcare resources planning for the natural variation in patient arrival could be best handled. Analysis of patient flow shows that to achieve best possible optimized and controlled patient flow is segmentation of patients. If patients are divided into segments on the bases of their severity of illness and resources are allocated to them accordingly. Defining the flow of patients on the bases of segments could reduce the deadlock. The patients should know where to go for getting services. Most of the time patients with lack of knowledge about hospital building and their respective services provider wander throughout the hospital which also cause the inefficiency of patient flow and waste of time and dissatisfaction for patients. Patients stream should follow the unique and customized pathways designed for individual process to ensure the smooth flow of patients.

For the desire of efficient and optimized patient flow the resources must be optimized. Hospitals must have appropriate number of staff and services providers to meet the projected and critical demand. In the regard of staff physician's lab technicians, middle level services providers and nurses are equally important. To handle variations in patient arrival and providing high quality services resources including staff and equipment should be radially available keeping in view the projected and critical demand. [27] In emergency departments not all the patients need to be admitted and need bed. Beds can also be treated as resources. The process of segmentation helps in diverting patients to proper direction for getting their type of services. In emergency department some patients need urgent treatment and then discharged, these kinds of patients don't need bed. If more patients are directed towards bed in emergency department then it means, we are increasing demand without increasing resources and capacity. Less serious patients should be kept moving without occupying beds. The more patients occupy bed more resources tend to limit. As we have discussed earlier

staff, physician and nurses are also resources. Nurses has to be bounded to bed occupying patient for the services and care. Optimization of effectiveness of resources requires that the staff members and resources should perform tasks which best suits them. Nurses should not enter the data of patient details similarly physicians should keep themselves busy in checking patients [27]. [8]

Keeping track of patients in healthcare systems using special monitoring and display devices for the optimization of patients are being used worldwide. Keeping record and analysis of the total time a patient spend in the system and how long patients has to wait for getting services can help in managing resources for patients. It helps patient care team to monitor the progress and points which has more backlogs. Analyzing the progress patient care team is enabled to predict the physicians and patient's location. This also helps in telling quickly about flow and bottleneck before it occurs so could be resolved without creating deadlock which could turn in log waiting times. Monitoring the flow and progress helps in predicting future needs and services capacity [4].

High utilization rate of resources causes increased waiting time for incoming patients and increase in rejection process or diverting patients. Hospital can afford higher utilization rates when greater proportion of scheduled patient in incoming flow is having invariable demand. Hospitals should keep utilization rate low when there is great proportion of unscheduled or invariable patients so diverting the patients and rejection process could be minimized. Resources should be managed so that they could be provided to unpredictable arrivals. These resources could be open rooms, beds and availability of staff for surgical schedules throughout the week. Pace of working staff also impacts largely on waiting time for patients. Management style of healthcare organizations should ensure maximum attended patients rather moving towards diverting patient's policy. High occupancy rate didn't prove the efficient and satisfactory care services for patients [28]. If all beds are occupied then unscheduled patients have to divert, although full occupancy could be helpful in generating revenue but in deep this approach fails as management should be like keep track and must consider how often the occupied beds turns over so that incoming unscheduled patients could be handled efficiently. For smooth, quick and efficient activities of healthcare, points to be considered are avoiding internal /external diverts and system gridlock.

3.3 Hybrid Modeling

Hybrid modeling approach is used when we need to take advantage of more than one modeling technique. Agent base paradigm is used to create models which mimic human behavior and characteristics such as the age group of people, his hours of work and ethical values of the society. [12]

Moreover, hybrid paradigm considers all the characteristics which are directly or in directly involved in certain behavior.

According to Athanasiadis et al. models developed using hybrid paradigm are more accurate and precise as compared to a model developed using a single paradigm. [23] [26]

3.3 Agent Based Modeling

An agent-based model (ABM) is a class of models meant for simulating the actions and interactions of autonomous agents - either individual or collective entities, with a view of assessing their effects on the system as a whole. [11] Application of Agent Based Modeling (ABM) provides microscopic insights to explore complex behaviors over time. [23]

Microscopic models help in simulating real-world problems with greater accuracy as this considers many small details that can produce minor deviations from the actual result if not considered. Agent based modeling is a modeling paradigm in which individuals, their interaction with each other and their environment are represented as an agent. ABM offers a toolkit for behavioral science which can help in developing models as to how individuals interact and what is the behavior and organization which materialize from these interactions. [24]

3.4 Our proposed framework in the State of the Art

Hybrid modeling approach integrates Agent-based modeling with Discrete Event modeling to exploit the potential of both paradigms. ABM focuses on microscopic details of the system whereas DES aims to aggregate the modeling details at macro level. Former provides the advantage of capturing essential details at entity level models that mimic human behavior and characteristics such as moving through a population for getting services, ethical values of the society etc., however it suffers from performance issues specially when dealing with large-scale population. Latter has

an edge in building large-scale long-term models and helps in modeling the nonlinear continuous behavior of complex system over time but it lacks expressiveness for entity level behaviors. In our observation, either most of the existing simulation models focus on agent-based modeling or on Discrete event modeling, but not on both. We, therefore, propose a hybrid model based on the combination of ABM and DES. ABM paradigm is used to model the agents, such as patients and patient wards .While, DES paradigm is used to model complex behavior of patient flow and management using stocks and flows.

Chapter 4
Methodology

In this chapter we propose a hybrid Agent-Based Modeling (ABM) and Discrete Event System Modeling (*DES) approach in developing the proposed simulation framework.*
Our proposed framework is composed of three modules

1. Agent Based Modeling
2. Discrete Event System Modeling

4.1 Selecting Suitable technique for modeling

In this section, different techniques for proposed modeling approach to optimize patient flow are discussed in detail. Healthcare systems have been very complex for modeling and simulation domain. Therefore, selecting a suitable modeling paradigm for a specific scenario of healthcare for simulation is challenging task. This research has been carried out on hybrid modeling approach which combines both Agent based modeling and Discrete event modeling. Patients are agents in our model and the healthcare delivery process from the point of arrival to the point of discharge has been modeled using discrete event modeling. Hybrid modeling incorporates the scenario of optimization of patient flow very precisely.

4.2 Why Hybrid Modeling?

Procurators of simulations long found that most of the problems of real world cannot be solved by being limited under the umbrella of single and obvious modeling domain. Anylogic is first software tool which incorporates with hybrid modeling. Options other than Anylogic for developing hybrid models involves quite a lot of coding. Anylogic provide an open source Agent based modeling tool Repast Simphony. This tool allows the user to use off the shelf components, packages, and write additional Discrete Event code for accomplishing the objective of cross paradigm modeling.

Anastognou et all (2013) develop a hybrid model for emergency healthcare for emergency healthcare services using Repast Simphony tool[5] Although this model was complex but proved successful as it runs on two separate processors.

Vianas (2014) tried to compose hybrid model using COTS software. He compares two possible options developing in separate single paradigm tool and then linking their interfaces. This all required a lot of effort and coding expertise.

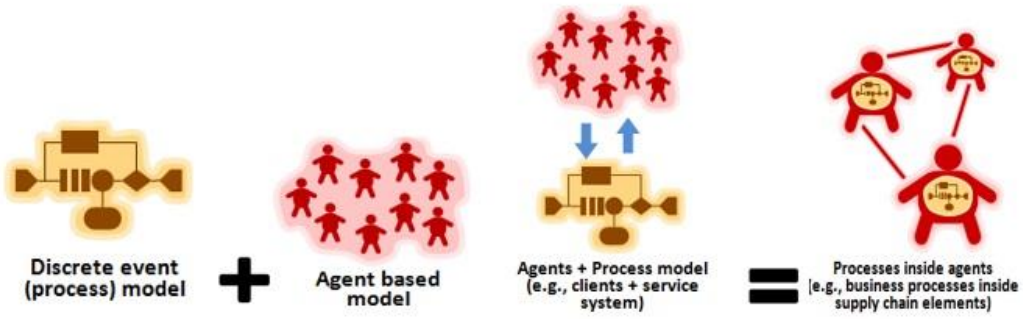


Figure 8: Hybrid Modeling based on DES and ABM [28]

Hybrid modeling is suitable modeling paradigm when agents have dynamically associated with other agents and are geographically spread. In our research model rate of patient's arrival changes over time. ABM is for patient arrival and DES is for hospital model. DES is straight forward approach for hospital model. Whenever an agent is priorities on the bases of first come first serve and decision to attend then agents become entity in DES model. To achieve the probabilities of attendance AMB's features can be embedded inside DES.

4.2.1 General System Properties

General system properties of our model include the modeling libraries and the component used for modeling in both type of modeling. In agent-based modeling module patient's states has been modeled, and in discrete event modeling module the process modeling library components are used to model the entire process of healthcare delivery system.

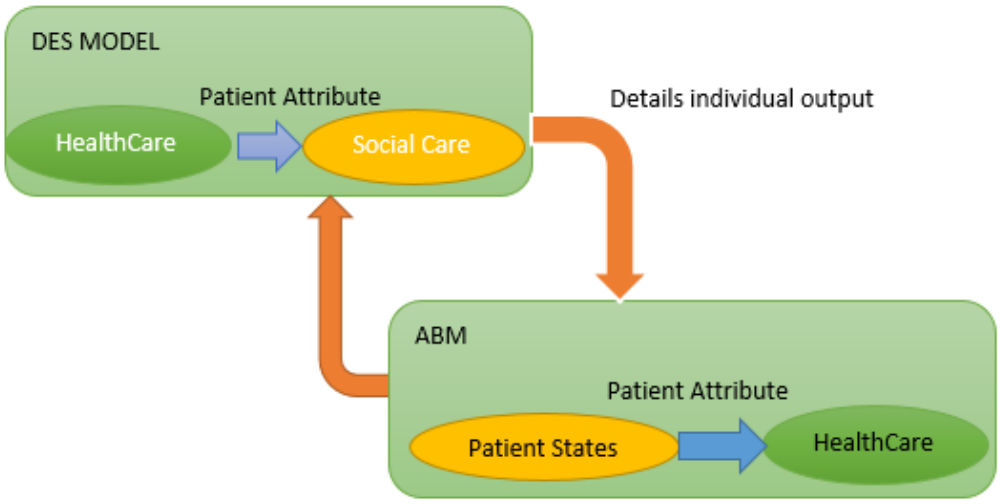


Figure 9: Variables exchange between model

4.3 Simulation in Healthcare

There are wide range of reasons for which simulation has been adopted in healthcare and delivery systems predominantly. Among modeling approaches discrete event modeling remained dominant. Healthcare software's are increasingly adopting quality visualization and molding. Nearly 90% healthcare environments have been studied under the umbrella of modeling and simulation inclusive of hospitals, extended care, specialty care, long-term care, public health. Persistent problems incorporate patient flow, staffing, works schedules, resources, demand and capacity, admissions/scheduling, appointments and planning [29] Healthcare problem domain is considered too complex in modeling as in this domain both customer and supply are like people serving people. Patients come up with complex and unscheduled demand. This is challenging task for simulation as the resulting process (providing services using resources) is also very complex.

4.4 Agent Based Modeling

Agent Based module consists of a number of Agents: (i) Patient, (ii) Nurse. Patient activities when entered in healthcare environment, is modeled using state chart, as shown in the Figure 4. Patients are basically dived into three categories. Category 1 patients are severe ill and need urgent care service, patients with less illness are categorized as category 2 patients and the patients who arrive at reception for clearing their dues after getting discharge fall in category 3 patients. The behavior of patient's

flow is modeled using a state chart, where: (i) States represent different activities; (ii) Transitions are guarded by the conditions of the occurrences of activities and time-out durations of each activity. When a patient moves through different stages, his state transits to the corresponding activity state. A patient might be moving in the system from one stage to another or may be in waiting state for getting services When a person enters into healthcare environment, it triggers the rate of patient arrival of the respective category of patient which specifies patient's next state of movement.

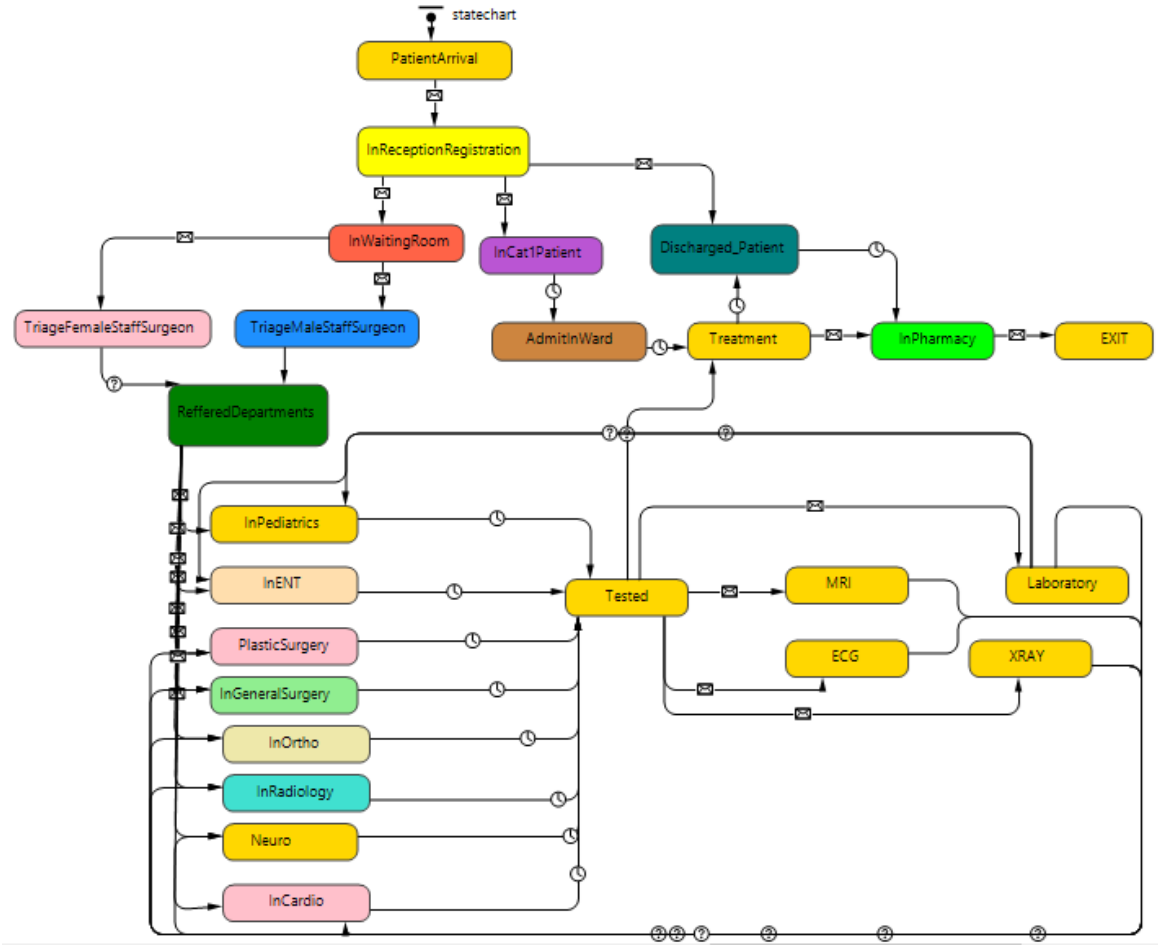


Figure 10: Agent base component of Hospital Model

4.5 Discrete Event Modeling

We use Discrete event modeling to model patients flow components. Patient arrivals are shown as source of entry of patients into the system. Whenever patient need to stay at certain stage for some task it may be getting service from physicians or for registration at reception Service component of Process modeling library is used. The

purpose of service component is to seize, delay and release in sequence. After patients entered in the hospital, they go the Reception at reception patients are divided into three type of categories. These categories are based on the severances of patient's condition. The first and high priority patients are subjected to as category one patients. Patients with less illness are categorized as category 2 patients and the patients who arrive at reception for clearing their dues after getting discharge fall in category 3 patients. Not all category one patients need to be admitted. Some patients need urgent treatment and then discharged. Some need to admit for minimum 4 hours and maximum for months depending upon the condition and recovery of patient.

After diverted from reception as categorized patient move to his respective pathway

4.5.1 Elements of Discrete Event System

Discrete event system's library possesses very useful components which help in modeling a system in smooth manner some of which we have used in our research model that are discussed below in Table 1

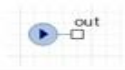
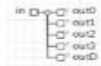
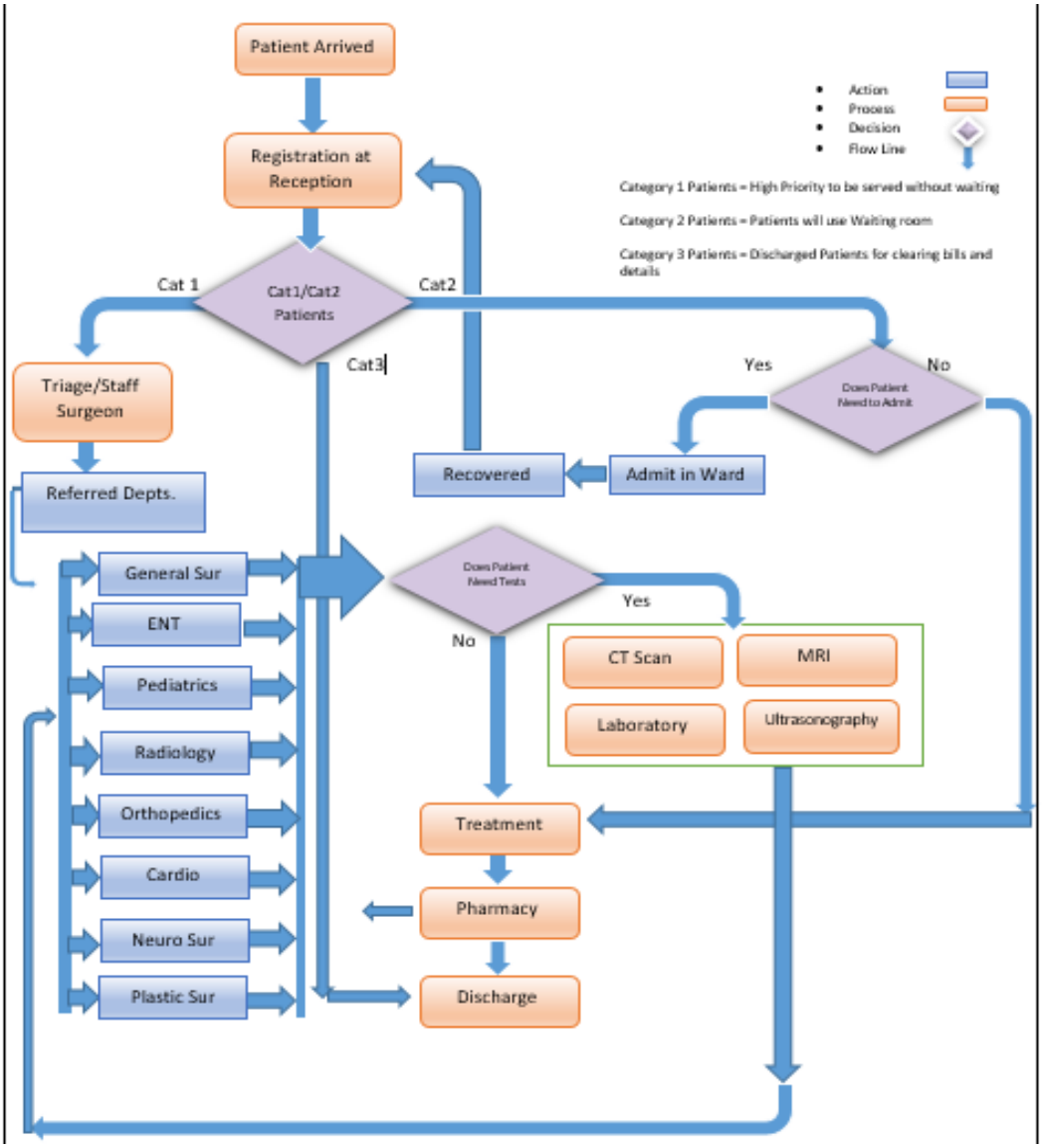
	Source	Generates entities. Is usually a starting point of a process model.
	Sink	Disposes entities. Is usually an end point in a process model.
	Delay	delay function is frequently needed in system dynamics for modeling postponed effects, i.e. situations when it takes some time for decision-making, or for some processes to occur before the action is taken.
	MoveTo	Moves the agent/entity to a new location in the network. If any resources are attached to the entity, they will move with it
	SelectOutput5	This object routes the incoming entities to one of the five output ports depending on (probabilistic or deterministic) conditions
	Service	Seizes a given number of resource units, delays the entity, and releases the seized units

Table 3:Elements of Discrete Event System

Simulation engine controls the execution of model in a variety of ways. It provides different modes to execute the model either in virtual or real mode. Real-time mode is used when the model's presentation is required to appear as in real life whereas virtual model is used to make the model execution as fast as possible without mapping the

model time to real time. This mode is useful when we need to execute our model for a long period of time. Simulation engine also defines the stopping criteria of model execution. Its different modes such as: start time, stop time, start date and stop date help modeler to analyze the model in multiple ways.

4.6 Process flow Chart



4.7 Discrete Event Model of Hospital

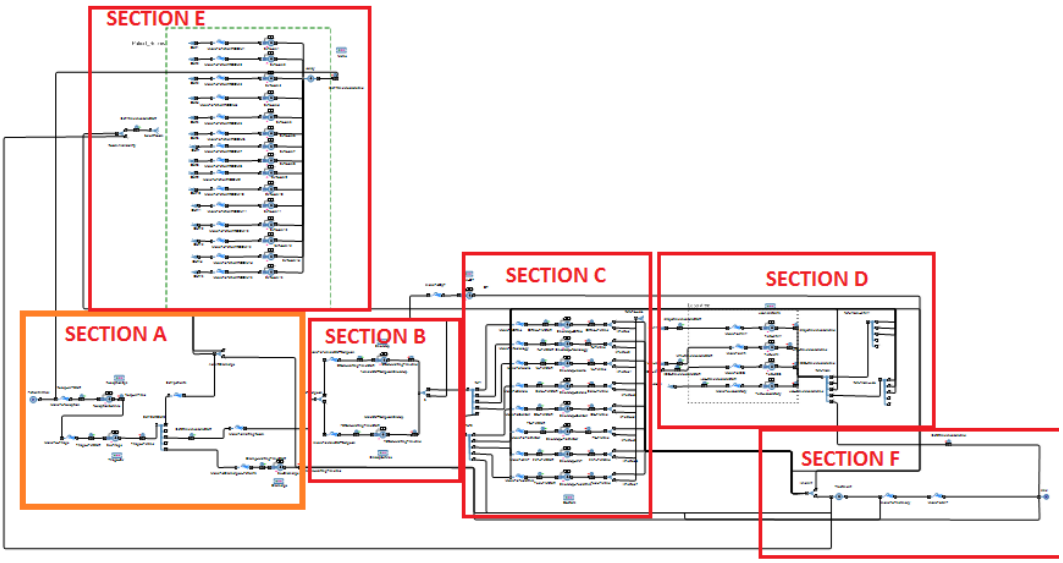


Figure 11: Discrete Event Model of Hospital

Discrete event model of hospital has been divided into Six sections.

4.7.1 Patient Arrival and Registration (Section A)

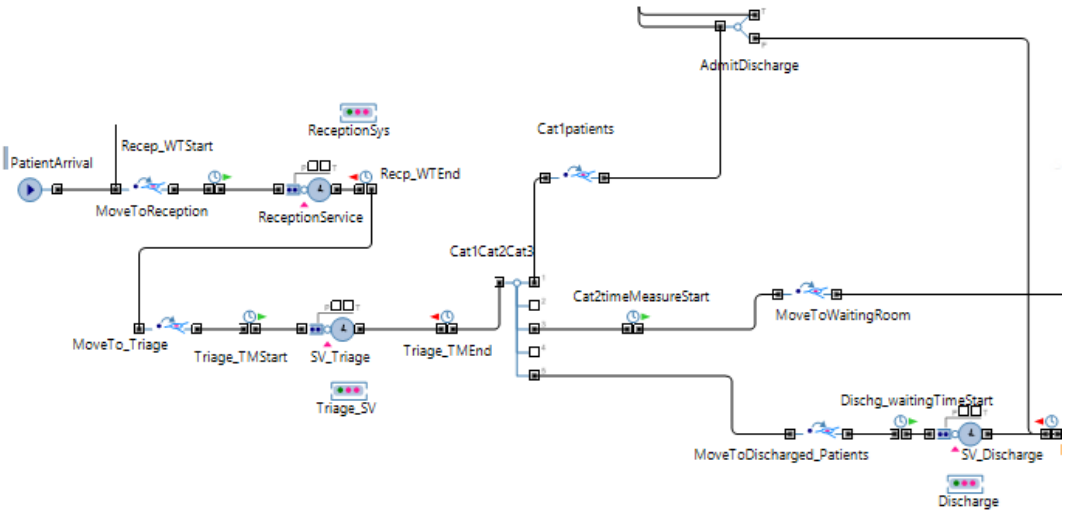


Figure 12: Patient Arrival and Registration (Section a)

For analysis of patient flow in hospital, hospital model is built in discrete event modeling. In figure 11 first section of hospital is shown, in which patient arrives in hospital and then move to reception for getting registered as category 1, category 2 or category 3 patient. Injured patient goes to triage for urgent and quick treatment. And if patient is more serious than he is shifted to operation theater.

Category 1

Category 1(Emergency Patients which may be subjected for admit or for quick treatment without facing any waiting area) Minimum Length of stay in the system for emergency patients is four hours it may be extended to days if patient is subjected foe admit.

Category 2

Category 2(Normal Checkup Patients) shows slightly lower LOS as compare to Cat 1 patients. This is the total time a patient takes from arrival and first visit to physician. Cat 2 LOS includes the time which patient takes at reception, Staff Surgeon, Referred Department, Referred Lab and Pharmacy respectively.

Category 3

Cat 3 (Discharged Patients) LOS is too low as it takes 10-15 minutes, in which a patient clears his bills and other formalities after getting discharged from ward.

4.7.2 Male/Female Staff Surgeon (Section B)

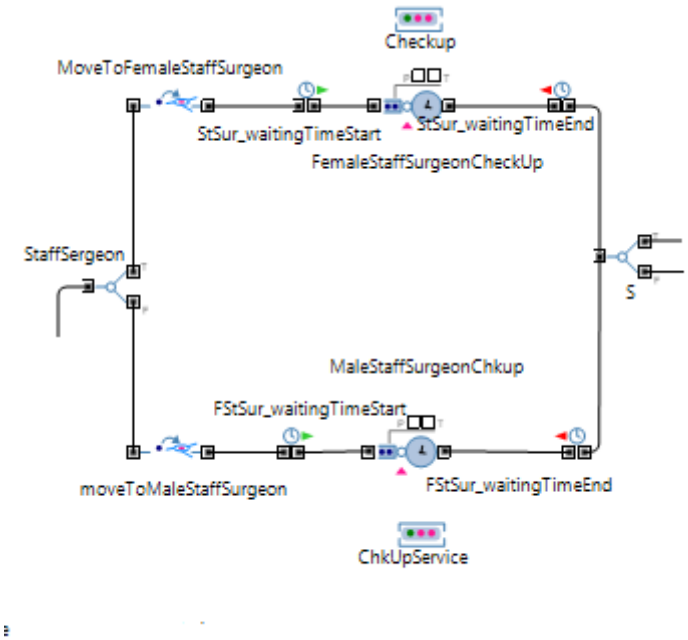


Figure 13: Male/Female Staff Surgeon(Section b)

Category 2 patients move to staff surgeon, which is further divided into Male/Female staff surgeon. Staff surgeon examines the patient and refer them to their respective specialists.

4.7.3 Referred/Specialist Doctors (Section c)

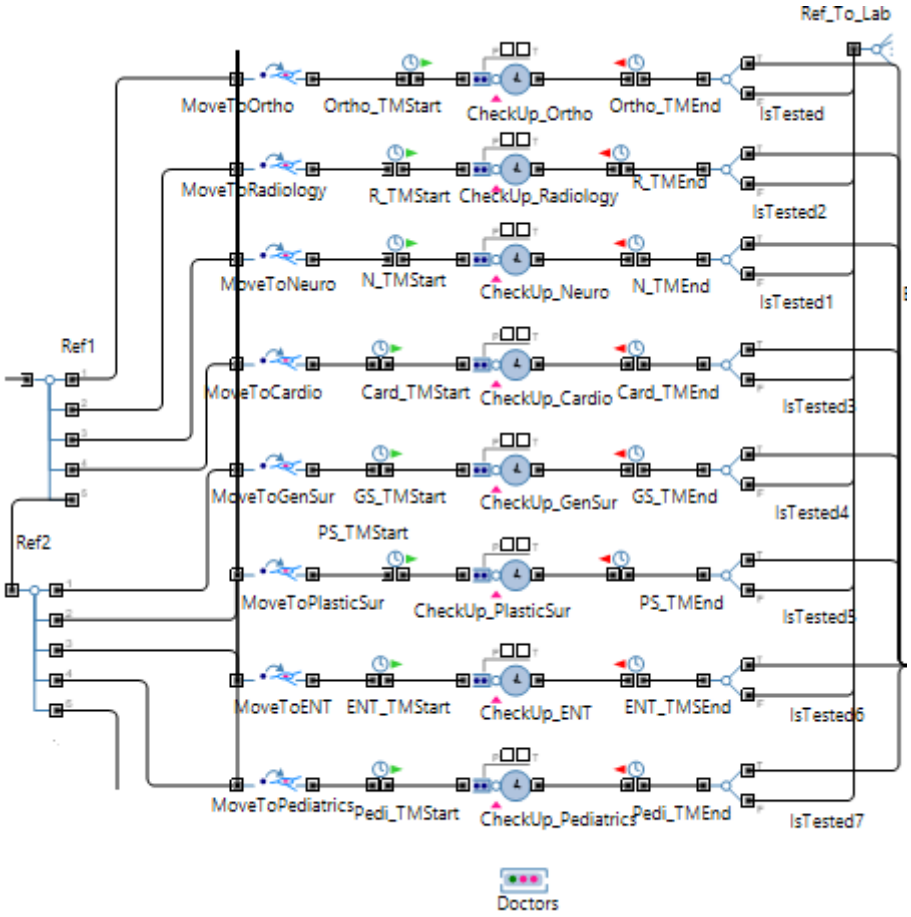


Figure 14: DES View of Hospital Model (c)

After referred to specialist patient go to their respective specialist Figure 13 shows different specialist.

4.7.4 Labs Area (Section d)

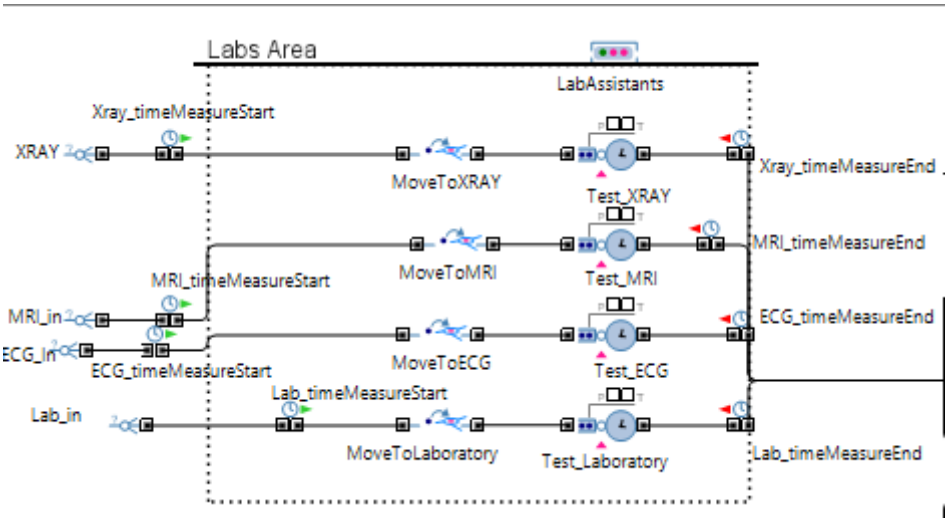


Figure 15: Labs Area (Section d)

Specialist physicians further refer the patient to labs for tests according to their examination report. Figure 14 shows Labs which include ECG, MRI and XRAY section.

4.7.5 Patient Rooms (Section e)

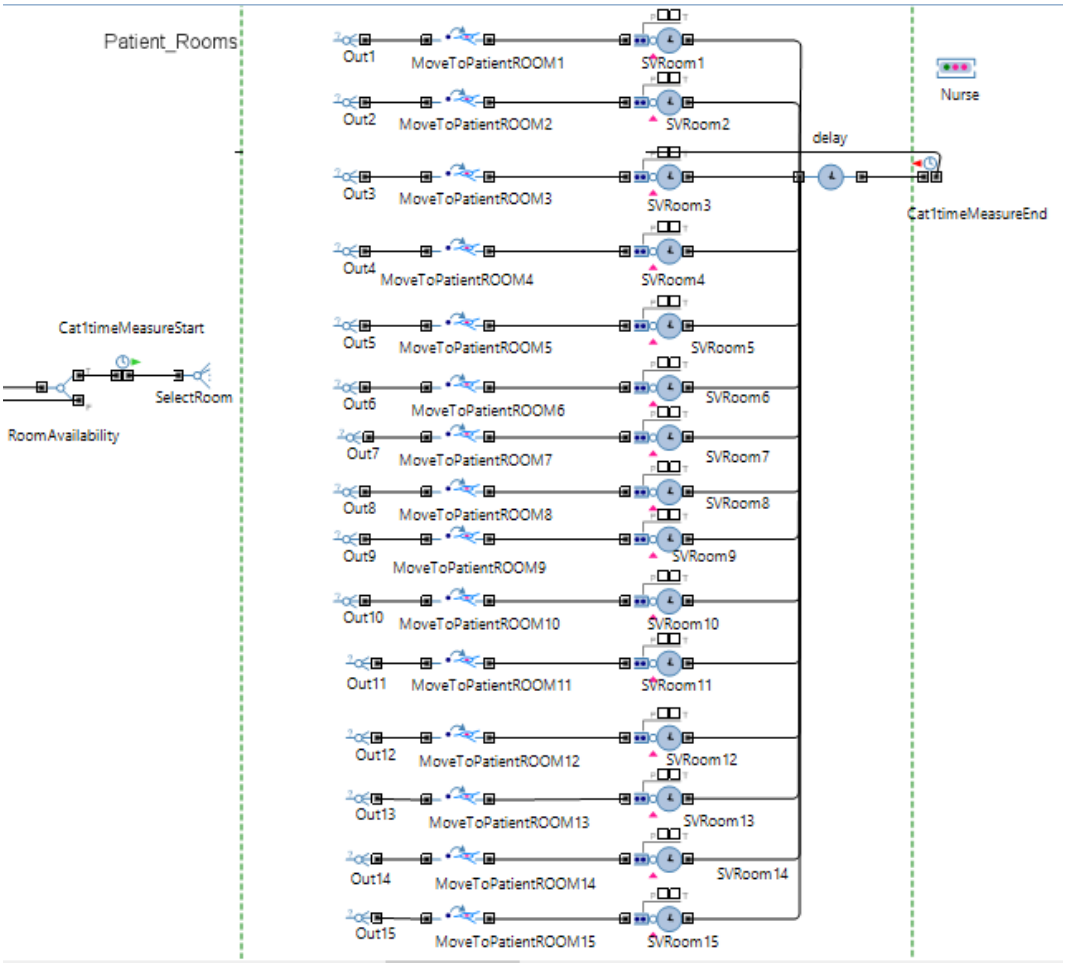


Figure 16:Patient Rooms (Section e)

After examining the test report of patient specialist physician decides that if patient needs to be admitted or not. If patient is admitted, he goes to patient rooms which are shown in figure 15.

4.7.6 Exit Area (Section f)

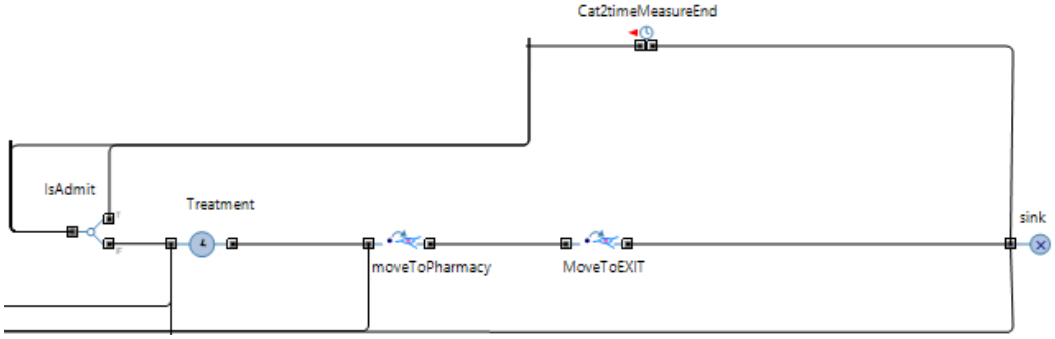


Figure 17:Exit Area (Section f)

Figure 16 shows patients after getting necessary treatments according to their category finally moves to pharmacy and then exit from hospital.

Chapter 5
Simulation and Results

In this section, we demonstrate the functionality of our proposed framework. We simulate the scenario of patient flow in a hospital located in Rawalpind, Pakistan , to help regulatory authorities in forecasting relation between demand and capacity for efficient and quick process of healthcare services.

5.1 Model Development

5.1.1 Simulation

We have run the simulation for seven days to analyze the pattern of patients flow towards different departments. Once the pattern has been recognized simulation has been run over the data of one year. Simulations are performed for procuring and analyzing patients total length of stay in the system, utilization percentage of room by patient, how frequent patient visits a specific physician, how much time they spend at reception, checkup from staff surgeons, time spent in labs and in discharge process. Calculating mean times that a patient takes at different stages in hospital through simulation gives us optimized results through which we can predict future needs and reasons of deadlock in the system where it takes too long waiting times for patients.

5.1.2 Hospital Enviornment Layout

Firstly, the physical environment of Hospital has been developed for patient flow simulation using AutoCAD and this design has been imported in Anylogic using CAD feature. Hospital layout is divided into two parts one show outpatient department and second shows in-patient area which is shown by designing patients rooms for admitted patients. Once the hospital design has been imported in Anylogic environment, different space markup elements are then used to draw paths and point nodes for regularizing the patient's movement on specific paths according to their categories.

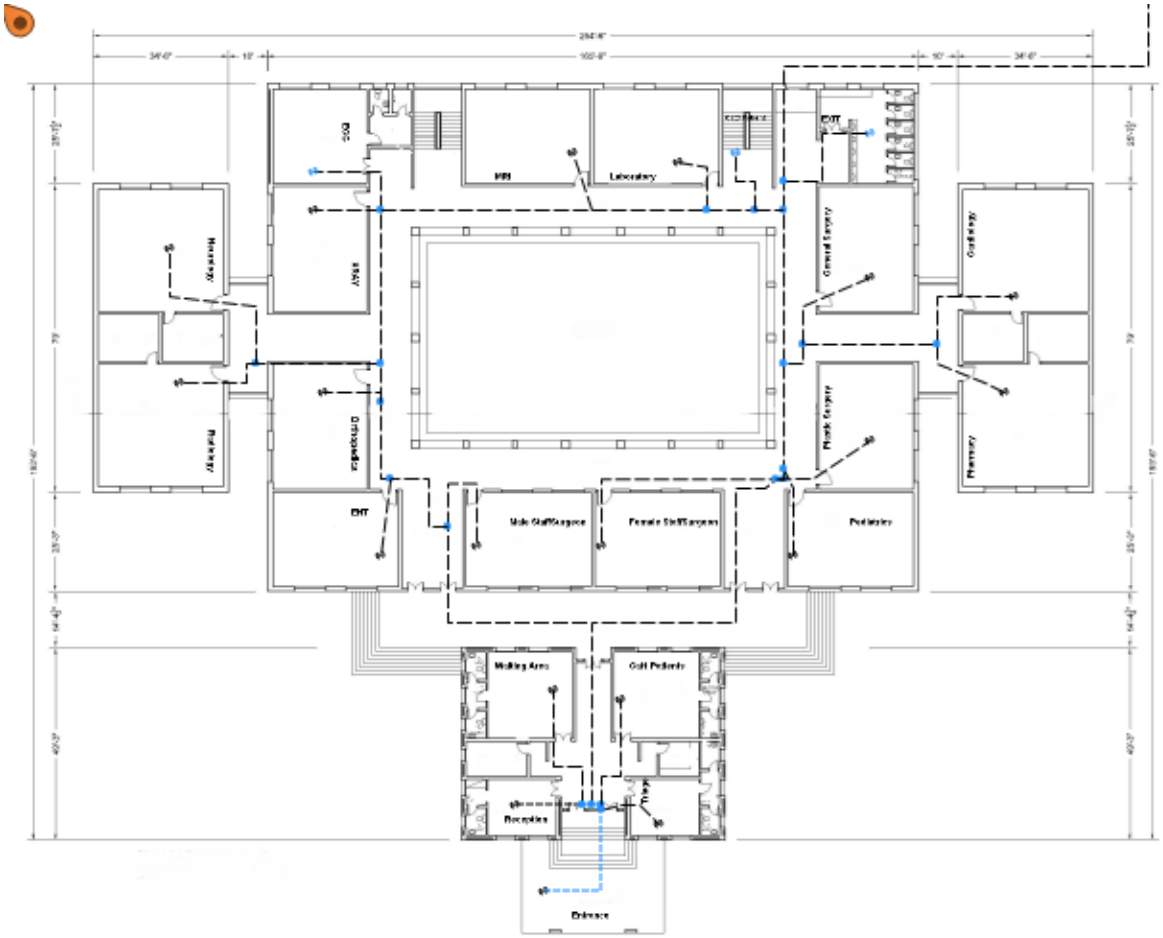


Figure 18: Hospital Model layout

Figure 17 shows view of hospital layout. Blue dotted line shows path in entrance area. Rest black dotted lines shows paths to different specialist departments and labs e.g Male/Female staff surgeon, Neurosurgery, ECG, MRI, Radiology etc. patients can move along to paths according to their specific category. After entrance area patients will move to reception. At reception category of patient would be decided either a patient belongs from first, second or third category patient.

5.1.3 Patients Movement

After the development of hospital environment layout, modeler can use Anylogic Process modeling Library to simulate the patient flow in hospital environment. At first, some environment control blocks, also known as patients movement settings blocks, are used to make necessary configurations. Initial population of patients is produced by using source component of discrete event modeling library. For movement of patients from one place to another GoTo component is used. At reception where

patients have to spend some time for further movement plan Service component is used.

5.1.4 Category 1

Emergency Patients which may be subjected for admit or for quick treatment without facing any waiting area) Minimum Length of stay in the system for emergency patients is four hours it may be extended to days if patient is subjected foe admit.

5.1.5 Category 2

Category 2(Normal Checkup Patients) shows slightly lower LOS as compare to Cat 1 patients. This is the total time a patient takes from arrival and first visit to physician. Cat 2 LOS includes the time which patient takes at reception, Staff Surgeon, Referred Department, Referred Lab and Pharmacy respectively.

5.1.6 Category 3

Cat 3 (Discharged Patients) LOS is too low as it takes 10-15 minutes, in which a patient clears his bills and other formalities after getting discharged from ward.

5.2 Input Modeling

Resources	**Serving Time**
Reception	8-10 min
Male/Female Staff surgeon	10-15 min
Triage	10-20 min

5.2.1 Specialist Doctors

Resources	**Serving Time**
Cardiology	15-20 min
Orthopedic	25-30 min
Neurology	15-20 min
ENT	10-15 min
Pediatrics	10-15 min
Radiology	15-20 min
Plastic Surgery	15-20 min
General Surgery	25-30 min

5.2.2 Labs

Resources	**Serving Time**
XRAY	5-10 min

ECG	8-12 min
MRI	20-50 min
Labs	10-15 min

By reducing service duration or by increasing the number of resources at more loaded resource point we can get optimized results. Optimized results can also be achieved by reallocating dynamic resources. When services time is reduced then waiting time for patients would also be reduced and hence more patients could get services in a better manner.

5.3 Results

Figure 19 shows utilization of rooms, how often these fifteen rooms are occupied by admitted patients

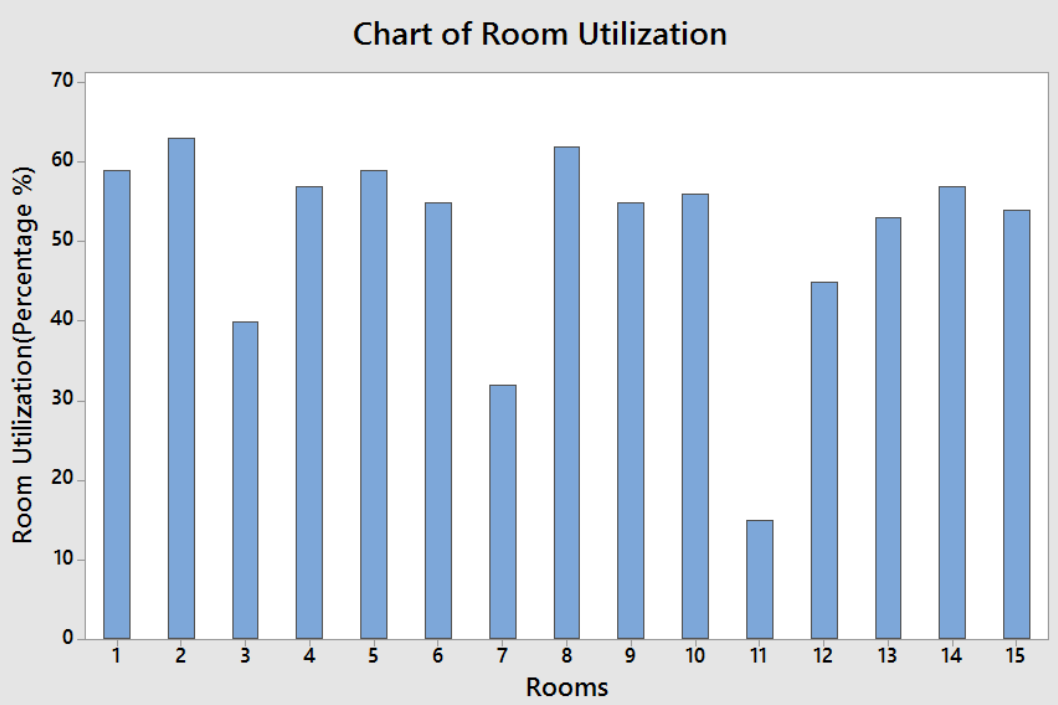


Figure 19: Room Utilization (Percentage)

Figure 20 shows count of patients visit to different physicians. It can be said that which department has highest utilization rate by analyzing count of patients visits to that department.

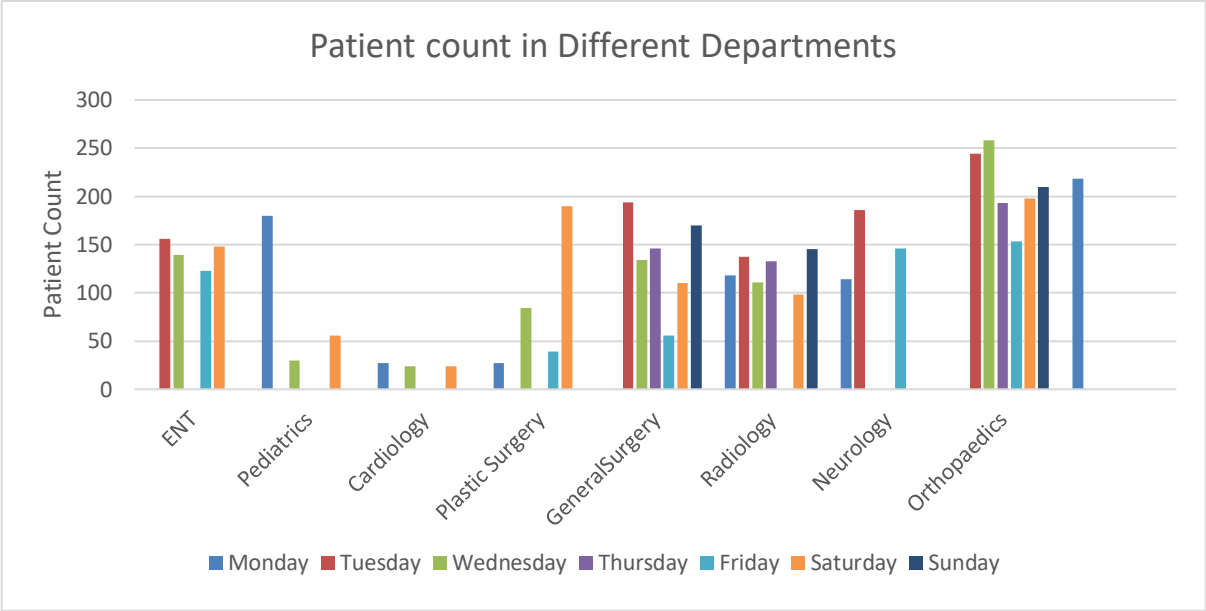


Figure 20: Patients Count in Different Departments

In Figure 20 each department is shown on week scale. As each department has different working days along the week. ENT, General surgery, and orthopedics have maximum working days, so these departments show greater count of patients as compare to others. Colored bars show different days of week. If we see ENT's patient count, 180 patients visited on Monday, 156 on Tuesday, 139 on Wednesday ,123 on Friday, 148 on Saturday, Thursday and Sunday are Non OPD days of ENT. Similarly displayed bars showing the patient count and missing bars are showing 0 patient count on that day of week as Non OPD day of that department.

It can be seen in graph that large number patients visit ENT specialists as compare to another specialist. Departments of Orthopedics, General Surgery and Plastic Surgery also showed greater count of patients visits. Simulation has been run over the data of one year, during the week days there are different days of week which are specified to different specialist some days are Non OPD Days for departments so some departments will show greater count of patients on the basis of how much OPD days that department have. By keeping track that how much utilization of a department helps in keeping balance in demand and capacity for better optimization and smooth patient flow, as we can see in which department, we need how much resources against the maximum utilization.

Figure 21(a,b,c,d,e,f,g,h,i,j) shows mean waiting time that a patient takes at different stages in hospital, the mean waiting time of different departments analyzing that in

which department waiting time for patient is high. Measuring and analyzing waiting times of provided services is the best way to improves quality of hospital services.

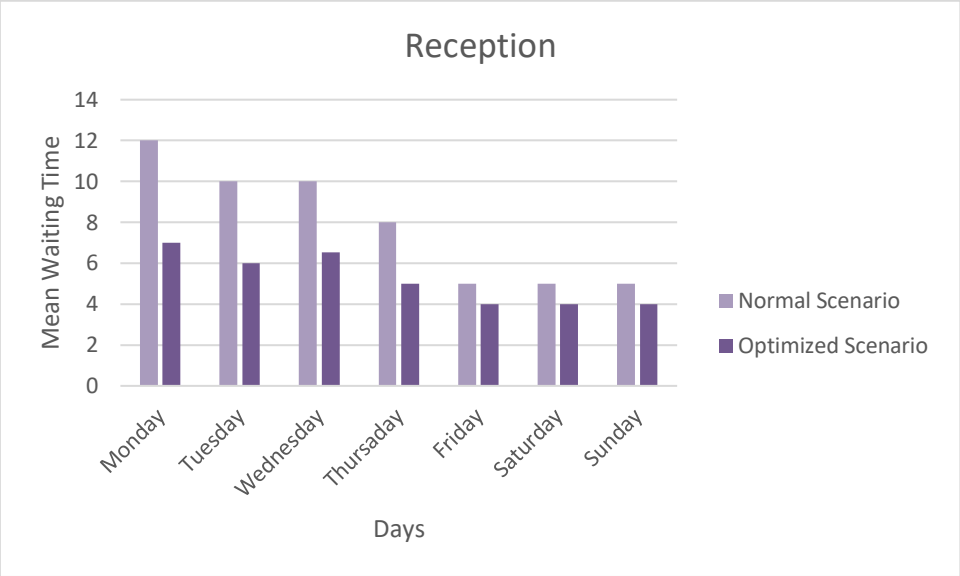


Figure 21a: Mean Waiting time at Reception

In figure 21a waiting time at reception from Monday to Sunday is shown. Waiting time is high at the start days of week and then gradually decease. The reason behind this is that patient count is higher at starting days of week as compare to end days of week (verified through R&D). Graph shows two bars one for the normal scenario waiting time and second bar shows mean waiting time after simulation. Comparison of normal scenario and simulated result of mean waiting time is shown in Figure 21(a, b, c, d, e, f, g, h, i, j).

We can prove through these graphs that after simulation of streamlined activities of categorized patients waiting time has been reduced up to some extent which is helpful in achieving efficiency in optimal patients flow in healthcare environment.

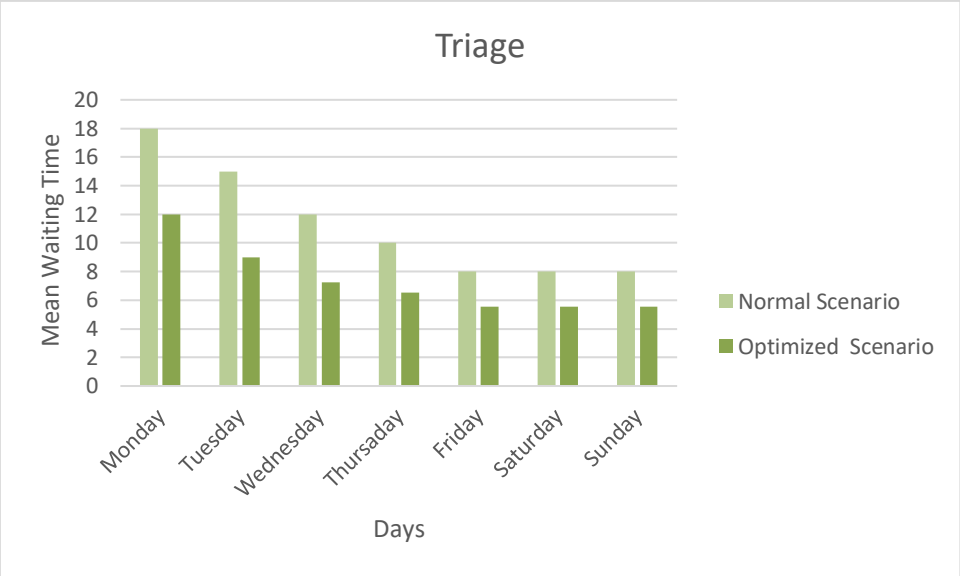


Figure 21b: Mean Waiting time at Triage

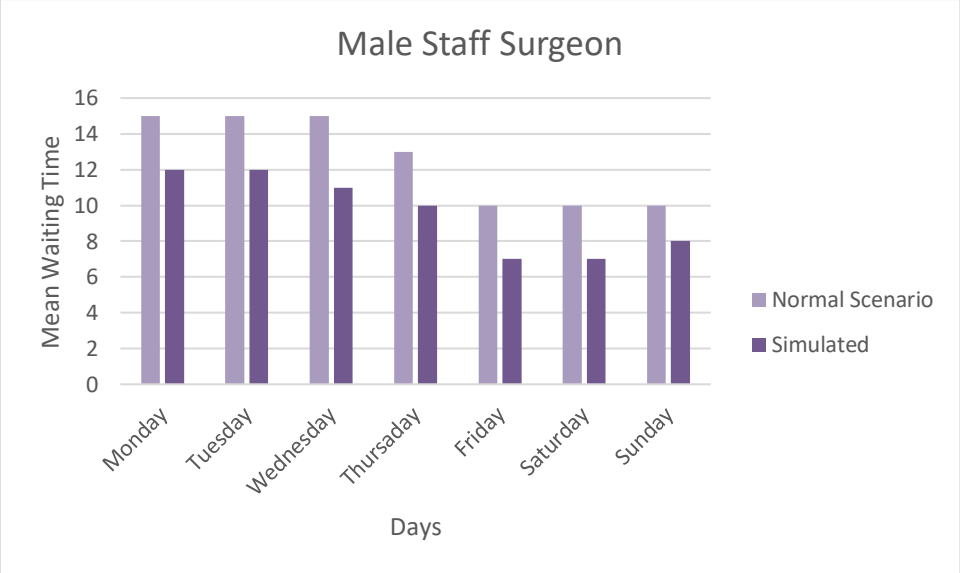


Figure 21c: Mean Waiting time at Male Staff Surgeon

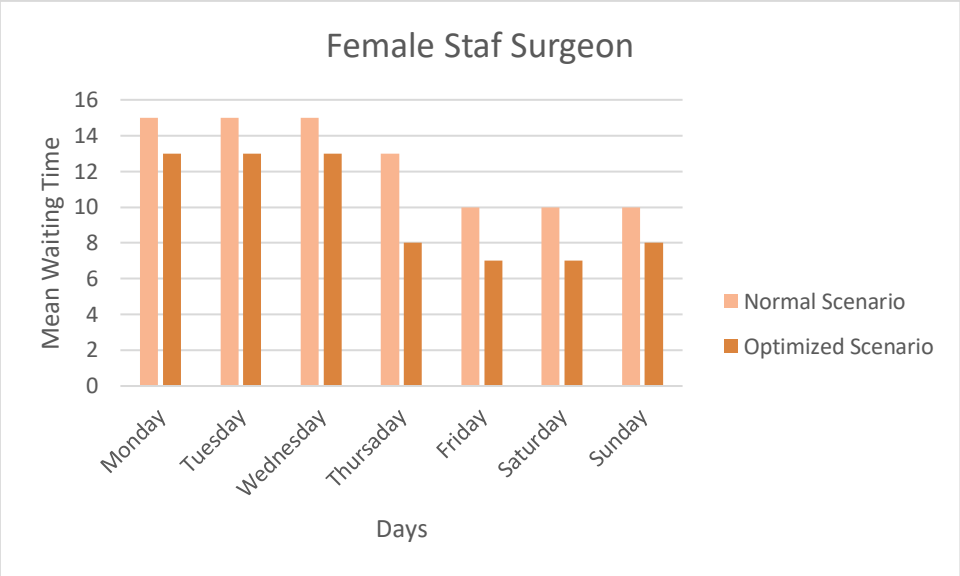


Figure 21c: Mean Waiting time at Female Staff Surgeon

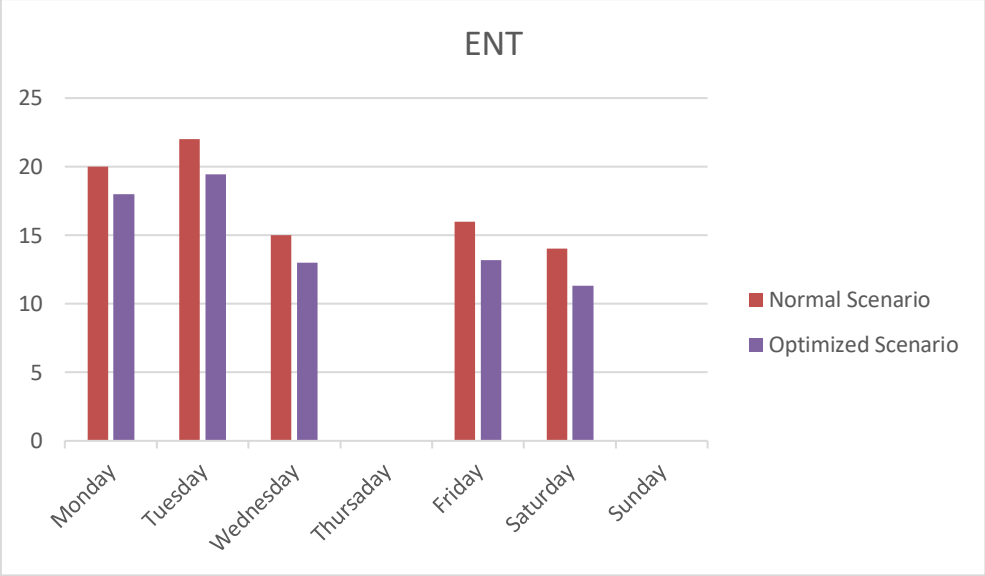


Figure 21d: Mean Waiting time at ENT

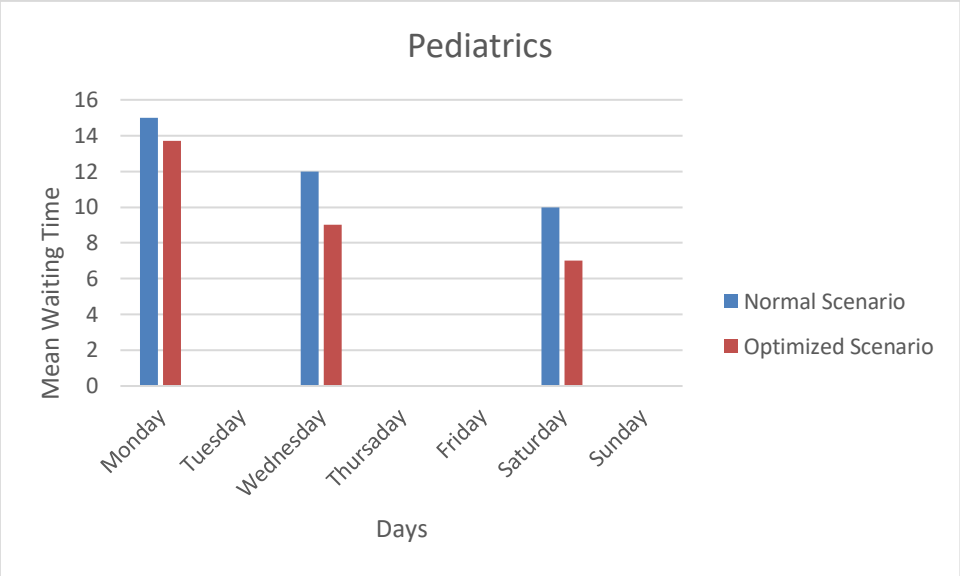


Figure 21e: Mean Waiting time at Pediatrics

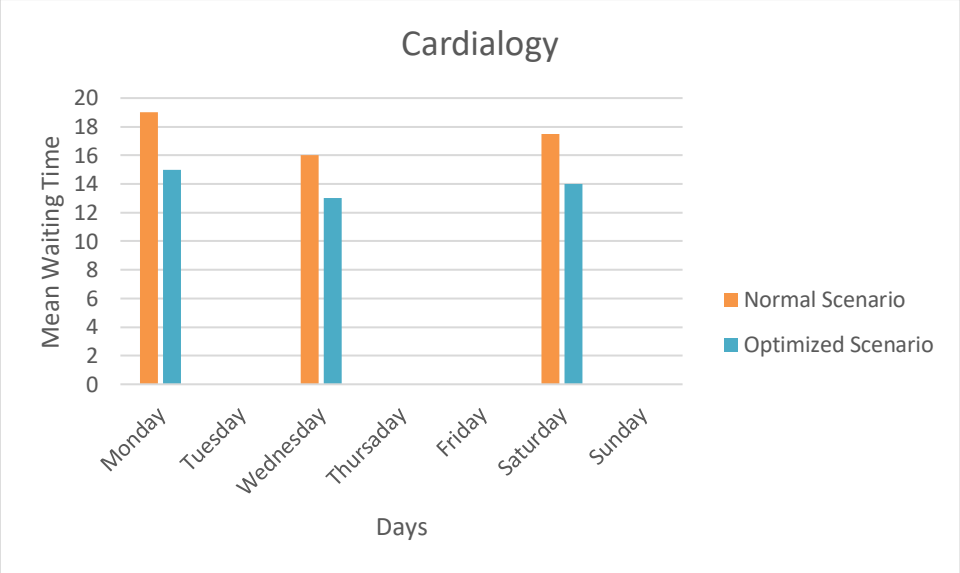


Figure 21f: Mean Waiting time at Cardiology

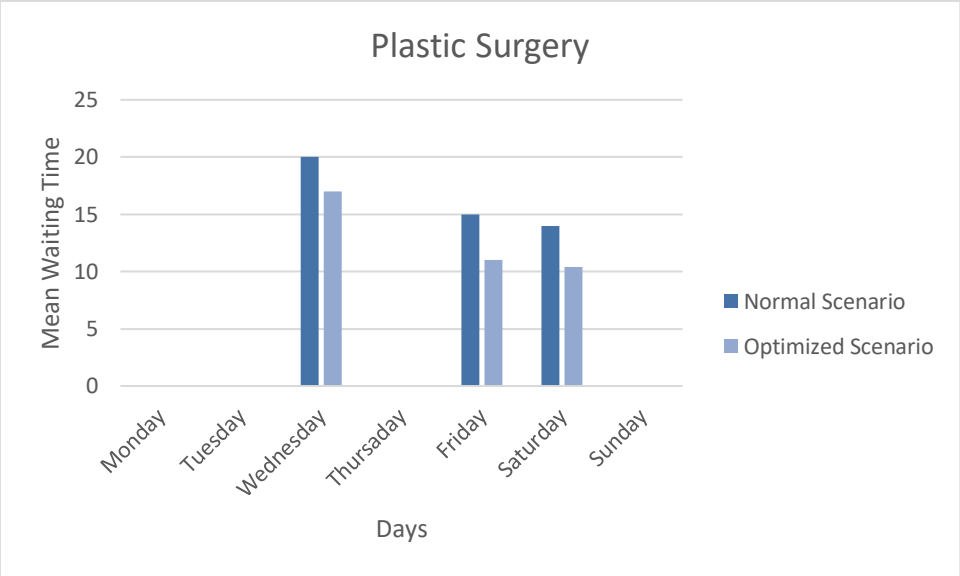


Figure 21g: Mean Waiting time at Plastic Surgery

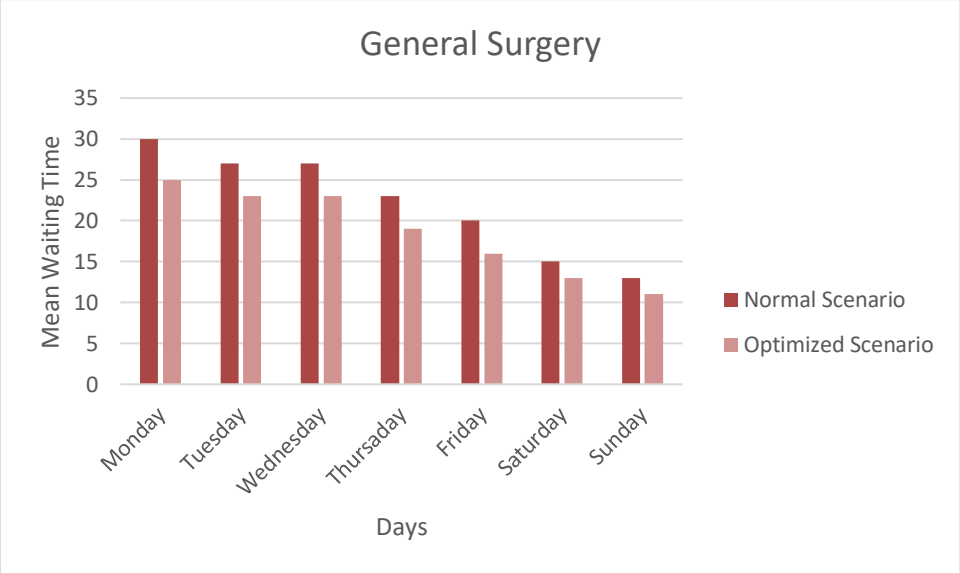


Figure 21h: Mean Waiting time at General Surgery

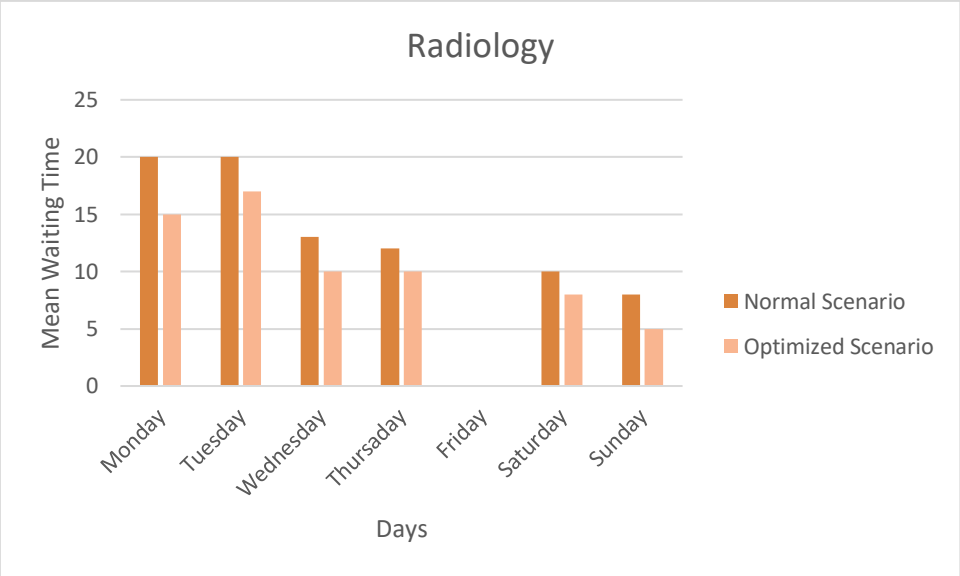


Figure 21i: Mean Waiting time at Radiology

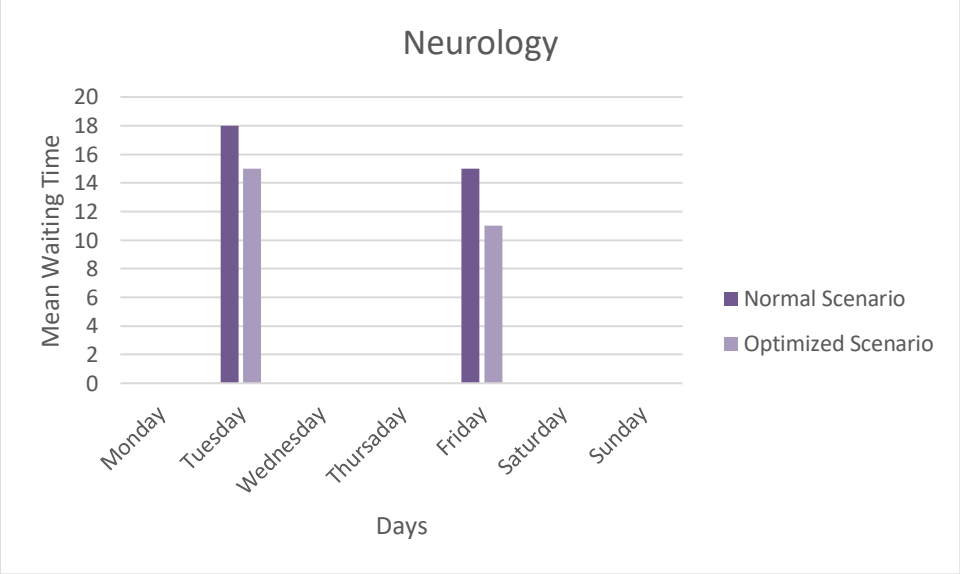


Figure 21j: Mean Waiting time at Neurology

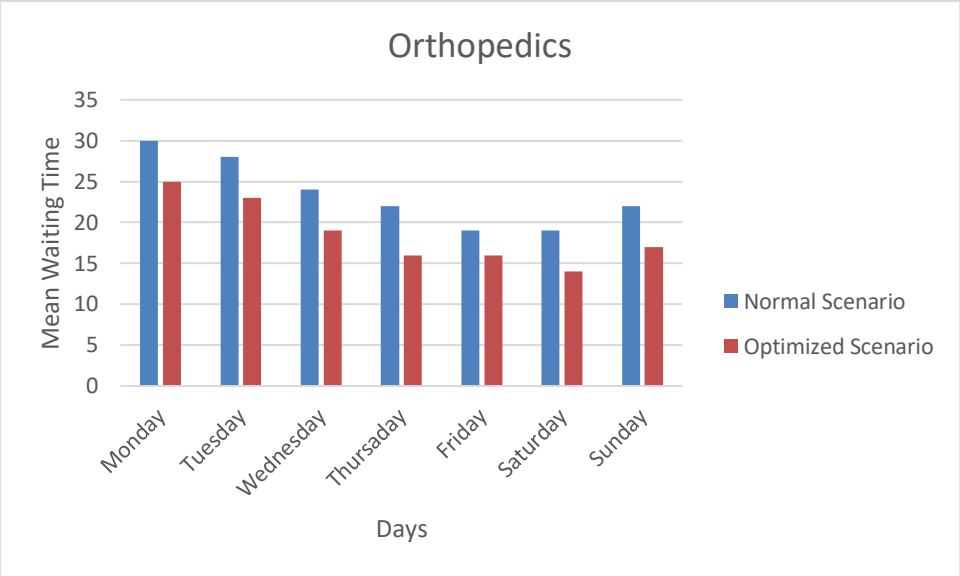


Figure 21j: Mean Waiting time at Orthopedics

In figure 22a patient count at ENT from Monday to Sunday is shown. Patient count is high at the start days of week and then gradually decreases. Graph shows two bars one for the normal scenario patient count and second bar shows mean patient count after simulation. Comparison of normal scenario and simulated result of mean patient count is shown in Figure 22(a, b, c, d, e, f, g, h).

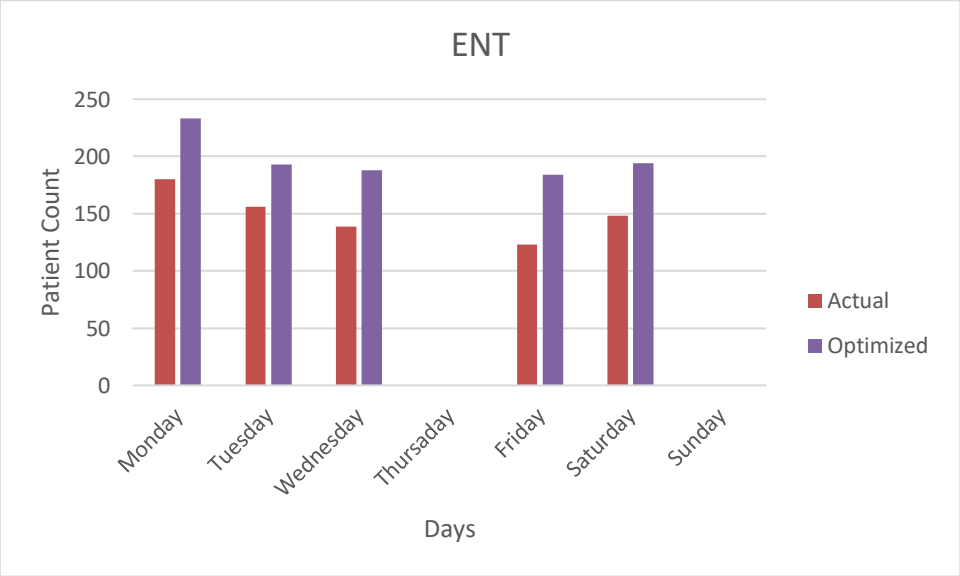


Figure 22a: Patient Count at ENT

In figure 22b patient count at Pediatrics from Monday to Sunday is shown. Thursday, Friday and Sunday are Non OPD days. Graph shows two bars one for the normal scenario patient count and second bar shows mean patient count after simulation. Comparison of normal scenario and simulated result of mean patient count is shown.

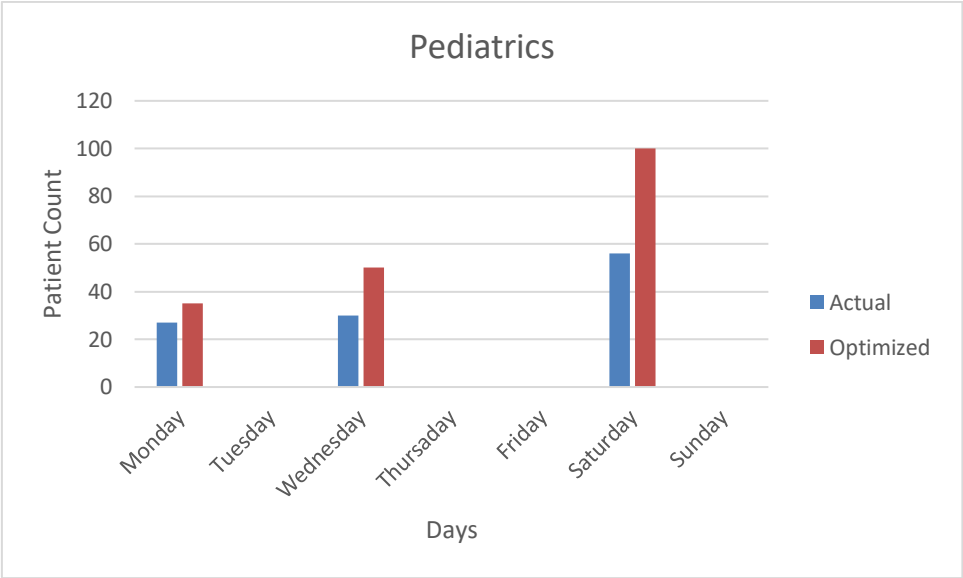


Figure 22b: Patient Count at Pediatrics

In figure 22c patient count at Cardiology from Monday to Sunday is shown. Thursday, Friday and Sunday are Non OPD days. Graph shows two bars one for the normal scenario patient count and second bar shows mean patient count after simulation. Comparison of normal scenario and simulated result of mean patient count is shown.

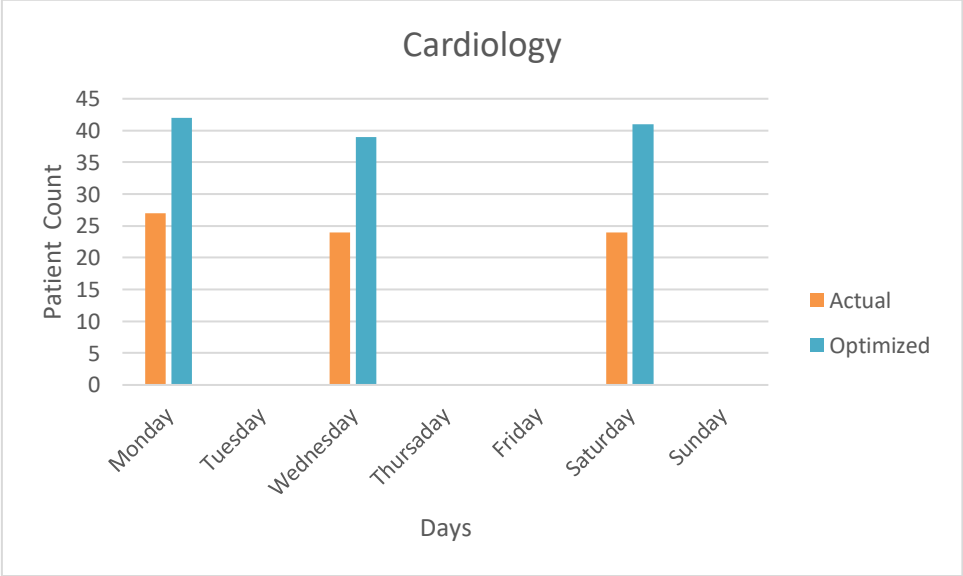


Figure 22c: Patient Count at Cardiology

In figure 22d patient count at Plastic Surgery from Monday to Sunday is shown. Monday, Tuesday, Thursday and Sunday are Non OPD days. Graph shows two bars one for the normal scenario patient count and second bar shows mean patient count after simulation. Comparison of normal scenario and simulated result of mean patient count is shown.

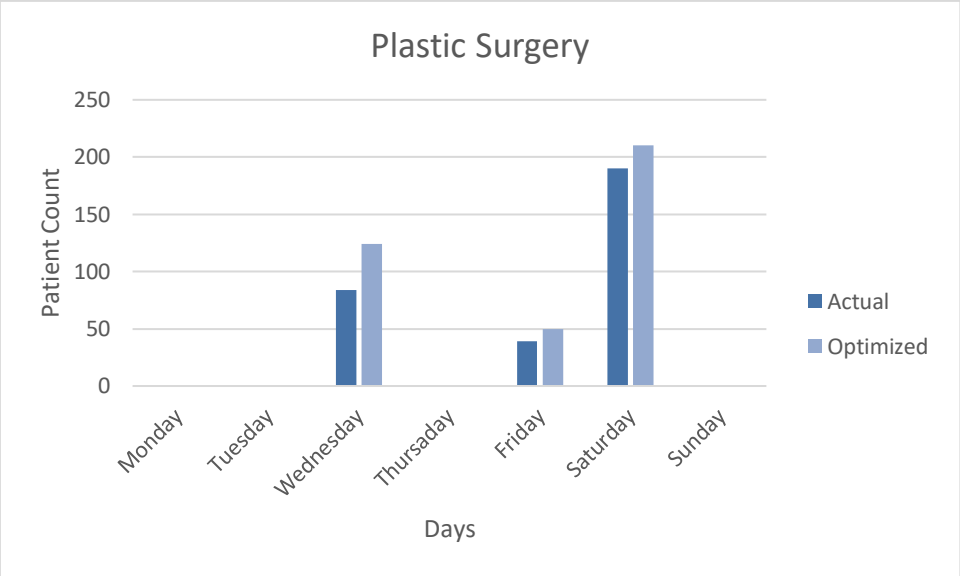


Figure 22d: Patient Count at Plastic Surgery

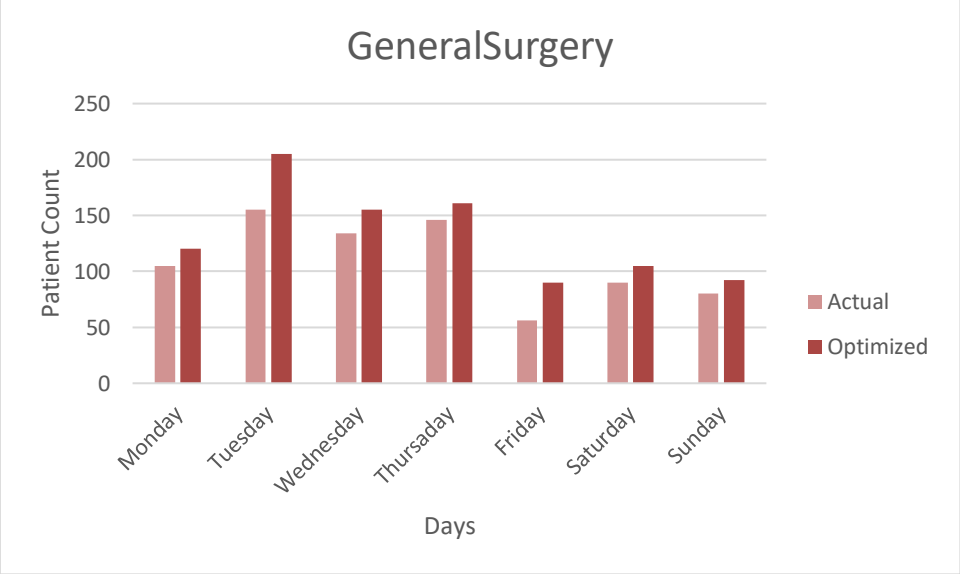


Figure 22e: Patient Count at General Surgery

In figure 22e patient count at Plastic Surgery from Monday to Sunday is shown. Graph shows two bars one for the normal scenario patient count and second bar shows mean patient count after simulation. Comparison of normal scenario and simulated result of mean patient count is shown.

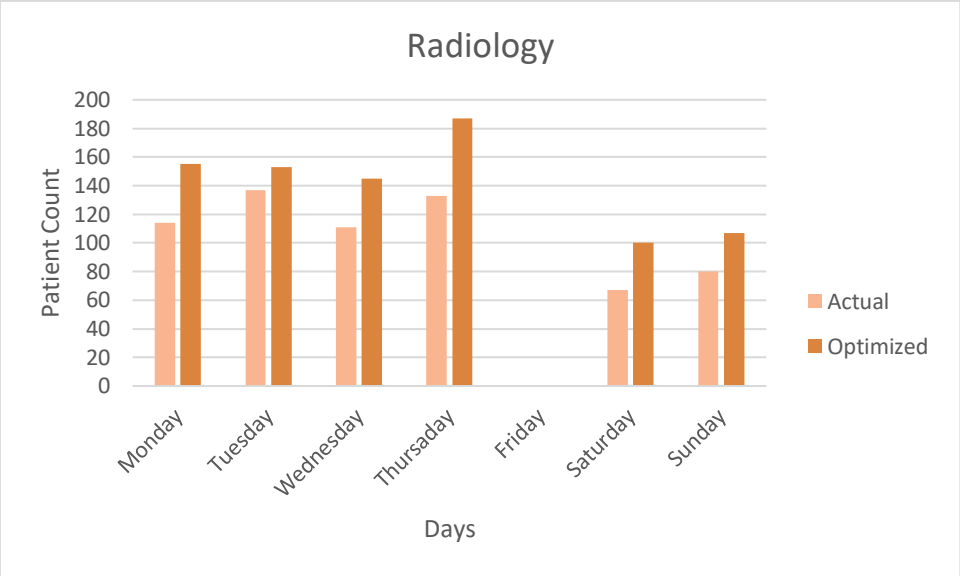


Figure 22f: Patient Count at Radiology

In figure 22f patient count at Radiology from Monday to Sunday is shown. Friday is Non OPD day. Graph shows two bars one for the normal scenario patient count and second bar shows mean patient count after simulation. Comparison of normal scenario and simulated result of mean patient count is shown.

In figure 22g patient count at Neurology from Monday to Sunday is shown. Monday, Wednesday, Thursday, Saturday and Sunday are Non OPD days Graph shows two bars one for the normal scenario patient count and second bar shows mean patient count after simulation. Comparison of normal scenario and simulated result of mean patient count is shown.

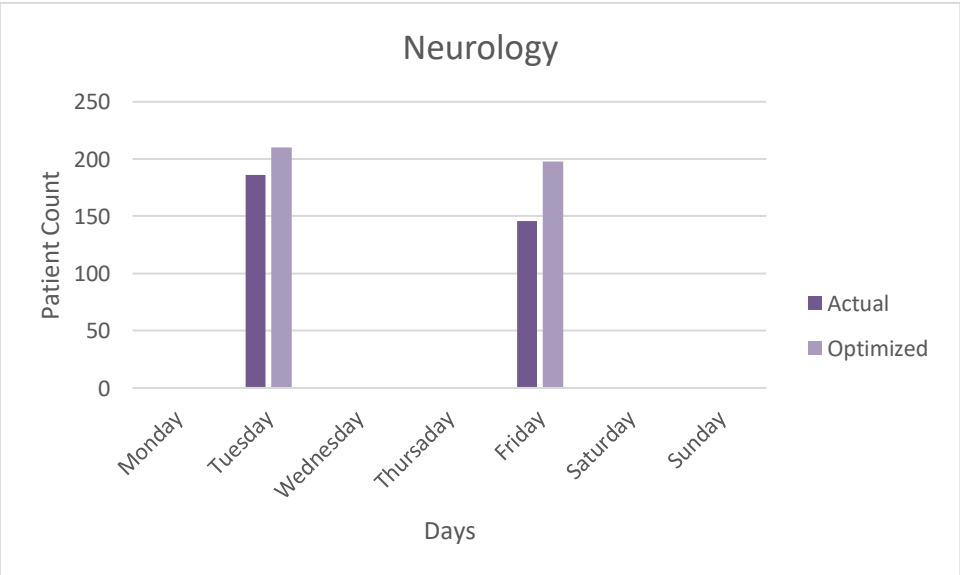


Figure 22g: Patient Count at Neurology

In figure 22h, Patient Count at Orthopedics from Monday to Sunday is shown. Graph shows two bars one for the normal scenario patient count and second bar shows mean patient count after simulation. Comparison of normal scenario and simulated result of mean patient count is shown.

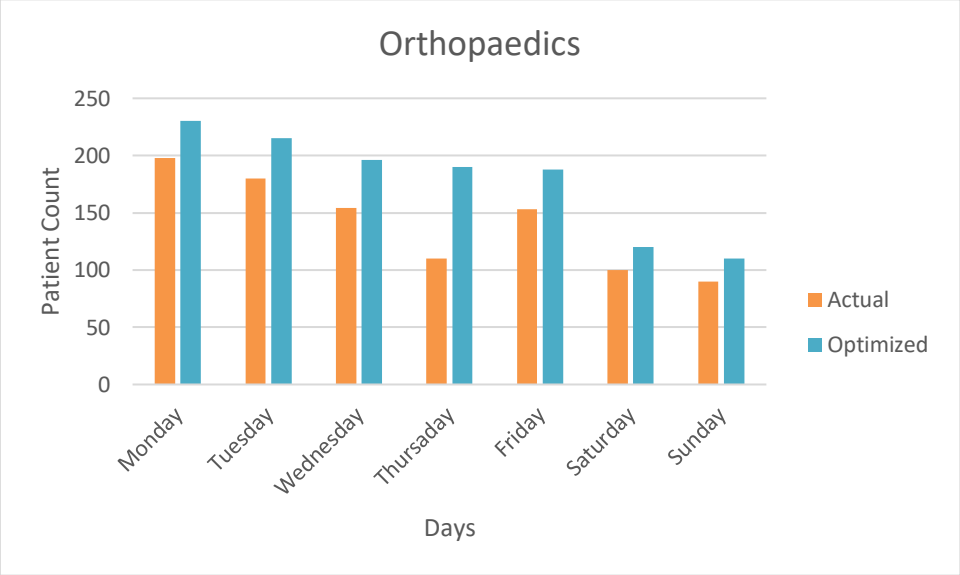


Figure 22h: Patient Count at Orthopedics

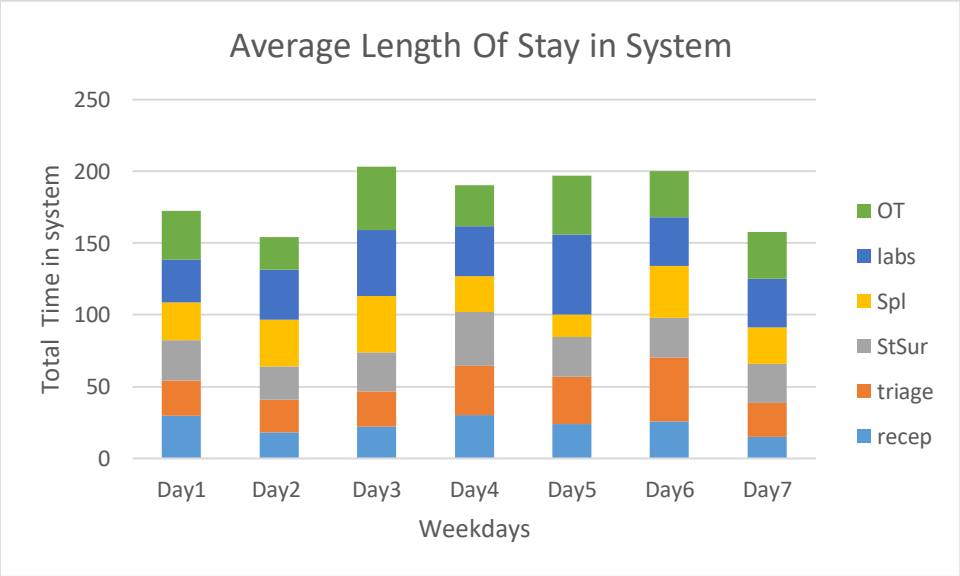


Figure 23: Length Of Stay In System

Figure 23 shows stack chart of total length of stay of different category patients in the system.

Chapter 6
Conclusion and Future Work

This chapter provides the discussion, conclusion and future work of the thesis.

6.1 Conclusion

We proposed a modeling, simulation and analysis framework for maximizing patient flow throughput by optimizing the patient, keeping demand and capacity in balance using hybrid modeling approach which combines Agent based modeling and Discrete event modeling. Our framework allows the modeler to analyze and forecast bottle necks in patient flow at different stages and ratio between demand of unscheduled patients and available capacity or resources. Our framework which consists of two modules: (i) AB module which is used to replicate a patient's flow and demands (ii) DEs module which allows the modeler to replicate complex and dynamic behavior of Patient flow from arrival to first visit to physician.

We present hybrid simulation optimization approach to improve the overall efficiency and effectiveness of the healthcare environment under a limited budget and resource capacity.

It can be analyzed and proved through this framework as to which area in healthcare environment is more crowded as compare to others. It can be seen through all the graphs, what is average waiting time of patients at different stages of healthcare environment, how much time they spend with physician, which department has highest patient count, how are the rooms utilized according to demand, how much time it takes to discharge a patient after completing all formalities. Total length of stay of each category patients in the system, all these key indicators of this research are discussed in detail and proved through graphs, it can be seen through results that to acquire optimized patient flow, activities at healthcare environment, should be streamlined so that the waiting time at each stage of hospital could be reduced. It is not always to increase resources to cope up with higher waiting times it can be managing all activities so that no deadlock can occur. Most of the time patient flow gets affected by mismanagement of administration of healthcare organizations. Improving patient flow require to analyze current flow, available resources, forecast the future demands and implementing strategies which could keep balance between demand and capacity.

Modeling healthcare environment activities is a complex domain of modeling, for which we have used hybrid modeling approach for getting best and optimized result of streamlined activities of healthcare environment.

The simulation framework will help to develop strategies/policies for preventive demand side management as well as better planning for supply and resource management.

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