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SIMULATION AND VISUALIZATION OF LARGE SCALE DISTRIBUTED HEALTH SYSTEM INFRASTRUCTURE OF DEVELOPING COUNTRIES

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A Dissertation submitted to the Faculty of Science, University of the Witwatersrand, in fulfillment of the requirements for the degree of Master of Science.

Johannesburg, 2014

Declaration

I, **ETONDE EMMANUEL NGOLE**, Student Number **707404**, solely declare that this research report entitled **"Simulation and Visualization of Large Scale Distributed Health System Infrastructure of Developing Countries"** is my original work. All sources used or quoted in the report have been appropriately indicated and acknowledged by way of complete references.

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Abstract

Developing countries are faced with a number of health-care challenges: long waiting hours of patients in long queues is just one of such challenges. The key cause of this has been identified to be a lack, or uneven distribution human resources among health facilities. This sets the stage for poor and inefficient delivery of quality primary health care, especially to the rural dweller as they usually have a fewer medical professionals in their area. The impact of this affects not only the state of health of the population, but also the economy, and population growth of the affected community. To try and address this, the introduction of Information Technology (IT) into health-care has been suggested by many health governing bodies like the World Health Organization (WHO) and other authorities in health care. The ability of IT to go beyond physical boarders and extend professional care has been the key characteristic that supports its integration into health-care. This has eventually lead to the development of Health Information Systems (HIS) that support remote consultation. Despite all these innovations, there is still evidence of poor and inefficient delivery of services at health facilities in many developing countries.

We propose a completely different approach of addressing the problem of poor and inefficient delivery of health-care services. The key challenge we address is that of lengthy queues and long waiting hours of patients in health facilities. To cut down on the use of financial resources (whose lack or shortage is a major challenge in developing economies), we propose an approach that focuses on the routing of patients within and between health facilities. The hypothesis for this study is based on a suggestion that alterations to the routing of patients would have an effect on the identified challenges we seek to address in this study. To support this claim, a simulator of the health system was built using the OMNET++ simulation package. Analysis of test-runs for different scenarios were then tested and the simulation results were compared against controls to validate the functioning of the simulator. Upon validation of the simulator, it was then used to test the hypothesis.

With data from the different health-care facilities used as input parameters to the simulator, various simulation runs were executed to mimic different routing scenarios. Results from the different simulation runs were then analyzed. The results from the simulator and analysis of these results revealed that:

- In a case where patients where not given the liberty to consult with a doctor of their choice but rather to consult with the next available doctor/specialist, the average time spent by patients dropped by 26%.
- The analysis also revealed that moving a receptionist from the first stage upon patient entry into the health facility reduced the average patient life time by 85%. This was found to be a consequence of a drop in queue length (a 28% drop in queue length).
- On the other hand, the analysis also revealed that the total removal of a general receptionist increased patient life-time in a facility by 30.19%.
- This study also revealed that if specialists were deployed to certain health facilities rather than having referred patients come to them in the urban health facilities, patient population in the urban health centers will drop by 32%. This also saw a drop in patient waiting time in the rural health centers as more doctors were available (a reduced patient-to-doctor ratio in rural health facilities).

The results from the analysis support our hypothesis and revealed that indeed, alterations to the way patients are routed does have an effect on the queue lengths and total waiting time of patients in the health system.

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List of Acronyms, Symbols, and Words/Phrases

Acronym	**Description**
IT	Information Technology
WHO	World Health Organization
HIS	Health Information Systems
IOM	Institute Of Medicine
IS	Information System
SAN	Storage Area Network
AICD	Africa Infrastructure Country Diagnostic
PEPFAR	President's Emergency Plan For AIDS Relief
CHITS	Community Health Information Tracking System
UNDP	United Nations Development Programme
QED	Quality and Efficiency-Driven
GP	General Practitioner
PDF	Probability Density Function
SD	Standard Deviation
RNG	Random Number Generator
DC	Departmental Configuration
HC	Hospital Configuration
CC	Community Configuration

Symbol	**Meaning**
λ	Patient arrival rate
μ	Service time
$\bar{\mu}$	Average/Mean service time

t	Time
τ	Time interval
P	Probability
P_0	The probability of an event at $t = 0$
k	An integer value/constant
$\bar{p}$	Mean of the Poisson process
n	Number of patients/customers
c	Number of service points
ρ	The system load or the density of patients in the system
P_n	The probability that n events have occurred
L_q	The length of the queue
W_q	The waiting time at a queue
SD_{mst}	Standard Deviation of the mean service time
SD_{mat}	Standard Deviation of the mean arrival time

Words/Phrase	**Description/Meaning**
Reception	The desk/post where the receptionists interact with the patients.
Receptionist	The nurses/health workers who get to first interact with the patient entering the facility.
Life time	The total time spent by a patient in a given health facility.
Architecture	The different possible permutations of how various health-care facilities can interact with each other.
Queue length	This number of people (patients in this case) lined up and waiting to be attended to.
Route/Routing	By this, we are referring to the possible pathways patients can take within the health infrastructure.
Health Network	By health network, we are referring to the various health-care facilities within a given region or community. This could be within a municipality or any population grouping unit.

Chapter 1

INTRODUCTION

In this chapter of the report, we will briefly talk about health-care in sub-Saharan African countries and other developing countries around the world. We discuss some of the challenges faced by the health systems of these economies and some prior attempts that have been made to address these identified challenges. We also give a brief discussion of how the identified attempts have affected health-care so far. We then enumerate some of the shortcomings still faced in the health system of developing economies and discuss how this study aims to address them and further improve the quality of health-care and service delivery. Later in the chapter, we introduce our proposed approach for dealing with long queues and long waiting hours and later on discuss how our findings would improve health-care. We also outline some anticipated contributions this study aims to make in computer science and health-care.

In recent years, improvements in Information Technology (IT) have increased the boundaries within which "businesses" can operate. This has pushed for the use of IT in a wide variety of disciplines, one of which is public health. The integration of IT into various disciplines has proven to improve the general quality of service and efficiency of various business processes. A testimony to this can be seen in improvements in communication, productivity, efficiency, and timely access to information [15] in environments that have embraced IT into their business processes.

Health-care in sub-Saharan African countries and other developing countries around the world face several challenges that have a negative impact on the quality of service being delivered. One key challenge is the

lack of sufficient resource: financial, infrastructural, and professional staff. The effects of these drawbacks in health-care is mostly felt in the rural communities.

A study carried out by Munga and Mæstad [25], revealed that up to 90% of professional health workers in developing countries work in health facilities that serve urban communities. This makes it a challenge for inhabitants of the rural areas to access quality primary care from a health facility. This compels patients in the rural communities to make long trips to the urban towns in search of quality service [32]. Infrastructural challenges like bad road and poor transportation facilities does not make this move any easier for the rural dwellers. Reasons for this uneven distribution of professional staff can be attributed to challenging working environment in the rural areas and other challenges identified by Kamien and Cameron [20] in an earlier study carried out in 2006.

Attempts to try and address this uneven distribution of health workers between rural and urban areas has seen the introduction of innovative communication techniques between rural and urban health facilities. Some of these innovative techniques have seen the introduction and implementation of the following in various health facilities.

1. Mobile communication technology [21, 41].
2. Low-cost information technology [3, 30], and
3. The use of mobile clinics to expose rural dwellers to professional care [39].

During the course of this study, we plan to acquire a better understanding of the communication[1] between health facilities. With this knowledge, we plan to explore different possible configurations of this communication architecture between health facilities. This should improve health care by making professional care available to the local rural community in a shorter response time without the inconvenience of having to travel long distances to seek professional care.

1.1 Motivation

The primary purpose of any health-care facility is to provide inhabitants of the local community with health-care services. This mandate is being challenged regularly in developing economies. Those who suffer the most from the effects of these challenges are the rural dwellers and this is especially due to the lack of sufficient resources in these disadvantaged communities (rural communities). The lack of sufficient health workers in

[1] By communication, we refer to the manner in which patients move within and between health facilities.

developing countries is no longer questionable, but a sure challenge faced by health-care in many developing countries [25, 30, 42]. Many reasons could be attributed to this uneven distribution of professional health workers between the rural and urban areas. The most prominent ones being:

- The lack of a comfortable working environment:
  - Poorly equipped health facilities.
  - High disease spread.
  - Political unrest.
  - Poor living standard.
- The lack of proper roads and/or other means of transport.
- The lack of adequate communication facilities:
  - Internet access.
  - Poor mobile network signal reception.
- Partial or complete lack of research support facilities:
  - Partial or complete lack of research funding.
  - Partial or complete lack of access to up-to-date information.

These factors all play a major role in population migration and as a result, more and more professional health-care workers are forced to migrate from the rural areas to the urban areas where the effects of the above mentioned challenges are not as severe as is in the rural areas. This obviously makes it a challenge or completely deprives dwellers in the rural community from accessing quality health-care service.

Despite these and the many other challenges pointed out by Leonard K. L. [22] and Pathman et al. [31], local governments have devised plans to try and combat these challenges with the aim of improving health-care service delivery to the rural communities. One key means of improving health care involves the injection of resources into the system [24]. The key resources needed in most developing economies include human resources, road network infrastructure, communication network infrastructure, access to information, equipments, e.t.c.

The availability of human resources is vital to improving health-care. It is for this reason that some countries have introduced short-term training programs to train low level health personnel to carry out basic health-care services in the rural communities. In some cases, retired health personnel have been recalled to serve, all these in an effort to address the problem of shortage of health workers. There has also been an observed increase in

the donation of funds and other types of resources (mainly infrastructure and equipment) to under-developed health facilities by various health support initiatives and organizations. One of the major reasons for these donations is to attract professionals to work in *newly renovated* facilities and improve the quality of service being delivered by the previously disadvantaged health facility.

These efforts have, however, not been able to entirely address all the challenges as there are still high levels of inefficiency and poor quality health-care service being made available in the rural health centers. The way forward as suggested by most scholars and other health care governing bodies has been found to lie in the use of IT [40]. The main purpose for the use of IT has always been to contribute positively to the quality and efficiency of patient care [17].

Information Technology has proven to have a positive turnaround effect on the quality of services and product delivery in many enterprise environments. This strategy has also been shown by Bates et al. [10] to equally have the potential to improve health-care. It is for this reason that many proponents of this initiative like the World Health Organization (WHO) and Institute of Medicine (IOM) are pushing for its integration into health-care in many of the developing countries in sub-Saharan Africa and other parts of the world.

Until recently, extensive studies that had been carried out with regards to the use of IT in health-care centered around component aspects of the health system. Most of these studies focused on data/information storage [8, 36], security concerns (access management) [7], and also on the ethical implications of IT in health-care [19]. Most of the studies that have discussed information system (IS) for health-care in its entirety have mostly focused on the feasibility and limitations of such innovation in health-care [29].

This study, on the contrary aims to investigate, given the current available resources, the best possible communication configurations that can exist within and between health facilities to make more efficient use of the available resources. A built simulation will be used to analyze the various possible configurations and identify the best configuration that makes better use of the available resources.

1.2 A Typical Health-care Structure

Figure 1.1 depicts a typical health-care system that exists between health facilities in neighboring communities in developing countries around the world. In this abstraction, three urban hospitals and several polyclinics that serve their respective communities are shown. Usually, the urban hospitals are relatively well equipped and better staffed health facilities compared to the rural polyclinics.

As seen on Figure 1.1, the three urban hospitals communicate with each other over *high bandwidth Internet* connections and *storage area networks* (SAN). This permits them to share data and information with each

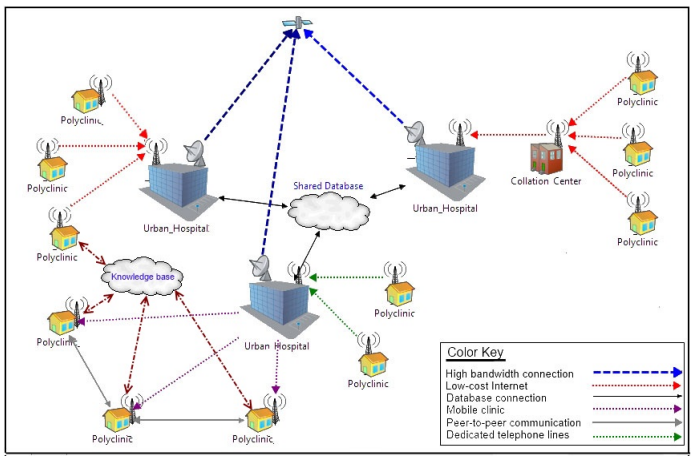


Figure 1.1: A basic overview of the Structure of Health-Care

other.

The rural polyclinics on the other hand receive patients who possibly require health services they can not offer. The polyclinics are forced to refer these patients to neighboring polyclinics or urban hospitals. As shown on Figure 1.1, communication between the rural and urban health center is done by means of

1. *low-cost Internet* communication,

2. *peer-to-peer* communication, or

3. *telephone* communication with devices such as smart-phones and tablets.

Innovations in transportation and technology has made it possible for the use of what is locally known as *mobile clinics*. This is used mostly by the urban hospitals as a means of taking professional service from the urban hospitals to the rural communities. This way, rural dwellers get a chance to receive professional care in the comfort of their local community without having to incur travel expenses and other inconveniences that come with the transportation of a patient.

1.3 Problem Definition

Considering a typical scenario in a developing country, lets say:

1. The rural communities have small polyclinic(s) with very few (if any) specialized health workers and are equipped with;

    - Small PC for patient record capture and storage,
    - Low-cost Internet facilities,

- Dedicated telephone lines,
- Poor transportation,
- Smart devices,

2. The urban cities, with a greater population of specialized health workers have reasonably equipped health center(s) with;

- Better and advanced equipment,
- High speed Internet connectivity,
- Medium to high performance computers,
- Specialized/professional health workers,
- Better communication facilities,

we address the problem of lengthy queues and long waiting hours of patients by configuring the manner in which patients are routed within and between health facilities. This configuration should be such that;

1. Queue lengths in health facilities are reduced,
2. Patient waiting time for service is reduced,
3. Patient referrals from rural to urban centers are optimized,
4. Patient relocation from rural to urban health center to consult with a specialist is reduced.

This is based on the a hypothesis under which we are basing the methodology we propose in this study.

1.3.1 Hypothesis

The proposed method we put forward in this study to address the problem of lengthy queues and long waiting hours in a health facility is based on a hypothesis which we state below.

> ***hypothesis:*** "*The manner in which patients flow within and between health-care facilities affects the length of the queue and the waiting time of patients in the system.*
> *Given this, there is therefore a given* ***pattern of flow*** *of patients which when implemented in the system, will result to shorter queue lengths and consequently, shorter lifetimes of patients in the system.*"

1.4 Motivations for the Research Methodology

As stated in section 1.3, this study aims to address the problem of lengthy queues and long waiting hours in your typical health facility. Based on the hypothesis in the previous section, the simulator tries test the hypothesis.

Given the vast size the typical health network, carrying out a study like this in real time in the real world was going to encounter many challenges. Some of the anticipated challenges include:

- **Financial challenges:** It was going to be a challenge having to travel around on a daily basis to the numerous sites (health-care facilities) that were chosen as sites for data acquisition centers for this study. Hiring research assistants would have also posed a financial burden to the progress of the study as this research had no sort of funding assistance from any body[2].

- **Time constraints:** If this study was to be carried out in real time, it would have required researchers to observe various doctors in various departments in the various health facilities for several days each. This would have lead to a much long research time to establish acceptable patterns with the data captured from the the various data capturing sites.

- **Obstruction:** Because the study involved humans, many health authorities for the various facilities were not willing to authorize this study in their respective facilities. Reasons being they did not want any alterations to their daily operations at the expense of patients. Also, they made it known that a prolonged daily presence of a researcher at their facility could infringe the rights of their patients and staff as well.

- **Simulation methodology:** The benefits of the simulation methodology itself were key to this research methodology:

  - It enables one to study an environment and subject it to all sorts of alterations and draw accurate conclusions even before building the system.
  - It enables a researcher deduce un-expected phenomena and behaviors of a system, thereby reducing the chances of surprises in the system under investigation.
  - Results drawn from the simulation research methodology are more accurate than those drawn from an analytical model.
  - The simulation research methodology provides a researcher with a means of testing a system for its behavior in extremes scenarios and sometimes impossible but plausible scenarios.

The above mentioned facts together with those mentioned in the second paragraph of chapter 3 were the key motivations for the choice of a simulation methodology as the key research method for this study.

[2]By body, we mean any institution or other research groups that have a research interest in this subject area.

1.4.1 Simulation Brief

To address the problem and improve service delivery, certain key properties of the current health-care system needed to be fed into the simulator as input parameters. Some of these properties include:

- The arrival rate (λ), and
- The service times (μ).

These two attributes[3] were the two key inputs into the simulation. Firstly, an assumption used in the system is that patient arrival into the system can be described by a *Poisson distribution* function. Another assumption made was that the distribution of service times for health workers is (random and) normally distributed about a given average mean value ($\bar{\mu}$).

For each of the service stations in the system, i, the parameters for the respective arrival rate and service time were denoted as λ_i and μ_i respectively. Given these (as input parameters), the simulator was then used to test the hypothesis.

1.5 Anticipated Contribution

This study goes to demonstrate the capabilities of the simulation methodology, especially in studies whereby the final outcome cannot be determined directly through analysis due to the complexity of the system under investigation. The main contributions we make in this study include:

1. Developing and implementing an easily configurable simulation model for a complex environment is possible using the OMNET++ simulation tool.
2. The building and analysis of a system or environment which is not necessarily a computer network is possible with the simulation providing reliable results, Given then the various system properties are properly managed and correctly interpreted by the simulation tool.
3. We demonstrating the capabilities of the *OMNET++* simulation tool to effectively build a parameterized simulation of a communication architecture for health-care and visibly mimic activities in the health-care system at simulation run-time.
4. We also demonstrating the use of *network of queues* to analytically validate, evaluate, and analyze different possible configurations of the communication architecture that can exist within and between health-care centers.

[3]Two from among others [23] which are used to access and characterize the quality of a given health system.

1.6 Chapter Summary

In this chapter we briefly talked about health-care in sub-Saharan countries and other developing countries around the world. We discussed very briefly, some of the problems faced by the health-care system in developing countries and also identified the key problem we address in this study. We then listed some of the possible contributions we anticipate this study to make in this area of study. In the next chapter, we focus our attention on prior studies that have been carried out in health-care to address the identified challenges faced by the health system in developing countries. We also site some of the differences and similarities between the various studies that were surveyed in this regard. Finally, we gave a brief discussion of how this study differs from the others and how the findings would possibly integrate with other results from other studies to improve the overall quality of health care service delivery in developing countries.

Chapter 2

LITERATURE SURVEY

In chapter 1, we talked about health-care in sub-Saharan countries and other developing countries around the world. We discussed the challenges faced by the health-care system in these developing countries. We also make mention of some of the attempts in place to try and improve service delivery. We later discussed some of the shortcomings still faced in health care and also discussed how this study intends to add value and quality to the health system. In this chapter, we give a brief outline of prior studies that have been carried out in this respect. We point out some of the peculiar characteristics of the respective studies and later on describe how our proposed approach differs from them.

2.1 Health and Health-care in Developing Countries

It is no longer questionable that one of the major challenges faced in developing countries is felt in the health sector. Some of the reasons for these challenges have been attributed to the lack of adequate resources in the health facilities. Poor living standards that result from a relatively low income are a recipe for wide spread of diseases which in turn can be attributed to the poor hygienic conditions that surround these environments. Political unrest, population migration, and even poor disaster management are among the many other contributing factors that play a great role in the health of any economy with developing countries facing the downside of such factors more than any other economy.

From an economic point of view, the economy of a population is dependent on a unit as small as the health of each household in that economy. There is no doubt that a healthy household will lead to a healthy community

which is unquestionably a positive driving force behind the success of any economy. A common illustration of this, as observed by Boutayeb [13], is seen in how the HIV/AIDS virus has impacted the young workforce of many developing countries in Sub-Saharan African nations. Families and households turn to focus more on looking after the sick and in so doing; their productive potential is severely hampered.

2.1.1 Challenges in Health-Care

Of the many challenges faced by the health-care in developing countries, the most sever of these challenges is the limitation or complete lack of the required resources [25]. This has shown to greatly reduce the quality of service being delivered from such economies in every aspect and as a result of this, the community which is supposed to receive services is bound to suffer. These effects can be seen in what is currently experienced in the health sector of many developing countries around the world. Making a comparison of the health and resource availability between the rural and urban communities reveal shocking gaps in the differences.

A key resource that is in high demand in health-care in developing countries is man-power. The migration of professional health workers from sub-Saharan Africa and other developing economies to the more developed countries has been on the rise as revealed in a report by the United Nations Development Program [4]. This migration of professional health workers has become a threat to the growth and development of emerging economies that have health-care at the center their socio-economic development program. This affects such economies through the health of its population as it is constantly being deprived of quality health-care.

For those health workers who reside in the developing countries, studies carried out by Munga and Mæstad [25] revealed that over 95% of them resided in the urban communities. This of cause leads to unusually high patient-to-doctor ratios in the rural communities and a relatively low patient-to-doctor ratio in the urban cities. Evidence of this is seen in Ghana where on average, there are 5,103 patients-per-doctor in Accra and 50,751 patients-per-doctor in the Northern region [27]. These high figures in the rural communities will definitely lead to over crowding in the medical facilities and therefore, long queues and lengthy waiting times in such facilities are inevitable. Other reasons have equally been put forward as possible causes for over-crowding in health facilities:

1. **Demand is greater than capacity:** There are more patients than the facility can handle. If daily patient arrivals into a facility are greater than the service capacity of the facility, the waiting list is bound to grow exponentially over time. The mostly likely reason for this is that *service time* $\gg$ *inter-arrival time*. Given this condition, Figure 2.1 describes how the queue length changes over time. Evidence of this can be seen in reports of Health Professionals [27].

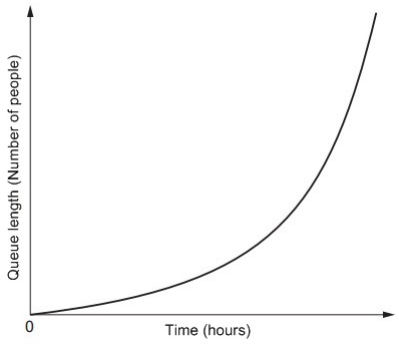


Figure 2.1: Generic projection of how queue length changes over time.

2. **100% usability of resources:** There is a notion in resource utilization that 100% usability will lead to greater efficiency. Conversely, free capacity is identified as a waste and is an indicator of inefficiency. Given that patients go through a series of activities throughout their cycle in a health facility, one of the activities can be seen as a possible bottleneck. The resources for this particular activity most likely governs the output rate of the entire process. In the event of varying demand and bottleneck capacity, this activity cannot be kept at 100% use. This is based on Erlan's theory on queues which suggests than high levels of such activities in a system will create queues [5]. The resulting relationship between queue length and use is described by Figure 2.2.

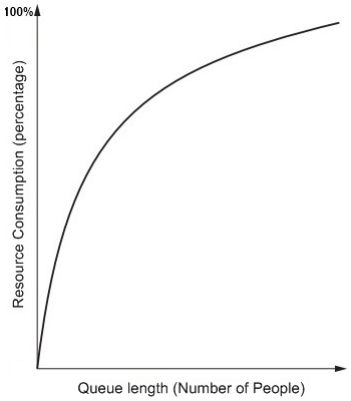


Figure 2.2: Generic projection of how resource usage changes as queue length increases.

Over crowding in the affected health facilities has prompted local governments find alternative solutions to the challenges faced by their respective health-care systems. Some of such measures and developments as cited by scholars like Robert W. Derlet and John R. Richards [33] include:

- A spacial expansion of health facilities (in terms of capacity).
- The growth of alternative for primary health-care.

- A change in admitting patterns.
- Provision of primary care only to emergency patients.
- The introduction of IT into health-care through the use of Video/Voice Over IP [1].
- Recall of previously retired health workers.
- The introduction of mobile clinics.

All these efforts have contributed greatly towards reducing crowds in rural health facilities. However, there is still evidence of crowding in public facilities and as a result, lengthy queues and long waiting hours. It is in an attempt to further reduce this that we have proposed the solution discussed in this report.

2.2 Prior Studies and Turnaround Strategies

Sub-Saharan African countries are among the many other developing countries around the world that are embracing changes in IT. With the advent of the Internet and mobile communication, more and more people have been getting acquainted with these new technologies to make their daily life tasks easier and more convenient.

In Kenya for instance, studies carried out by Ampah et al. [6] for the Africa Infrastructure Country Diagnostic (AICD) revealed that as of 2009, only as many as 30% urban inhabitants were Internet subscribers and users. This is by far lower than what was observed in a study carried out in Singapore by Teoa et al. [37] as far back as 1997 which revealed that on average, 89% of the population were Internet users.

Despite the observed low IT literacy levels in developing countries, the evidence of its positive impact in the economy of developed countries have made it worth investing for in the developing world. It is for this reason and many others that many funding bodies like the United States President's Emergency Plan for AIDS Relief (PEPFAR), Global Fund and the Bill & Melinda Gates Foundation, (just to name a few) have embarked on health-care developmental projects in developing countries. Such funding assistance and the positive impact they have made to the respective health-care systems can be seen in effect in countries like;

- Kenya (low-cost electronic health records for HIV/AIDS patients),
- Peru (web-based communication tools to address maternal and child mortality),
- Mongolia (telemedicine),
- Malaysia (e-pharmacy projects), and many others.

These examples, together with results from other studies by Black et al. [12] and the Institute of Medicine [28] confirm the positive impact IT has shown to have on the quality of service in the health sector.

Despite the projected improvement in the quality of health services as a result of a communication infrastructure overhaul in developing countries, limitations in resources as cited by Fraser et al. [16] and digital gaps in IT that exist in developing countries posse questions about the success and feasibility of this initiative. However, an abundance of choice of system hardware has made them relatively cheap to purchase [34]. Given Moore's law and other finding by The Bureau of Labor Statistics [38] on the trends of the cost of IT and communication hardware, it has become relatively cheaper to carry out such proposed infrastructural make-overs.

A survey of publications on the use of IT in health-care by Braa and Hedberg [14] revealed that until recent years, most of the research work in this area have focused mainly on patient information/record management, disease management and statistics, and administration. Some of these projects include:

2.2.1 Direct IT Strategies

Community Health Information Tracking System (CHITS), Philippines

CHITS is a low-cost computerization initiative that was founded by the International Development Research Center of Canada and subsequently by the United Nations Development Programme (UNDP) in 2004 to assist rural health centers in the Philippines. Its main purpose was to automate many of the core process in the local health centers.

Given the amount of data collected from patients in the rural communities, it had always been a challenging task to combine the collected information into a relevant whole. Conventionally, patient records were recorded on paper, a process that wasn't just time consuming, but also very prone to error. This process was labor intensive and the collected data was often outdated or incorrect. Some key positive features of this system are that:

- Patient queuing time was greatly reduced since less time is spent searching for patient's electronic records as opposed to the traditional time consumed doing paper-record search.
- It made data consolidation, report generation and planning possible at any time.
- It enabled patient monitoring and reporting possible and easier.
- It made detection of possible disease outbreaks easier.
- It provided the ability to monitor the health of the community through daily data buildup.

- Information was readily available to stakeholders in the community for better decision making.
- It provided easier and timely generation of health reports.

Careware, Uganda

This is free software that was developed by a team at the US Department of Health and Human Services to assist and support HIV patients. Its main purpose is to gather information about those suffering from HIV and generate reports. It also enabled patient tracking with regards to their treatment, billing data, and clinical assessment.

This system was originally built in the US but has also been deployed to assist in developing countries like Uganda and Puerto Rico where it currently serves the local population in managing HIV patients. Some of the key positive features are that:

- It has ability to harness the internet.
- It has a feature which allows health centers to import data from others Health Information Systems and health facilities.
- It can operate across international borders.

Telemedicine Project, South Africa

The South African Department of Health, in 1998, decided to put together a team that was tasked with the introduction of telemedicine into the health care system. The main objective behind this project was to deliver high quality cost effective health care services to impoverished communities and also to augment the knowledge of health workers. The project has been sponsored by the National Health Information System committee and it involved several participating provinces: Mpumalanga, KwaZulu-Natal, Free State, North West and the Eastern Cape provinces. The project covered a number of specialist fields in medicine, some of which include ophthalmology, radiology, and pathology, with each having their pilot sites distributed among the participating provinces.

2.2.2 Simulation and Modeling Strategies

Out-patient queuing in Chia-Yi

This study involved addressing the problem of overcrowding of patients in the outpatient department of a local health facility in Chia-Yi in Taiwan. This study also found that medical staff were over worked in this facility.

To address these problems, a simulation methodology was used to investigate various ways of reducing the population (queue length) in the out patient department.

Findings by Huarng and Lee [18] revealed that the queue lengths in the outpatient department was greatly reduced after subjecting the system to changes which mimicked changes in the appointment system, staffing policies and service units.

Out-patient waiting time in Jitra health center

In this study, bin Salleh et al. [11] came to the conclusion that overcrowding and long waiting hours of patients in health facilities also result from a high patient-per-doctor ratio in the facility. In other words, they discovered that the unbalance between the number of patients arrivals and the number of available doctors was creating a bottleneck effect in the department.

To address this problem, results from the simulation of this study revealed that a rescheduling of out-hospital consultations would dramatically reduce these queues. This addressed the problem at hand by making more health staff available to the population.

Hospital pharmacy performance

The hospital pharmacy is the center point for the distribution of medication to patients from various departments in a given hospital. As a result, there are bound to be queues of patients waiting to obtain drugs. This process can be seen as a rate determining step in the general life-time of a patient in any given health facility with pharmaceutical services in house.

To address this, Bahadori et al. [9] carried out a study to investigate ways of improving this particular activity in health-care. At the end of the study, after analysing simulation results for various tested queue models, they were able to conclude that relocating multi-tasking staff to requiring points of service will reduce queue lengths and patient waiting time.

2.3 Models of Suggested Turnaround Strategies

The QED (Quality and Efficiency-Driven) regime

This model tries to balance resource availability and utilization in a system [2] that is comprised of multiple "servers" constantly receiving demand for services. This context is of great importance as it is a typical scenario in a health facility. This relates to health-care as follows: resources (health workers) are being used by patients and have long queues of patients waiting to be served.

The effects of this regime are characterized by high levels of resource utilization together with short periods of queuing delays [44]. This queuing model has been getting much attention from researchers and this is greatly attributed to its characteristics, some of which are:

- QED queues have high service-quality due to the fact that waiting times have an order of magnitude smaller than service times. Over 30 - 70% get served immediately upon arrival; abandonment probabilities in systems with impatient customers are very low.

- Service efficiency is measured based on a server's utilization. QED queues are known to have high server utilization with an average occupancy of about 95%. This is achieved by constantly balancing demand with capacity. This of cause gives rise to high levels of both service Quality and efficiency - hence the term QED.

Lean Thinking

Another approach that has been used in health-care to try and reduce waiting time to its minimum is *lean thinking*. This is a Just-In-Time principle that was developed by Womack and Jones [43]. This idea has been used in health-care to try and address the problem of long queues in health facilities. It works with some principles of design to improve flow in any given process. To achieve this, lean thinking tries to eliminate unnecessary waiting times by controlling grouping in the system in question. The flow of resources is controlled by "demand-pull" systems that restrict the lengths of queues at particular work stages. Lean thinking methodologies indirectly reduces variation through the standardization of work and the reduction in batching.

Administrative Strategies

Other strategies have been proposed by some population analysts to administrators of some health facilities as a means to manage the population in their respective facilities. Some of such strategies are enumerated below.

- The use of a limited delay for non-urgent patients to address patients that need urgent medical attention.

- Over-booking of patients. This behavior is facilitated by the queue and the long wait because there is high probability that some of the patients who have waited a long time for an overbooked session will fail to attend.

- After-hours is a strategy that has been implemented in many business environments to meet demands for services which is usually unable to achieve with normal working hours.

- Batching. This involves the grouping and execution of certain processes that are not needed urgently. This makes way for the more urgent processes that need to be executed. The less urgent processes can then be executed at a later stage when service demand is low. This is especially implemented in laboratories.

2.4 A Different Approach

Unlike the methods mentioned in Sections 2.2, we address the problem of long queues and long waiting hours of patients from a different perspective. The studies cited in Section 2.2 and most of what has been done in this discipline so far have focused mostly on issues pertaining to data (data capture, data management, data security, ...) disease outbreak detection, report generation, and other administrative tasks. Our approach tackles the target problem from a different perspective. The aim is to demonstrate how the quality of health-care service can be improved by optimal utilization of available resources. In other words, we aim to show that proper use of the available health workers can reduce queue lengths and long waiting time of patients in a health facility.

2.4.1 Key Differences

The CHITS system for instance addressed the problems of queues in a health facility by speeding up the process of data retrieval. Our study addresses this problem by redistributing servicing points to reduce the number of patient influx into a particular service point in the facility. The Careware project in Uganda did little to address queue lengths or waiting times in hospitals. Its main function was data management.

The Telemedicine project was a breakthrough in many under-developed facilities. It enabled patients to gain access to health professionals from the comfort of their local health center. However, this also gave rise to an increased number of patients in the remote location and consequently, queue were bound to grow by the day. In addition to this, the system also needed specialized hardware and a trained staff to operate it. This of cause requires financial expenses on both hardware purchase and maintenance, and staff training. This adds more strain to an already strained economy.

Our approach does not impose any financial demands to the currently existent system. Rather, it tries to identify how the currently available resources can be properly managed to get the best out of the system. Our system can therefore be seen as an addition with known positive consequences to what is already in existence in health-care in developing countries. It is therefore true to say that our results, together with results from other studies that have been carried out in this respect will definitely improve the quality of health-care in developing countries.

The studies described in subsection 2.2.2 are seen to have applied the simulation methodology to address

challenges of long queues and long waiting times of patients in health-care. In their various respects, they have manged to address this problem in their own respect.

Contrary to these and other prior studies carried out in this regard, our approach differs in that we address the problem from a different perspective. We address the problem of queues and waiting time by addressing the manner in which patients move in the system. Our study not only simulates this at the lower level of the department but it also scales up to the level of a community (multiple facilities).

2.5 Chapter Summary

In this chapter, we have seen how other scholars have tried to address challenges faced by health-care in developing countries. We selected a few of such prior studies and briefly talked about them, siting their unique properties and also siting how they have contributed towards the improvement of health-care service delivery. We also discussed our approach on how we address the target challenge for this study. In chapter 3, we describe an overview of our methodology. We discuss the reasoning behind our methodology and also provide some analysis to support our proposed methodology.

Chapter 3

METHODOLOGY I

In chapter 2, we gave a brief outline of earlier studies that have been carried out. We pointed out some of the peculiar characteristics of the respective studies we talked about and later on described how this study differs from them. In this chapter, we outline our proposed approach towards addressing the identified problems of lengthy queues and long waiting hours in health facilities. We give a brief description of the simulator that was built for this study and relate it to the actual health-care structure that is in existence in many developing countries. We outline some of the assumptions that were taken into consideration when building the simulator and later on describe the concept and hypothesis behind our proposed solution to the problem we are trying to address. We also demonstrate and support the validity and proper functioning of our simulator through some analysis and also provide some preliminary results to further support the validity of the simulator.

Our proposed approach to address the problem lengthy queues and long waiting times in a typical health-care facility required the manipulation of various variables in a very complex environment. This therefore makes it very tedious to carry out such a study in real-time. For this reason, the simulation methodology was chosen as the preferred research methodology for this study.

The simulator was built and used to study the different configurations of how patients can be routed between and within the various health-care facilities. The simulation tool that was chosen for this study is the *OMNET++* simulation package. This choice was influenced mainly by the package's relative ease of use and its versatility to create almost any possible scenario using one of the existing wide range of configurable modules.

Figures 3.1 and 3.2 are logical representations of the basic structure of a health-care facility (hospital and clinic respectively). Each of these models can be seen to consist of queues with

1. *Customers* arriving at a given rate (λ_i), and
2. *Service Points* (**queue, queue1, queue2, ..., queue11**), serving customers at a given rate (μ).

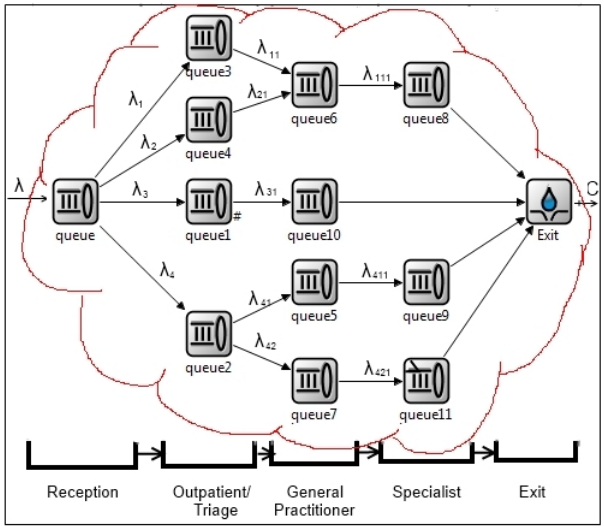


Figure 3.1: An abstraction of a typical urban hospital

Figure 3.1 shows what we would typically find in an urban hospital. Generally, patients follow a sequence of activities from the time they enter the health facility until they leave. This, as portrayed in Figure 3.1, follows the following sequence of events;

- Upon a patient's arrival at the hospital, he or she enters a queue at the **Reception** (*queue*) where some basic information, such as: names, address, age, and others, is collected.
- The patients then move on and queue at the **Outpatient/Triage** (*queue3, queue4, queue1,* and *queue2*) where their vitals (blood pressure, temperature, height,...) are captured.
- From the Outpatient/Triage, the patients then move to the next queue, waiting to be served by the respective **General Practitioners** (*queue6, queue10, queue5,* and *queue7*).
- The General Practitioner could further refer them to a **Specialist**, (*queue8, queue9,* or *queue11*) or give them a prescription, after which they **Exit** the facility.

Each of the queues in Figure 3.1 represent the different departments in an urban hospital. They each have a *service time,* (μ_i), which is a random value from a service-time distribution. This value is not necessarily identical or fixed for each of the queues in the system.

The rural polyclinics also follow the same general sequential flow of events described for the urban hospital. The difference is in a reduction in the number of departments, or queues (in the case of our simulation). This difference can be seen when we compare Figures 3.1 and 3.2. The sequence of activities for the rural heath facility is as follows:

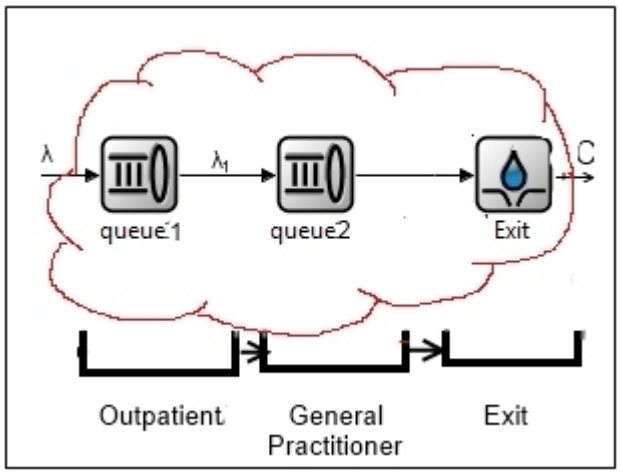


Figure 3.2: An abstraction of a typical rural polyclinic

- A patient visits the polyclinic and joins a queue at the **Outpatient** (*queue1*) where vitals and other information collected.

- They then move to a new queue, *queue2*, where they wait to be served by a **General Practitioner**.

- The General Practitioner could further refer a patient to another facility or discharge them after consultation, **Exit**.

Despite the differences cited by Nyman et al. [26] between urban and rural health-care centers, the similarities they both share in the queue models portrayed on Figure 3.1 and Figure 3.2 reveal three main sub-processes that are common to both scenarios:

1. An ***arrival*** process,

2. A ***waiting*** process, and

3. A ***serving*** process

Values for the *arrival* and *service* processes are going to be the key input parameters of the simulator.

3.1 Assumptions

Given the sequential nature of the flow of events in a typical health facility, we used theories that govern queuing networks to analyze results from the simulation to reach our final results. We also made certain assumptions about the "patient" objects generated in the simulation at run-time. Some of these assumptions made include:

1. Patient arrival into the system can be described by a *Poisson distribution* function.

   (a) The number of patients entering a queue during time period $t \longrightarrow t + s$ only depends on the length of the time period (s), and is not related to the arrival time of the first patient, (t).

   (b) Inter-arrival times of a Poisson process are exponentially distributed.
   Let τ_1 = the time until the next arrival ($t_0 \longrightarrow t_1$).
   And $P(\tau_1 > t) = P_0(t) = e^{-\mu t}$
   Then $P(\tau_1 \leq t) = 1 - e^{-\mu t}$

2. Each "patient" only suffers from a single disease. That is, each patient object generated in the simulator can only have **one value** for the patient-type (`jobType`) attribute. This was to ensure that each patient object was routed to the appropriate "department" in the system.

3. Every patient who gets into the system **must exit** the system. Once a generated patient object is pumped into the network of queues, it must eventually exit the network.

4. Every patient can only visit a "health-care" facility once. This assumption ensures that every generated patient object in the system does not return to a previously visited server as this can lead to the possible occurrence of an endless loop in the simulator.

5. The time used by a patient to move from point A to point B is assumed to be zero. I.e., in the simulation, we assumed that the delay encountered when a patient walks or is wheeled to another/next department/service-point is zero. This of cause is not the case in reality as it is a possibility that a patient from a previous queue can arrive at the next service point before an already racing patient.

3.2 Concept of Our Method

Our approach to addressing the identified problems in health-care makes certain assumptions (sub-section 3.1). One of these assumptions is that patient arrival into the system can be described by a Poisson distribution. This is a key assumption in this simulation as it ensures that there is no particular "order" in which patients

arrive into the system. This distribution is defined by a *Probability Density Function* (PDF), and is defined over an infinite number of positive integers. Equation 3.1 defines this function as $P(k|\theta)$ such that

$$P(k|\theta) = \frac{\theta^k}{k!}e^{-\theta} \tag{3.1}$$

where k is a positive integer

θ *is a parameter of the distribution.*

The probabilistic nature of patient arrivals into the system makes the PDF a "random" function. Unlike normal functions that map a set of inputs to corresponding values, a probabilistic process maps a set of inputs to a probability distribution over values.

3.2.1 The Poisson Process

Given that patient arrivals is Poisson in nature, the Poisson process gives probabilities of a number of arrivals, k, as a function of time, t, given an arrival rate, (λ). The PDF now becomes a function of time and is defined as $P(k|t, \lambda)$, such that

$$P(k|t, \lambda) = \frac{(t\lambda)^k}{k!}e^{-t\lambda} \tag{3.2}$$

Upon close observation of equation 3.1 and equation 3.2, θ is being substituted with $t\lambda$. This expression is the mean of the Poisson process. If we denote this as $\bar{p}$, then

$$\bar{p} = t\lambda \tag{3.3}$$

Equation 3.3 also represents the expected number of arrivals at a given time, t. This means that the Poisson process is a sort of increment where the counts are expected to increase with time.

3.2.2 The Queue Model of our Simulator

The queue model used in our simulator is the M/M/1 model. By this, we mean that each queue in a system has a single "server", with an arrival rate that can be determined by a Poisson process and the service time which is exponential. A theoretical analysis of such a model will see us using parameters like:

n : the number of customers in the system.

c : the number of parallel servers being fed from a single waiting queue.

λ : the arrival rate of customers into the system.

μ : the service rate of servers in the system.

ρ : the system intensity or load.

$c\mu$: the serving rate when $c > 1$.

3.2.3 Equations for Queue Analysis

Given that arrival is independent of any variable, and that the probability of an idle servers in the system is P_0.

$$P_0 = \left[\sum_{n=0}^{c-1} \frac{\gamma^n}{n!} + \frac{\gamma^c}{c!(1-\rho)}\right]^{-1} \text{ where } \gamma = \frac{\lambda}{\mu} \tag{3.4}$$

Consequently, the steady-state probability for exactly n customers in the system (P_n) will be

$$P_n = \frac{\lambda^n}{c!c^{n-c}\mu^n} P_0 \text{for } n > c \tag{3.5}$$

The average number of waiting customers in the queue is denoted by L_q.

$$L_q = \frac{\gamma^c \rho}{c!(1-\rho)^2} \times P_0 \tag{3.6}$$

The average waiting time of a customer on the queue is denoted by W_q

$$W_q = \frac{L_q}{\lambda} \tag{3.7}$$

3.3 Analysis

Given the equations in sub-section 3.2.3 and the data in appendix B, we can theoretically calculate and estimate the confidence intervals for the average service times and arrival rates respectively. For this study, we chose to use a 95% confidence interval for our analysis. Reasons being that with a 95% confidence interval, our results are going to be more convincing. A 95% Confidence Interval is calculated using the following generic formula:

$$95\%\ Confidence\ Interval\ = Mean\ Value \pm 1.96(Standard\ Deviation)$$

Using the data from Appendix I, we compute the following values.

$n = 24$ patients

$c = 1$

Mean service time, $(\bar{\mu}) = 12 : 25$ minutes per patient

$SD_{mst} = 03 : 38$ minutes

Mean arrival time $(\bar{\tau}) = 04 : 43$ minutes per patient

$SD_{mat} = 03 : 40$ minutes

From these values, we compute the 95% Confidence intervals for the Service Times.

95% Confidence Interval for Service Time $= 12.417 \pm 1.96(3.633) = [19.538, 5.296]$

Also, we compute the following from the data in appendix B.

Arrival rate, $(\lambda) \approx 13$ patients per hour

Serving rate, $(\mu) \approx 17$ patients per hour

System intensity, $(\rho) = \dfrac{\lambda}{c\mu} = 0.7647 = \gamma$

Consequently,

The probability that server is idle, $(P_o) = 0.308$

Average number of patients in a queue, $(L_q) \approx 5$

Average time a patient spends in the queue, $(W_q) \approx 18$ minutes

Interpretation: The values just computed in this sub-Section reveal the following:

Patients come into the system at an average rate of 13 patients within an hour.

The health workers get to serve an average of 17 patients per hour.

The Confidence Interval show that a health worker can spend as much as 5 to 20 minutes consulting a single patient.

3.4 Simulation Results (Analytical)

The simulator was supplied with the two key inputs: average service time and patient arrival rate. The simulator was able to produce results which we demonstrate in this sub-Section.

3.4.1 Queue Length over Time

The graph shown on Figure 3.3 demonstrates how the queue length changes over time in the simulator.

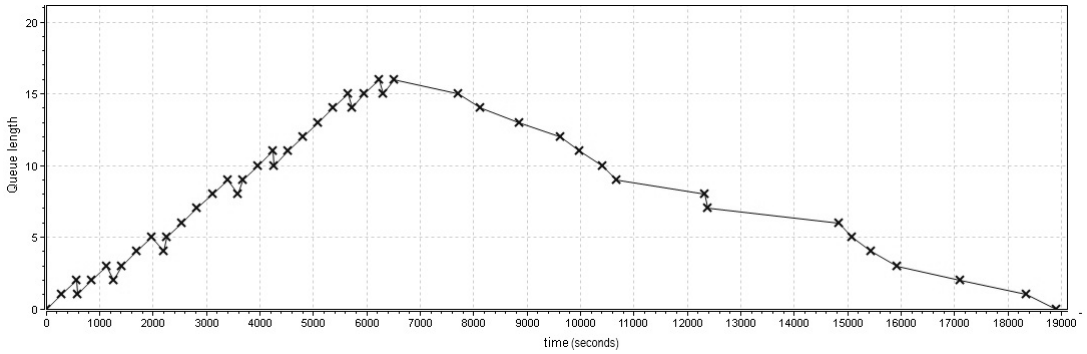


Figure 3.3: Simulator: Queue length against time

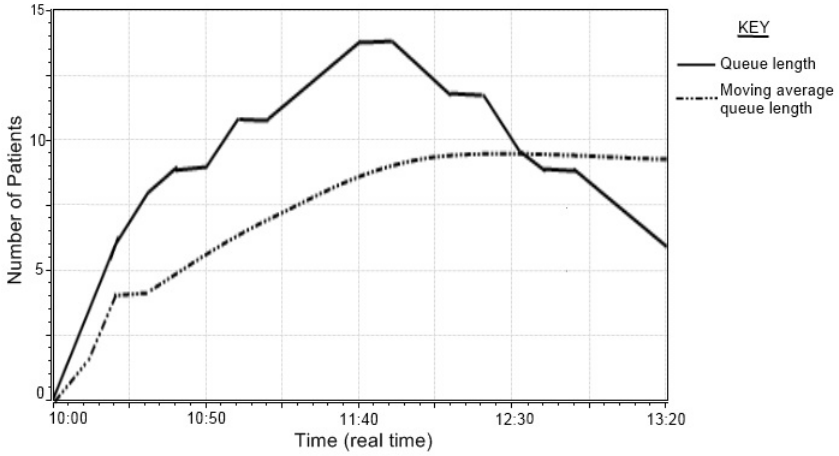


Figure 3.4: Average Queue Length

On close observation of Figure 3.3, we can say the curve is seen to peak at around 16. What this means is that the maximum queue length in the simulator is about 16. Figure 3.4 on the other hand shows that from the simulator, the average queue length is about 9 and the queue length peaks at 14.

3.4.2 Service Time

Figure 3.5 demonstrates the mean service time per patient in the simulator. From the figure, this is approximately 13 minutes.

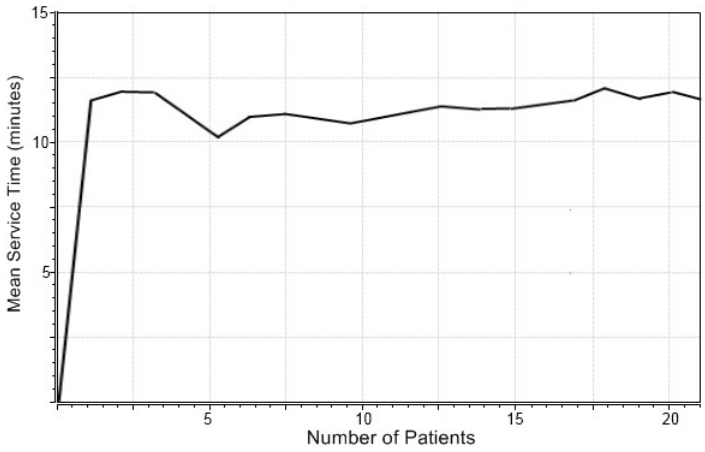


Figure 3.5: Simulator: Mean service time

3.5 Analysis Vs Simulator

In this sub-section we compare some results from the analysis of our test scenario against results from the simulator. This goes to demonstrate how close the simulator mimics reality. To do this, we have used Table 3.1 to show corresponding values side-by-side.

Table 3.1: Side-by-side Comparison of Analytical results and Simulator Results

	Analytical Value	**Simulator Value**
Mean Service Time	0:12:25 per patient	0:13:19 per patient
Average Queue Length	5	7
Arrival Rate	13 per hr	15 per hr

The closeness of these values suggests that our simulator is a close representation of reality.

3.6 Chapter Summary

In this chapter, we discussed our method for addressing the identified problem. We made mention of some assumptions that were made while building the simulator. We discussed the hypothesis behind our approach and provided some results from sample scenarios to support our proposed method of approach. In the next chapter, we elaborate more on the simulator. We discuss the various modules and packages that were used to build the simulator. We also describe how these modules were configured to suit the environment under investigation.

Chapter 4

METHODOLOGY II

In chapter 3, we discussed our method for addressing the identified problem. We made mention of some assumptions that were made while building the simulator. We discussed the hypothesis behind our approach and provided some results from sample scenarios to support our proposed solutions. In this chapter, we elaborate more on the simulator. We discuss the various modules and packages that were used to build the simulator. We also describe how the various modules used were configured to suit the environment under investigation for different scenarios.

As described in the previous chapter, this study was carried out entirely by way of simulation. OMNET++, being the main simulation tool for this study was configured to appropriately reflect a typical health-care structure. This was done by using various modules that are available to the simulation package from the *queueinlib* library.

Each of the respective modules were configured accordingly to mimic the behavior of the respective parties involved in the environment. They mainly simulated the activities and properties of patients and the health workers who interact with the patients directly.

4.1 Modules

4.1.1 Modules Used

In this section of this chapter, we discuss the modules that were used from the *queueinglib* library and describe how they were used to create the respective aspect of the health-care structure as a whole.

Source module

This module was used to generate *patient objects* in the simulator. They were configured to generate different *patient types* based on the different types of patients that visit the respective health-care facilities. The number of patients generated, the frequency (arrival rate), and the type generated were all configured for according to the data that was collected from the field.

Patient Generation

The mechanism through which the *source* module generated patient objects was by means of a random number generator (RNG). The RNG used in this case was one of the SIM_API functions: *poisson*(). This function returns a random integer which falls within the 95% acceptance interval as explained in section 3.3 of chapter 3 from the Poisson distribution. The function takes two parameters: :

- The number of arrivals per unit time, denoted lambda (λ): , and

- An integer number: the underlying random number generator.

Upon creation of each patient object, a type identifier is assigned to each of them. This serves to distinguish between patients that enter the system. The deceleration in appendix E.1 demonstrates what each patient object is actually composed of.

Connections

Connections were used to inter-connect the various components of the simulation. They basically served as a "channel" through which patients traversed the simulator. they have no effect on the patient object traversing them. This is based on one of the assumptions (see page 23) made in this study during the construction of the simulator: The time which the patients takes to move from point A to point B is assumed to be zero.

Classifier Module

The classifier module is another module that is of importance to the simulator. This module, like its name describes was used to identify and classify the different "types of patients" that were generated and channeled into the system. The `jobType` attribute of the patient object was used to distinguish between the different types of patients in the simulator.

The classifier module was used to ensure that patients were channeled to the appropriate departments in the simulation: the classifier would receive a patient object. With the aid of the `jobType` attribute of the patient object, the patient will then be channeled through the appropriate route (*connection*) to the appropriate department. The class declaration in appendix E.2 describes the classifier module.

Queue Module

This module was used to represent the unit/department/office where health workers interact with patients.
As seen on the code in appendix E.3, each queue object has attributes which can/were mapped accordingly to create a typical working scenario you would find in a heath-care facility. These include :

- Queue length,
- Queuing time,
- Busy,
- Capacity, and
- Service time.

These attributes were assigned values accordingly to properly simulate the respective aspects of this unit in the environment we are simulating.

Router Module

This module was implemented in the simulator to channel patients to the alternative routes in the simulator. This was especially used in cases where there was more than one health worker offering the same service. For instance, in a case where patients have to queue up to get to the reception, there could be more than one receptionist. In this case, the router module will send patients to the next available receptionist. The code in appendix E.4 defines this module.
As seen on the code, various possible routing algorithms are available for use by this module when it comes to making a choice of route. At run-time, the `shortestQueue` algorithm was used to send patient objects to the

appropriate queue as is the case in a typical health-care unit. This is to ensure that a patient is only sent to a worker who is free at the instant.

Merger Module

This module was used mainly for convenience and clarity. It has absolutely no effect on any of the attributes of the patients that go through it. Neither was there any changes on the destination of patient objects that went through them. What they served for in the simulator was to collect multiple `connections` and merge them into one. Especially in cases where "patients" from various "departments" headed for a common destination.

Delay Module

This module was used in the simulator to mimic patient referral times. This was used in cases where "patient" were referred from one "department" or "facility" to another. The delay time was randomly generated by the simulator's RNG in this case. appendix E.6 shows the declaration for this module.

SinkExt Module

This module served more or less like the exit point from the simulator. All "patients" in the simulator were made to exit from the respective `SinkExts` of the respective facilities in the simulator. As seen on the class declarations, the `SinkExt` module is actually an extension of the `Sink` class.
As seen on appendix E.7 from the parent class declaration, a lot of statistics about the lifetime of each "patient" in the system is captured at the various exit points of the simulator.

4.1.2 Module Configurations

Section 4.1.1 outlined the modules that were used from the `queueinglib` and `queueinglibext` libraries to build the simulation. In this section, we have highlighted how the various configurable modules were configured to properly mimic the health system.

At the start of each simulation run, default attribute values as seen in the respective class declarations in section 4.1.1 were assigned to each of the objects in the system. Some of these properties were maintained during run-time, while others were altered to best suit the scenario being simulated. Alterations to the default values for class attributes was done in the `omnetpp.ini` file[1] of the simulation project. In this file, the attributes of interest were explicitly assigned values accordingly. The sub sections of sub-section 4.1.2 below describe how

[1]The `omnetpp.ini` file is the simulator's configuration file where all aspects of the simulation environment at run-time are being set.

the respective attributes of interest were configured on the `omnetpp.ini` file to achieve the respective intended scenarios. The generic equation described by equation 4.1 describes how the assignment was done. The module properties were each identified and assigned values as per the equation.

$$Network.Module.property = Value \tag{4.1}$$

Source Module

The `source` module is one of the most important modules that was used in the simulator. Its main purpose was to generate patient objects for the system. In this section, we describe how this module was configured in the simulator to mimic reality in a typical health-care environment.

`jobType`: An instance of the `source` module (a patient) generates patients that suffer from a particular type of disease. This property of every patient is represented by the `jobType` attribute of each patient object. We then assigned each disease type an integer value through which the system was able to identify and distinguish between the various types of patients in the system. A list of patient type-identifier pairs is found in appendix D.1. The pseudo code below describes this.

```
//A patient is declared and initialized
simple Patient extends Source {}
Patient UPatient_Dentist = new Patient();

//Integer variable that uniquely identifies a patient is declared
int identifier = 1;

//The patient is assigned a type
UPatient_Dentist.jobType = identifier;
```

This property assignment is done in the `omnetpp.ini` file using a different syntax. Using the case of a patients heading for the dentist as an example, the generated patients were assigned a `jobType` of 9 as per appendix D.1. The code on the `omnetpp.ini` file that executes this assignment is:

```
Hospital_Structure.UPatient_Dentist.jobType = 9
```

`jobPriority`: Every patient that is generated by the simulator is assigned a priority digit. A default value of 0 is assigned to each patient as can be seen in the class definition in Appendix E.1. Casualty patients on the other hand were assigned a value of 1.

This attribute was used by the simulator to determine whether or not patients should be given priority when they arrive at a queue. A patient having a default value of 0 simply joins the queue at the back. On the other hand, a patient with a `jobPriority` value of 1 goes right through the queue. In a typical health facility, casualty patients hardly ever have to wait in queues. This scenario was addressed through the use of the `jobPriority` attribute in the simulator.

`numJobs`: The value for this attribute was determined by a RNG that generated a value within an acceptable range. The input parameter for the RNG function were values that were calculated after analysis of the captured data.

General statistics about the number of (different types of) patients that entered a health facility was collected for a number of days. These values were then used to calculate a mean value which was the input value for the simulator. The mean was used in the `omnetpp.ini` file as follows:

```
Hospital_Structure.UPatient_Dentist.numJobs = poisson(mean, rng)
```

This assignment was able to generate a random number that is within Poisson range of the calculated mean.

`interArrivalTime`: This value was equally randomly generated by a RNG function in the simulator. Just as was the case for the `numJobs`, data was captured over a period of time. Among which was the inter-arrival time between successive patients entering the system. The mean inter-arrival time (λ) was calculated and the resulting value was entered into the RNG function of the simulator. This caused the generator to generate a new patient after a randomly calculated inter-arrival time that is within the 95% acceptance range of the mean value. This was achieved in the `omnetpp.ini` file using the following expression:

`Hospital_Structure.UPatient.interArrivalTime = poisson`$(\lambda) * 1s$

`startTime`: This refers to the time which the first patient object is generated. This value was not changed from the default value in many cases. However, in some facilities, the value was altered in the `omnetpp.ini` file.

This value was mostly altered in cases where the simulator created scenarios whereby health workers came in hours after the working day had started. To better understand this, let us look at a possible scenario in a typical (private) health facility.

A normal working day starts at 8:00am. A specialist comes into the facility only at 11:00am. Most of the time, patients who consult with this specialist are aware of this and usually arrive in the facility a few minutes before 11:00am. This is unlike the others who come in at 8:00am.

Given this scenario, the simulator does not start generating patients for this service at the default start time (system start time). There is a delay between the system start time and the time the particular service starts. This time difference is what is used to determine when the `source` object should start generating patient objects.

`stopTime:` This attribute works just like the `startTime` attribute just discussed above. The difference is that instead of setting the time when patient generation begins, it specifies the time when patient generation should stop in the simulation. This is similar to specialist leaving a facility before the normal closing time.

Queue Module

The source module, after generating patients would inject them into the system where their destination is set to a particular `queue`. This is made possible by the `jobType` attribute of each patient. The `queue` module which represents the workers in health-care was configured differently for the different facilities according to the data that was captured. There was one key (input) attributes for this module that was of great importance to the simulator: `serviceTime`.

`serviceTime:` This attribute mimicked the time which a health worker would spend with a patient. The value for this attribute was generated by the RNG in the simulation, together with the statistical mean of the data that were captured from the respective health facilities. Together, this generated a random value for the service time that fell within the 95% acceptance range for the service time. This was done in the `omnetpp.ini` file using the following piece of code:

```
Hospital_Structure.UDoctor.serviceTime = poisson(X) * 1s
```

where `X` is the average service time of the worker.

The other attributes of the `queue` modules were left at their default values as they did not really apply in the context of this research and they had no effect on the smooth functioning of the simulator. While some of the attributes steered the functioning of this module in the simulator, others were used to capture data that was used in the analysis of results from the simulation. Two of such that was used include:

- `queueLength`, and
- `queueingTime`.

Router Module

The `router` module as described in section 4.1.1 was used to direct patients to their appropriate destination in the simulator. The key attribute that was changed from the default value in this module was the `routingAlgorithm`. This was changed from `random` (the default) to `shortestQueue`. The following piece of code in the `omnetpp.ini` file was used to achieve this.

```
Hospital_Structure.UReception.routingAlgorithm = "shortestQueue"
```

This alteration to the `router` was used in cases where there were more than one "workers" providing the same service. This routing algorithm ensured that patient were only sent to workers who were not "busy".

The other modules used in the simulator were all used with their default values.

4.2 Simulator

The modules we have discussed in section 4.1.1 were the main modules that were used to build the simulator. In this section of the report, we describe the simulator in detail.

The simulator was built such that the different types of health-care facilities were represented in the system:

- Government facilities:
    * Hospitals,
    * Polyclinics,
    * Health centers,
    * Others
- Private facilities,
    * Hospitals,
    * Clinics,
    * Others (general practitioners, surgery, e.t.c.)

The various types of health facilities were each represented in the simulator. Connections were made between them through `connections` (see section 4.1.1) according to the way patients flow between and within interacting facilities and departments respectively (Figure 1.2).

The modules used and their attributes were changed accordingly. As stated in section 4.1.2, this was done in the `omnetpp.ini` file. Initialization and alterations to the various module attributes were made at this point according to the captured data. This included changes to the respective attributes (section 4.1.2) from their default values as per the various class declarations in appendix E.

4.3 Analysis of Simulation Results

After assigning data values to the appropriate attributes in the simulation, the various possible configurations where then implemented and run for each of these configurations. Analysis of each of the alternative configurations was done at the various levels in the health-care structure (see Figure 4.1). That is to say, analysis was carried out on each of the layers, beginning from the smallest (department), right up to the top (community). Figure 4.1 shows and gives a brief description of what the various levels comprise of.



Figure 4.1: The different levels in the health-care structure

4.3.1 Analysis at the Level of the Department

At this stage, analysis of the simulation was carried out at the level of the departments. This was done most especially in cases where there were more than one locally based practitioners/specialists in the department under investigation. To better understand this, let us consider the following scenario in a typical urban hospital.

> *In a given medical facility, the Gynecology department has up to 5 permanently based doctors who come in to attend to patients. This means that at any given working day, there are 5 gynecologists at the health facility. Patients visiting the facility for the first time are presented with alternatives as to which of the 5 available doctors they want to see. This therefore means there are 5 different queues in this single department, one for each of the gynecologists present.*

Given this possible scenario in a facility, analysis at the departmental level was done on each of such queues. The aim of this was to find the best possible way to distribute patients between the 5 gynecologists such that

queue lengths and patient waiting time for this department are reduced, assuming that patients do not show preference of any particular doctor, over the others.

4.3.2 Analysis at the Level of the Hospital/Clinic

At this level, analysis will be carried out at the level of the hospital/clinic. The purpose of this will be to determine the best possible way of routing patients from the time of entry into a facility to their destined departments. This of cause will be in conjunction with results from the analysis of the (various) department(s).

4.3.3 Analysis at the Level of the Community

This is the stage that gives the big picture of this study. Given the results from the analysis at the level of the hospital/clinic, this stage was used to determine the optimal configuration for how various hospitals and other health facilities should interact with each other on the basis of patient referrals, and other activities that see patients moving from one facility to another.

4.4 Chapter Summary

This chapter has seen us described in more detail, the individual components of the simulator that has been built. We enlisted the modules that were used, how they were used, and what they were used for. We also discussed how the various module classes were configured to serve their respective roles in the simulator. We rounded up the chapter by describing how we intend to carry out the simulation and analysis of the health system, stating different layers of the health structure based on different levels of complexity. This saw us divide the health system into department, hospital, and community layers. In chapter 5, we discuss the results we were able to achieve using the simulator. We also discuss these results and how they affect the various aspects of health-care as a whole.

Chapter 5

RESULTS AND DISCUSSION

In chapter 4 we talked mostly about the simulator. We discussed details of the simulator in terms of the modules that were used, the way they were each configured to suit the needs of this study, and also made mention of the step-by-step approach of how we carried out our analysis of the entire health-care system. In this chapter, we give a layout of how the simulation was actually run. We outline and describe the different arrangements that were tested with the simulator and discuss the results that were generated for each of them.

Progress Review

To quickly remind ourselves of the research progress so far, we briefly touch on what has been done in order to achieve the results and analysis we discuss in this chapter.

In chapter 3, we made mention of OMNET++ as being the preferred choice for a simulation package for reasons which were stated in the introductory paragraph of the same chapter. We later on described a model of a typical health system, from which we identified three key variables that drive the system: arrival time (λ), waiting time , and service time (μ). The simulator was built (see chapter 3) using modules from the simulation package (see chapter 4). These modules were then (each) configured accordingly to mimic the scenario observed in a typical health facility. Analytical results in section 3.3 describe the behavior of the simulator.

The data captured from the field (Appendix F) provided us with a general pattern of how the above mentioned variables change in the system over time. These data was then analyzed and the results from these analyses

provided us with inputs values for the simulator. These included: an average ***arrival rate***, an average ***service time***.

The simulator was fed and run with these respective values as the main input parameters. The simulator used these input parameter values as guides to generate random values for the respective system parameters (inter-arrival time, service time, waiting time) that were within the 95% Confidence Interval[1]. These random values generated by the simulator during the various simulation runs (for the respective scenarios described in this chapter) produced the results we discuss in this chapter.

5.1 Department

5.1.1 Study Case I (2 Resident Specialists)

Simulation and analysis of the health-care structure started from the lowest structural level as described in section 4.3. At this level of the structure, analysis and simulation runs were performed only for those departments that were found to have more than one resident specialist. An assumption we made in this case was that the behavior of patients in this type of scenario was the same in all facilities. The only difference was in the number of alternatives they had at their disposal (differences in the number of resident doctors in various health facilities).

For purposes of simplicity, we only modeled a scenario which comprised of two doctors/specialists. I.e., this model described a situation where patients had a choice to visit either of the two specialist present at the health facility being modeled. Data for the arrival and waiting times of patients, and service time of the observed practitioner in the observed hospital is found in appendix A.1. Figures 5.1 and 5.2 below demonstrates how service time varied for various patients as they were being attended to by either doctors in the department that was observed.

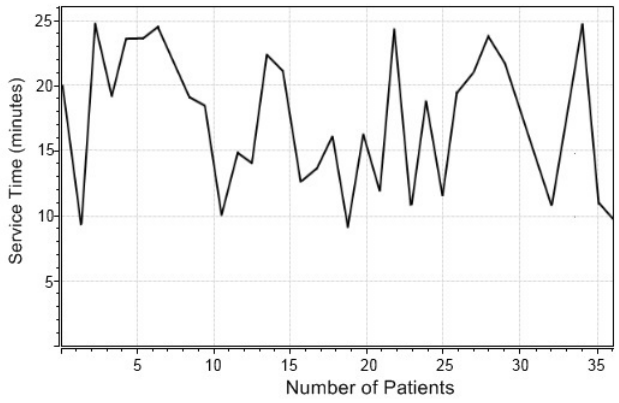


Figure 5.1: Variation of Service time with patients (Doctor 1)

[1]See section 3.2

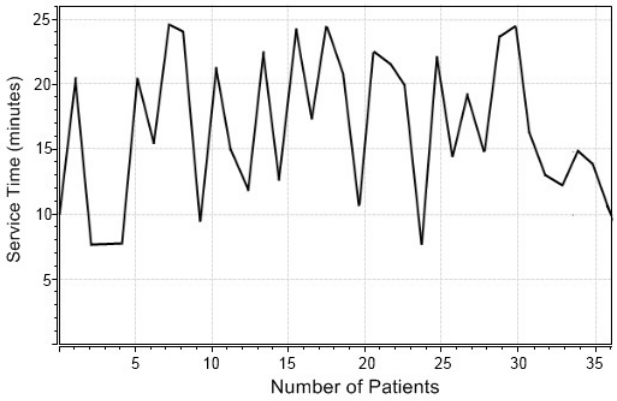


Figure 5.2: Variation of Service time with patients (Doctor 2)

Figures 5.3 and 5.4 are an extract from figures 5.5 and 5.6 respectively. They demonstrate the average service time over time for the respective doctors.

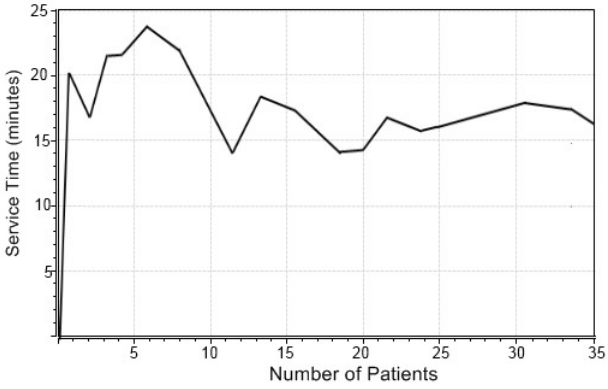


Figure 5.3: Average Service time (Doctor 1)

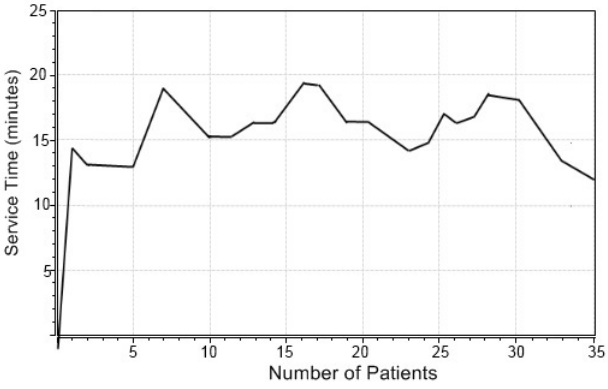


Figure 5.4: Average Service time (Doctor 2)

Figure 5.5 and 5.6 on the other hand demonstrates how the waiting time of the patients varied over the period

of time for which they were observed.

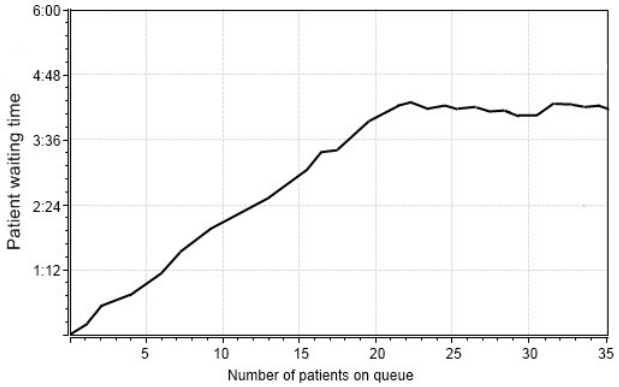


Figure 5.5: Variation of Waiting time (Doctor 1)

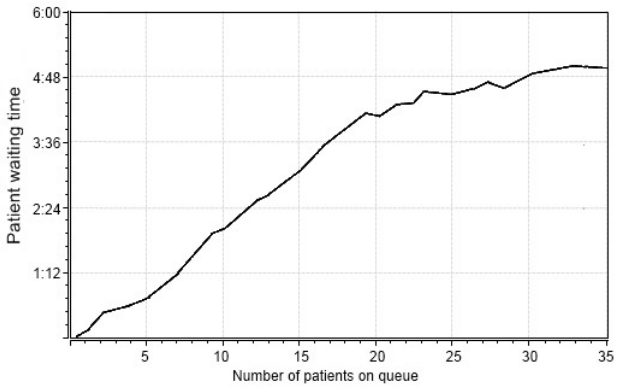


Figure 5.6: Variation of Waiting time (Doctor 2)

Table 5.1 and 5.2 shows the parameters that were set for the respective modules in the simulator (from Figure 5.3 and Figure 5.4 respectively).

Table 5.1: Simulation Parameters for this Department (Doctor 1)

Patient Inter-Arrival Time (μ)	**Average Service Time**
0:05	0:16

Table 5.2: Simulation Parameters for this Department (Doctor 2)

Patient Inter-Arrival Time (μ)	**Average Service Time**
0:06	0:15

An initial run of the simulator with these parameters produced the following results:

When patients were left to make the choice of which doctor they wanted to consult with (which is usually the case), Figures 5.7 and 5.8 demonstrates how the queue length varied over time for the two doctors respectively.

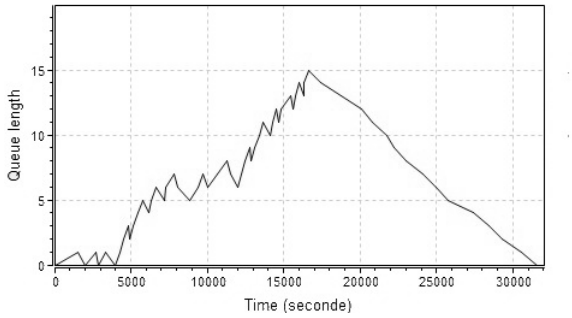


Figure 5.7: Queue length against Time (Doctor 1)

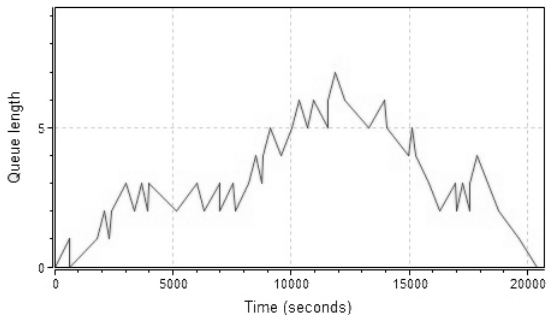


Figure 5.8: Queue length against Time (Doctor 2)

Configuration I (DC-1)

Configuration I describes a case where patients are not allowed the freedom to choose which doctor to consult with. Rather, the patient at the front of the queue was sent to an alternate doctor from the previous. After running the simulation with this configuration, changes in queue length for both doctors are described by the changes we observe on Figures 5.9 and 5.10

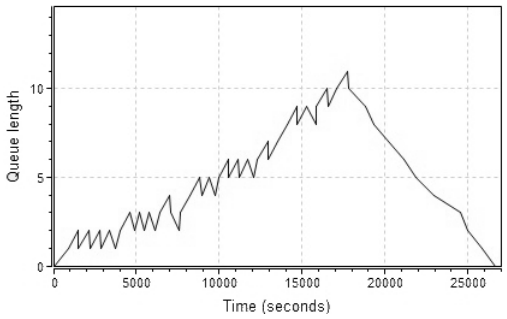


Figure 5.9: Queue length against Time with DC-1 (Doctor 2)

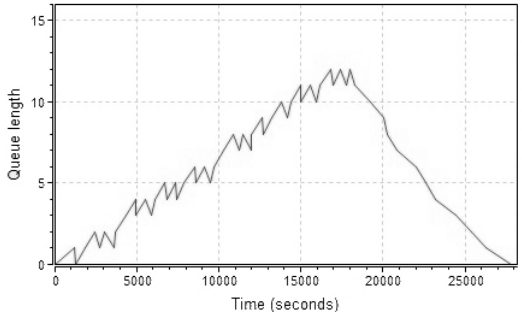


Figure 5.10: Queue length against Time with DC-1 (Doctor 2)

Conclusion

These results show that the queue length drops for Doctor 1 by about 30% and rises for Doctor 2 by about 36%. Also, the simulator projected that if this configuration were to be implemented, the combined average patient life time in the department would drop by 26% (01:32 to 01:08). As a consequence of this, the waiting times will also drop. It is therefore only logical to say that DC-1 is the best possible configuration at the level of the department.

5.2 Hospital

5.2.1 Study Case I (4 Departments)

After identifying an ideal configuration at the level of the department, we then used the findings from that level to determine the best possible configuration for how patients should flow withing the hospitals. Given that the hospitals each have different number of departments with different number of (specialized) staff, we were then able to determine different ways of how patients could be routed to reduce queue lengths and eventually, patient waiting time within the hospital.

The scenario we present in this case is a clinic that is composed of 4 departments. Two of which each have a single resident doctor and the other two have two and three resident doctors respectively.
The procedures at this clinic are as follows:
Assuming that all patients who are visiting are first time visitors, they each stop at the reception. At this stage, vital signs and other patient data is captured about each patients. On average, after observing this activity in a health facility, the mean service time for this was found to be 7 minutes. From here, the patient is then sent to the respective doctor (mean service time 0:15). After which, they exit the facility with an average life time of 01:14. Figure 5.11 demonstrates how the queue length varied over time at the reception of this small clinic.

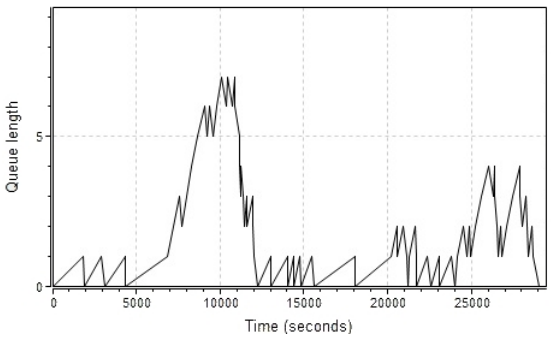


Figure 5.11: Queue length against Time

Captured data (see appendix A.2) at this health facility revealed that on average, the ***service time*** at the reception is 6.38 minutes and the ***inter-arrival time*** of patients is 5.2 minutes.

Configuration I (HC-1)

Given the typical setting described above, this configuration (HC-1) eliminates the worker at the reception. I.e., patients went directly to the respective departments where their vitals were collected by a departmental nurse before being sent to the doctor.

HC-1 reduces overcrowding of patients at the "entrance" to the facility. This will consequently lead to a reduction in queue length at the level of the receptionist and consequently, a reduction in the patients's life time in the department. This is demonstrated in Figure 5.12 where the average queue length drops from 7 (see Figure 5.11) to 1. At this stage, the average life time of the patient in the department is calculated to be 52.48 minutes.

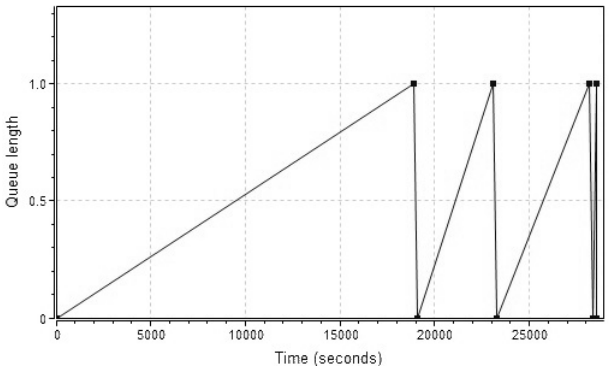


Figure 5.12: Queue length against Time with HC-1 (Reception)

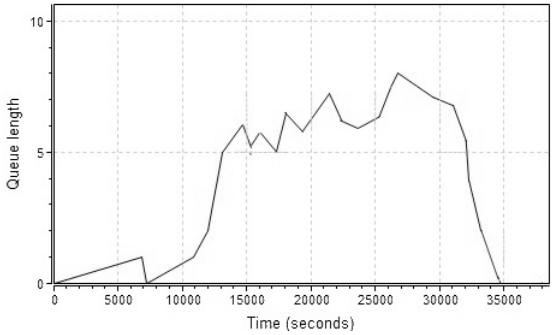


Figure 5.13: Queue length against Time with HC-1 (Doctor)

Configuration II (HC-2)

Contrary to HC-1 and the typical scenario, HC-2 completely eliminates the receptionists. In this configuration, patient vitals are collected by the doctors. The consequence of this is that service time for the doctors will definitely increase. The difference observed between Figure 5.13 and Figure 5.14 describes the effect of this on the total service time of the doctors (an increase). Figure 5.14 describes how queue length turns to change with this configuration in place in the hospital. With this configuration, the average life time of a patient in the facility increases by 30.19%.

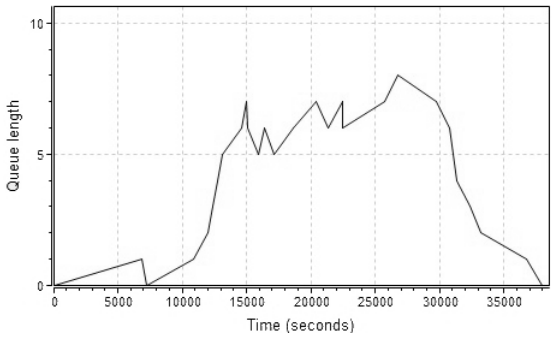


Figure 5.14: Queue length against Time with HC-2 (Doctor)

Conclusion

By observing and comparing the various results at the level of the hospital, Given that DC-1 is employed to each department in the hospital, we can draw the following conclusions about the hospital setup:

With HC-1, queue lengths at the reception dropped from 7 patients to 1. The average life time of the patients also dropped from 01:14 to approximately 00:53.

With HC-2, the effect of the reception was transferred to the doctors and this lead to a general increase in

service time for the doctors. This increase was by directly proportional to the service time of the respective receptionists. Consequently, this lead to doctors working for longer hours and this also lead to an increase in the average life time of a patient in the hospital (00:53 to 01:09)

5.3 Community

5.3.1 Study Case I (3 Hospitals, 4 Clinics, and 1 Dispensary)

At the level of the community, health facilities interact with one another with regards to patients. An overview of this arrangement is demonstrated on Figure 1.1. After having determined the best configuration at the various lower levels in the health-care structure, we will now use the results we have achieved to find the best configuration at this level.

The health-care model that was implemented at this level involved eight local[2] health facilities.

- 3 fully equipped[3] hospitals,
- 4 local clinics, and
- 1 dispensaries.

Given this scenario, and the corresponding statistical information (from the captured data) in appendix A.4, we then tested different configurations on this same model to find out how they affect and change queue length and patient waiting time in the model.

To achieve this, results from analysis from the lower levels (subsections 5.1 and 5.2) were used as input parameters.

Configuration I (CC-1)

In this configuration, we basically alter how referrals are made, in terms of which facility patients are referred to. From figure C.1 in appendix C, the usual practice (as observed) is that all patients from the clinics are usually referred to a doctor/specialist in the big hospitals. The statistical information of this setting can be seen on the table of statistics in appendix A.4.

CC-1 involved altering this by making one of the clinics a referral clinic where patients would go there first before being sent to the hospital if need be. The facility with the least number of patients (Garden City Dispensary) was used as the center point. The reason for this choice was to avoid a situation where crowds will

[2]Local in the sense that all the health facilities modeled at this level are within the same local municipality.
[3]This facility is referred to as being fully equipped as a results of its staffing, infrastructure, and technological advances in relation to the rural facilities.

grow exceedingly in already populated facilities. In other words, the reason for this choice was to try and bring the patient population levels in the clinics to about the same level[4], while reducing the crowds in the hospitals.

After running this scenario in the simulation, the results showed that the population at the hospital to which all patients were previously referred to dropped by 32%. On the other hand, the number of visits to the dispensary increased by 163%. These difference is demonstrated on Figure 5.15.

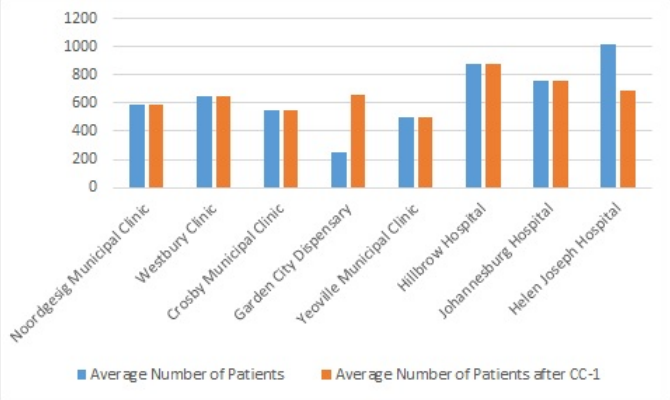


Figure 5.15: Difference in average population after implementing CC-1

Configuration II(CC-2)

CC-2 involved no referrals at all. Instead, this proposed configuration saw doctors or specialists from the hospitals coming to the rural clinics and consulting with patients at their respective local health-care centers. With this configuration, human resources are temporarily transferred from the hospitals to the clinics.

This will consequently lead to a slight decrease in the availability of human resources in the hospitals. This should lead to an increase in patient life time in the hospitals and patients-to-doctor ratio. On the other hand, patient life time in the clinics should equally drop as more resources will be available to the patient population.

Figures 5.16 and 5.17 project how this configuration would change queue lengths in the local clinics. The observed drop in queue length is as a result of a reduction in patient-to-doctor ratio. In other words, this configuration provides the patient with more doctors and hence, they spend less time waiting and consequently, a shorter time in the health facility.

[4]See Figure A.1 in appendix A.1 for differences in average number of daily visits.

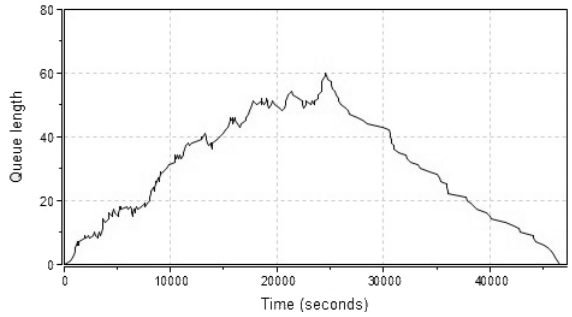


Figure 5.16: Average queue length in a clinic before the implementation of CC-2

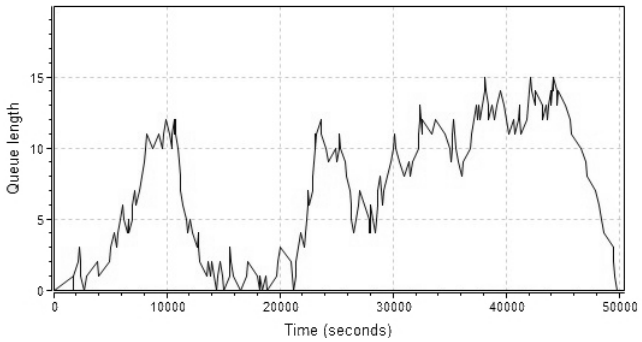


Figure 5.17: Projected average queue length in a clinic after the implementation of CC-2

Contrary to what is expected, the results projected by the simulator as seen on Figures 5.18 and 5.19 suggest that the queue length in the hospitals actually drops after implementing CC-2. A possible explanation to this observation is that because there are no referrals to the hospitals, the patient population drops proportionately with the drop in human resources, hence the observed reduction is average queue length.

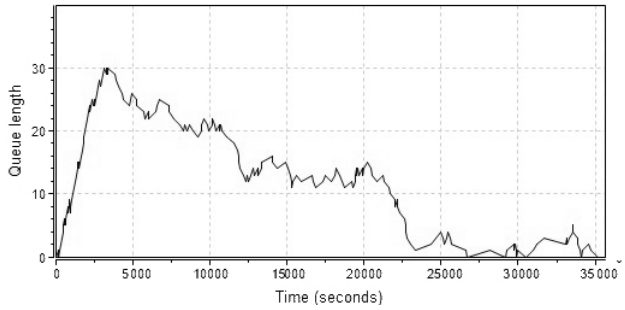


Figure 5.18: Variation of queue length at hospital(Helen Joseph)

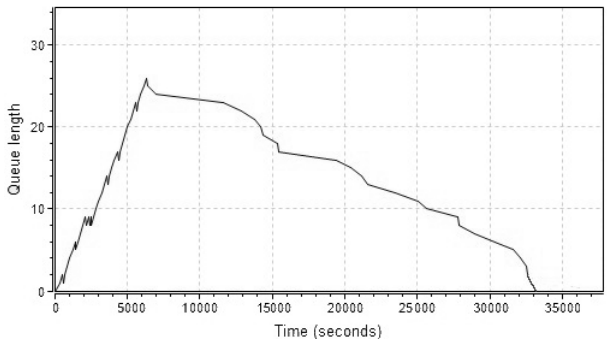


Figure 5.19: Projected change in variation of queue length at hospital after implementing CC-2

Conclusion

The results that have been presented in section 5.3 have proven that indeed, there is a change in patient waiting time upon implementation of configurations like CC-1 and CC-2. However, CC-1 is seen to be the better option as there is a general reduction in the maximum queue length and also, a shorter life time in the facility.

5.4 Chapter Summary

In this chapter, we have discussed the results generated by the simulator after several runs with various parameter values were fed into it. We identified the key input parameters for the simulator to be the average service times (μ) and inter-arrival times (λ) respectively. Given that the analysis done in sections 3.2.3 and 3.3 validated the simulator and our methodology, the simulation was able to provide us with results which support our hypothesis[5].

In summary, the results and discussions covered in this chapter revealed that:

1. The average time spent by patients in a given department dropped by 26% if they consulted with the next available doctor. This is in contrast to the practice commonly observed in health facilities where patients consult with a preferred doctor.

2. If a central reception is moved to the respective departments, over-crowding at the entrance of the health facilities will generally be reduced by about 85%. This was also observed to reduce the average queuing time by 28%.

3. The average service time of physicians was generally increased if the reception was completely eliminated from the system. The consequence of this was observed by an increase in the average life time by 30%.

[5]See section 1.3.1

4. If patients from the rural areas were not referred directly to the urban hospitals, the over-crowding in the urban hospitals will reduce by 32%.

5. If doctors made regular visits to the rural health facilities to consult with the locals there instead of having them come to the urban facilities, patient life time dropped in both urban and local facilities.

Chapter 6

CONCLUSION

In chapter 5, we have just explored the different possible configuration and their projected impact to the health system with regards to their effect on the queue length and waiting time of patients in a typical health facility. We were able to show, through results from the simulation, and also identify the best configuration for the modeled scenario. In this chapter of the report, we give a summary of this entire study, stating our findings and also voicing out some recommendations that could improve health-care service delivery.

6.1 Recommendation

From the results we have seen in chapter 5, We have been able to support our hypothesis (see section 1.3.1) and show that the routing of patients within and between health-care facilities does have an effect on queue length and waiting time of patients. The various configurations we were able to investigate suggest that it would be in the best interest of the health system to:

1. Have patients who are visiting a facility for the first time consult with the next available doctor on-call.

2. Have the patient's vitals collected at the respective departments rather than to have them taken at the "entrance" of the facility.

3. Have professional health workers make routine visits to local health facilities to assist dwellers of disadvantaged communities access quality health-care.

6.2 Future Research Work

This study has basically been a prove of concept study. It has made contributions to the fields of health care and computer science by showing that:

- Patient waiting time and queue length is affected by the way patients are routed within and between health facilities, and
- OMNET++ simulation tool can be used to simulated human environments as well as computer environments.

Therefore there is room and the possibility of a more detailed study into our proposed hypothesis from the perspective we have demonstrated in this study. This will entail a study wit h less assumptions of the environment being simulated and a more detailed look into the properties of the processes that take place in health care.

6.3 Summary of Report

6.3.1 Introduction

We started the report by discussing the health system in developing countries. We gave a brief description of the health system, stating its primary obligation to its community. We then went ahead to talk about some of the challenges faced by the health-care systems of developing countries in sub-Saharan Africa and other developing economies around the world.

Of the many identifiable challenges faced by health systems of developing countries, we identified the target challenge this study aimed at addressing: (long queue lengths and lengthy waiting times of patients). We described how this challenge affected health-care in terms of the quality of primary care being provided to dwellers of the local community of a health facility. After having discussed this, we then moved on to discuss the implications of addressing the target challenge. We pointed out the possible impacts of a solution to both the health of the local population and the economy of the affected community. We also made mention of some anticipated contributions this study could me to the world of computer science as a whole and on the simulation research methodology in particular.

6.3.2 Literature Survey

In chapter 2 of this report, we talked mainly about prior studies and research projects that have been carried out to try and address the problem of over crowding, long queues, and other challenges in health-care pertaining

to patient management, including patient data management.

We gave an in-depth discussion of the challenges faced by the health-care system in developing countries. Attempts by the local government to address the challenges in the sector was also discussed in this chapter. We then moved on talk about other research projects that have been carried out in this discipline like:

1. The Community Health Information Tracking System (CHITS) in the Philippines,
2. Careware project in Uganda, and
3. The telemedicine Project in South Africa that involved many institutions working together to make telemedicine a reality.

We also discussed some of the peculiar characteristics of the above mentioned projects and cited how they have improved the quality of health-care. In addition to the projects just mentioned above, we also discussed some of the ideologies and schemes employed by the administration of some health facilities, all in an attempt to address the challenge of long queues and lengthy waiting times in the health facility in question. In particular, we briefly talked about:

1. The Quality and Efficiency Driven regime, popularly known as the QED regime.
2. Lean thinking, a scheme which in summary involves the allocation and distribution of resources on a just-in-time bases.

Finally, we discussed our solution and methodology with more emphasis being made on how our proposed solution differs from the methodologies of prior research studied that have been done in an attempt to address the same health-care challenge we address in this study.

6.3.3 Methodology I and II

Chapter 3 of this report gave a brief description of our methodology. It started by describing the scenario and sequence of activities one would normally find in a typical health-care facility. We enlisted the sequence of activities a patient would normally go through upon their arrival into a facility that provides health-care services. We then correlated this scenario, together with its properties, to a typical network of queues which is the basis of our methodology.

With regard to the simulator, we made mention of the simulation package that was used to build the simulator and stated why it was the preferred simulation package of choice for this research study, given that there were other candidate simulation packages that could be used. We then discussed how the simulation was

built, making mention of the various modules that were used and also the assumptions that were made during the construction of the simulator.

The concept of our approach, the reasoning behind our methodology, was then discussed. In this discussion, we described how the various processes involved in the typical health-care scenario would be simulated by the simulator. We later provided some analysis to support our method of approach and validate the functioning of our simulator.

Chapter 4 on the other hand gave an in depth description of the simulator itself. It focused on the modules that were used to build the simulator. In this chapter of the report, we described how each of the modules were used to represent and mimic the various aspects of a health-care facility. In addition to this, we also described how the respective attributes of the modules were configured to represent the respective aspects of the scene being simulated. Towards the end of the chapter, we gave a more detailed description of how we intended on carrying out our analysis and simulation of the entire health-care system. We described the different layers of complexity which we identified and described how our simulation and analysis would move from the lower layer, the department, up to the more complex layer, the network of health facilities (the community layer).

6.3.4 Results and Discussion

In chapter 5 of this report, we discussed the results we were able to obtain from various simulation runs for the different possible communication architectures we investigated. The chapter started with simulation and analysis at the lowest level of our ladder as described by Figure 4.1. We started by first describing the scenario that is normally observed in a typical scenario. We then demonstrated some properties of this typical scenario graphically. These graphs and other analytical results were then used as a reference for corresponding results acquired after implementing the proposed changes to the health system.

At the level of the department, we were able to identify a single configuration change to the typical scenario. This configuration, which we called DC-1 revealed that upon its implementation, the average time a patient would spend at the department dropped by 24 minutes.

We then moved on to the next level at the ladder, the hospital, where we also demonstrated the normal and compared its results to results obtained after implementing some proposed changes. This configuration saw the use of the results from the lower level being used to further optimize the system at the level of the hospital. In other words, we demonstrated the best possible configuration for patient flow as they entered the a facility, given the implementation of DC-1 at the various departments in the facility. The configurations we proposed at this level (the hospital) were termed HC-1 and HC-2. HC-1 saw the queue length of the first queue a patient would join after entering the premises drop from 7 to 1. The results from this configuration also show that

the queue length at the doctor also drops from maxing at 13 (from DC-1) to maxing at 8. HC-2 also showed to have had an impact on the quality of health-care in terms of queue length and waiting time. The results shown on Figures 5.13 and 5.14 showed that there is almost no real effect on the queue length. How ever, it was discovered that patients would stay longer at the facility if this configuration was implemented. Therefore at the level, it was concluded that HC-1 was a better option.

The the community saw us testing two configurations: CC-1 and CC-2. With the implementation of CC-1, this saw the patient population at the referral hospital drop by 32%. This also saw an increase in patient population at the new referral clinic by 163%. This configuration was also observed as a means of *normalizing* the patient population at the different facilities when compared to each other as projected on Figure 5.15. CC-2 on the other hand showed a different effect on the population of patients in the respective health-care facilities. Contrary to what was expected to happen, CC-2 proved otherwise. Instead of the expected increase in patient life time at the hospital, and the expected decrease in the clinics, CC-2 actually brought about a drop in patient population in the (referral) hospital. The reason for this observation was attributed to the fact that the patient population dropped proportionately as the doctors were relocated to the clinics and communities that injected more patients into the facility.

Appendix A

CAPTURED DATA

A.1 Patient Arrival at General Practitioner - Urban Hospital

Patient Arrival Time	Patient Waiting Time	Start Time	Departure Time	Service Time	Inter-arrival Time
8:00	0:00	8:00	8:20	0:20	0:00
8:03	0:17	8:20	8:30	0:10	0:03
8:07	0:22	8:30	8:54	0:24	0:04
8:10	0:43	8:54	9:13	0:19	0:02
8:13	1:00	9:13	9:37	0:23	0:02
8:14	1:23	9:37	10:01	0:23	0:01
8:15	1:45	10:01	10:25	0:24	0:01
8:19	2:06	10:25	10:47	0:22	0:03
8:21	2:25	10:47	11:06	0:19	0:02
8:25	2:41	11:06	11:25	0:18	0:04
8:29	2:55	11:25	11:35	0:10	0:03
8:30	3:05	11:35	11:50	0:15	0:01
8:36	3:13	11:50	12:05	0:14	0:06
8:40	3:25	12:05	12:27	0:22	0:03
8:44	3:43	12:27	12:48	0:21	0:04
8:50	3:58	12:48	13:01	0:12	0:06
8:54	4:07	13:01	13:15	0:13	0:04
9:00	4:14	13:15	13:31	0:15	0:06
9:07	4:23	13:31	13:41	0:09	0:06
9:13	4:27	13:41	13:57	0:16	0:06
9:33	4:24	13:57	14:09	0:12	0:19
9:52	4:17	14:09	14:33	0:24	0:19
10:11	4:22	14:33	14:45	0:11	0:19
10:30	4:15	14:45	15:03	0:18	0:18
10:42	4:21	15:03	15:16	0:12	0:11
10:59	4:16	15:16	15:35	0:19	0:17
11:13	4:22	15:35	15:56	0:21	0:14
11:25	4:31	15:56	16:20	0:23	0:11
11:37	4:43	16:20	16:42	0:21	0:11
11:49	4:52	16:42	17:00	0:18	0:12
12:02	4:57	17:00	17:14	0:14	0:13
12:13	5:01	17:14	17:26	0:11	0:10
12:27	4:58	17:26	17:43	0:17	0:13

A.2 Patient Arrival at Rural Clinic

Patient Arrival Time	Inter-arrival Time	Patient Start Time	Patient Departure Time	Service Time
8:00	0:02	8:00	8:06	0:06
8:02	0:02	8:06	8:12	0:06
8:04	0:02	8:12	8:17	0:05
8:07	0:02	8:17	8:25	0:07
8:09	0:02	8:25	8:32	0:07
8:12	0:04	8:32	8:38	0:06
8:16	0:02	8:38	8:44	0:05
8:19	0:03	8:44	8:50	0:06
8:22	0:04	8:50	8:56	0:05
8:26	0:02	8:56	9:02	0:05
8:28	0:02	9:02	9:09	0:06
8:31	0:03	9:09	9:15	0:06
8:35	0:09	9:15	9:23	0:07
8:44	0:03	9:23	9:30	0:07
8:47	0:11	9:30	9:36	0:06
8:59	0:10	9:36	9:48	0:11
9:09	0:02	9:48	9:53	0:05
9:12	0:11	9:53	9:58	0:05
9:23	0:07	9:58	10:06	0:08
9:30	0:05	10:06	10:16	0:09
9:36	0:09	10:16	10:22	0:05
9:45	0:08	10:22	10:28	0:06
9:54	0:08	10:28	10:39	0:11
10:02	0:09	10:39	10:46	0:07
10:12	0:10	10:46	10:56	0:10
10:22	0:03	10:56	11:01	0:04
10:26	0:06	11:01	11:09	0:07
10:32	0:04	11:09	11:17	0:08
10:37	0:04	11:17	11:29	0:11
10:41	0:09	11:29	11:34	0:05
10:51	0:08	11:34	11:39	0:05
11:00	0:07	11:39	11:45	0:05
11:07	0:06	11:45	11:55	0:10
11:14	0:05	11:55	12:01	0:05
11:20	0:05	12:01	12:07	0:05
11:25	0:11	12:07	12:12	0:05
11:36	0:11	12:12	12:22	0:09
11:48	0:08	12:22	12:29	0:07
11:56	0:02	12:29	12:38	0:09
11:58	0:04	12:38	12:45	0:07
12:02	0:03	12:45	12:55	0:09
12:06	0:02	12:55	13:01	0:06
12:08	0:07	13:01	13:10	0:09

A.3 Patient Arrival at Specialist - Private Facility

Patient Arrival Time	Patient Waiting Time	Start Time	Departure Time	Service Time	Inter-arrival Time
8:00	0:00	8:00	8:23	0:23	0:00
8:19	0:04	8:23	8:41	0:17	0:19
8:48	0:00	8:48	9:00	0:11	0:29
9:08	0:00	9:08	9:25	0:16	0:19
9:37	0:00	9:37	9:52	0:15	0:28
9:55	0:00	9:55	10:12	0:16	0:18
10:29	0:00	10:29	10:39	0:09	0:34
10:48	0:00	10:48	11:02	0:13	0:19
11:12	0:00	11:12	11:22	0:09	0:23
11:32	0:00	11:32	11:51	0:19	0:20
12:04	0:00	12:04	12:18	0:13	0:32
12:29	0:00	12:29	12:52	0:23	0:24
12:57	0:00	12:57	13:13	0:16	0:27

A.4 General Statistics for the Observed Health Facilities

Name of Health Facility	Average Queue Length (doctor)	Standard Deviation (Queue Length)	Average Time in hospital	Standard Deviation (Life Time)
Hospitals				
Johannesburg Hospital	29	9	04:42	02:12
Helen Joseph Hospital	32	8	04:21	01:12
Hillbrow Hospital	51	24	04:19	02:01
Clinics				
Noordgesig Municiple Clinic	31	11	03:47	01:01
Westbury Clinic	34	10	02:11	00:58
Crosby Municipal Clinic	41	18	04:42	01:16
Yeoville Municipal Clinic	129	62	04:48	01:50
Dispensary				
Garden City Dispensary	24	11	02:57	01:40

A.5 Average daily number of patients

These numbers were gotten by word of mouth from workers at the reception for the named facilities in the table below.

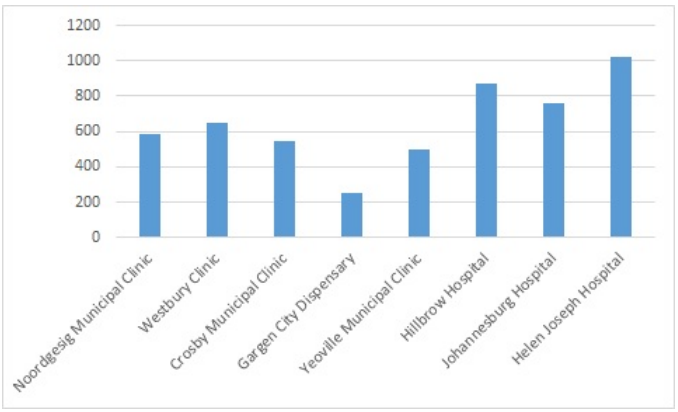


Figure A.1: Average number of patients who visit on a daily basis

Appendix B

PRELIMINARY RESULTS

B.1 Queue Length with Time

Time	queue length
10:00:00	0
10:02:00	1
10:02:00	2
10:10:00	3
10:14:00	3
10:15:10	4
10:16:10	5
10:19:00	6
10:25:23	7
10:27:02	8
10:32:45	8
10:34:33	9
10:49:10	9
10:57:30	9

Time	queue length
10:59:01	10
11:02:54	11
11:12:18	11
11:14:22	11
11:24:00	12
11:29:06	12
11:34:29	13
11:41:45	14
11:45:16	14
11:53:19	14
12:00:00	13
12:10:00	13
12:20:00	12
12:30:00	10

Time	queue length
12:40:00	9
12:50:00	9
13:00:00	8
13:10:00	7
13:20:00	6
13:30:00	6
13:40:00	6
13:50:00	5
14:00:00	5
14:10:00	4
14:20:00	4
14:30:00	3
14:40:00	0

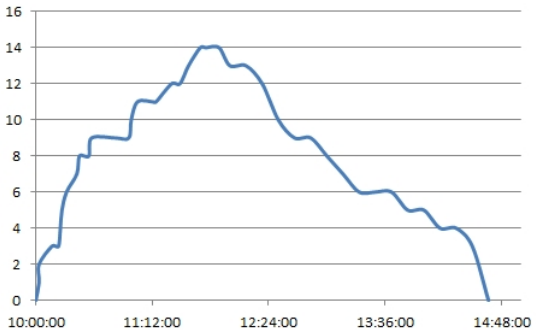


Figure B.1: Queue length against time

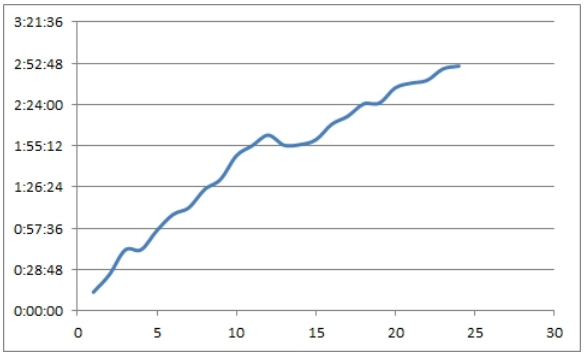


Figure B.2: Patient life time

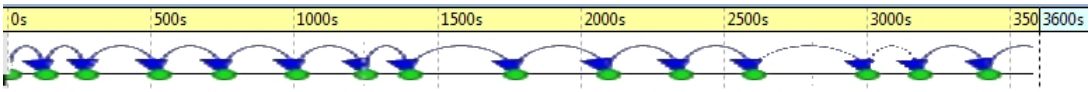


Figure B.3: Simulator arrival in 60 minutes

B.2 Data Capture Form

No.	**Arrival Time** (HH:MM:SS)	**Inter-arrival Time** (τ) (HH:MM:SS)	**Departure Time** (HH:MM:SS)	**Service Time** (μ) (HH:MM:SS)	**Queue Length** (L)
Mean Value					
Standard Deviation					

B.3 Sample Data

	Arrival time	**Inter-arrival Time** (τ)	**Departure Time**	**Service Time** (μ)
	10:00:00	0:00:00	10:14:00	0:14:00
	10:02:00	0:02:00	10:23:56	0:09:56
	10:02:00	0:00:00	10:34:26	0:10:30
	10:10:00	0:08:00	10:49:22	0:14:56
	10:14:00	0:04:00	10:57:26	0:08:04
	10:15:10	0:01:10	11:02:42	0:05:15
	10:16:10	0:01:00	11:19:19	0:16:37
	10:25:23	0:06:23	11:41:52	0:10:22
	10:34:33	0:01:48	12:17:25	0:13:15
	10:49:10	0:14:37	12:32:46	0:15:20
	10:57:30	0:08:20	12:42:49	0:10:04
	10:59:01	0:01:31	12:55:03	0:12:13
	11:14:22	0:02:04	13:41:42	0:17:56
	11:24:00	0:09:38	13:48:45	0:07:03
	11:29:06	0:05:06	14:03:54	0:15:09
Mean	**10:48:23**	**0:04:43**	**12:28:35**	**0:12:25**
Standard Diviation	**0:36:33**	**0:03:40**		**0:03:38**

Appendix C

CONFIGURATION DIAGAMS

C.1 Routing Path of Patients

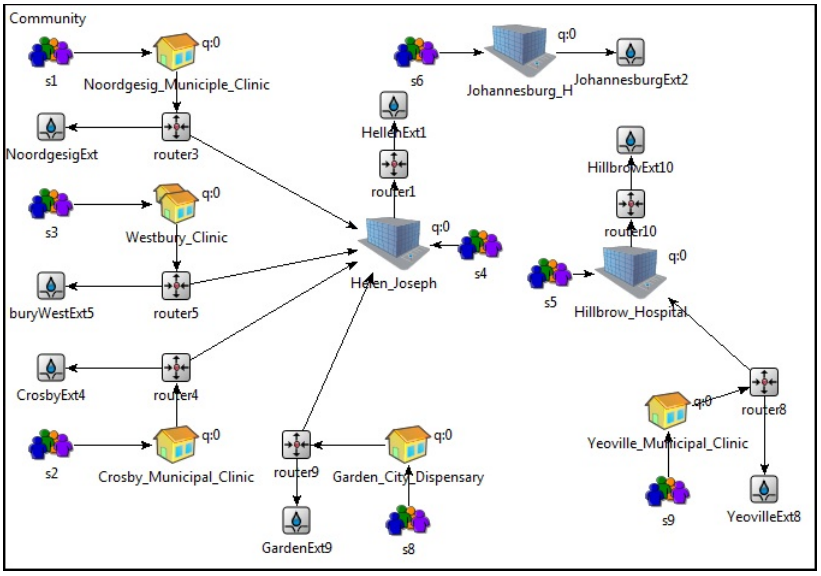


Figure C.1: General Structure of patient exchange between neighboring health facilities

Appendix D

CONSTANTS USED

D.1 Patient Types

Patient Ailment	**Destination Department**	**Identifier Number**
Accident victims	Trauma	0
Musculo-skeletal issues	Orthopaedics	1
Female issues	Gynaecology	2
Mental issues	Psychiatric	3
Hormonal issues	Endocrinology	4
Abdominal digestive issues	Hepatology	5
Skin issues	Dermatology	6
Pregnant women	Maternity	7
Chest and heart infections	Cardiology	8
Teeth issues	Dentist	9
Nerve issues	Neurology	10
Eye infections	Ophthalmology	11
Children	Paediatry	12
Surgery	Theatre	13
Urinary issues	Urology	14
Radiation therapy	Radiology	15

Appendix E

CLASS DEFINITIONS

E.1 Source Module

```
package org.omnetpp.queueing;
simple Source
{
    parameters:
        @group(Queueing);
        @signal[created](type="int");
        @statistic[created](title="the number of jobs created";
        record=count;
        interpolationmode=none);
        int numJobs = default(-1);
        volatile double interArrivalTime @unit(s);
        string jobName = default("Disease Name");
        volatile int jobType = default(0);
        volatile int jobPriority = default(0);
        double startTime @unit(s) = default(interArrivalTime);
        ouble stopTime @unit(s) = default(-1s);
   gates:
        output out;
}

simple Patient extends Source {}
```

E.2 Classifier Module

```
package org.omnetpp.queueing;
simple Classifier
{
    parameters:
        @group(Queueing);
```

```
        string dispatchField @enum("type","priority") = default("type");
    gates:
        input in[];
        output out[];
        output rest;
}
```

E.3 Queue Module

```
package org.omnetpp.queueing;
simple Queue
{
    parameters:
        @group(Queueing);
        @display("i=block/queue;q=queue");
        @signal[dropped](type="int");
        @signal[queueLength](type="int");
        @signal[queueingTime](type="simtime_t");
        @signal[busy](type="bool");
        @statistic[dropped](title="drop event";
         record=vector?,count;
         interpolationmode=none);
        @statistic[queueLength](title="queue length";
         record=vector,timeavg,max;
         interpolationmode=sample-hold);
        @statistic[queueingTime](title="queueing time at dequeue";
         record=vector?,mean,max;unit=s;interpolationmode=none);
        @statistic[busy](title="server busy state";
         record=vector?,timeavg;interpolationmode=sample-hold);

        int capacity = default(-1);
        bool fifo = default(true);
        volatile double serviceTime @unit(s);
    gates:
        input in[];
        output out;
}
```

E.4 Router Module

```
package org.omnetpp.queueing;
simple Router
{
    parameters:
        @group(Queueing);
```

```
        string routingAlgorithm @enum("random","roundRobin",
         "shortestQueue","minDelay") = default("random");
         volatile int randomGateIndex = default(intuniform(0, sizeof(out)-1));
    gates:
        input in[];
        output out[];
}
```

E.5 Merger Module

```
package org.omnetpp.queueing;
simple Merge
{
    parameters:
        @group(Queueing);
    gates:
        input in[];
        output out;
}
```

E.6 Delay Module

```
package org.omnetpp.queueing;
simple Delay
{
    parameters:
        @group(Queueing);
        @signal[delayedJobs](type="int");
        @statistic[delayedJobs](title="number of delayed jobs";
           record=vector?,timeavg,max;
           interpolationmode=sample-hold);
        volatile double delay @unit(s);
    gates:
        input in[];
        output out;
}
```

E.7 SinkExt Module

```
import org.omnetpp.queueing.Sink;
simple SinkExt extends Sink
{
    @class(SinkExt);
}
```

The definition for the `Sink` class is shown below.

```
package org.omnetpp.queueing;
simple Sink
{
    parameters:
        @group(Queueing);
        @signal[lifeTime](type="simtime_t");
        @signal[totalQueueingTime](type="simtime_t");
        @signal[totalDelayTime](type="simtime_t");
        @signal[totalServiceTime](type="simtime_t");
        @signal[queuesVisited](type="int");
        @signal[delaysVisited](type="int");
        @signal[generation](type="int");
        @statistic[lifeTime](title="lifetime of arrived jobs";
         unit=s;record=vector,mean,max;
         interpolationmode=none);
        @statistic[totalQueueingTime](title="total queue time";
         unit=s;
         record=vector?,mean,max;
         interpolationmode=none);
        @statistic[totalDelayTime](title="total delay";
         unit=s;
         record=vector?,mean,max;
         interpolationmode=none);
        @statistic[totalServiceTime](title="total service time";
         unit=s;
         record=vector?,mean,max;
         interpolationmode=none);
        @statistic[queuesVisited](title="total number of queues visited";
         record=vector?,mean,max;
         interpolationmode=none);
        @statistic[delaysVisited](title="total number of referals";
         record=vector?,mean,max;
         interpolationmode=none);
        @statistic[generation](title="the generation of the arrived jobs";
         record=vector?,mean,max;
         interpolationmode=none);
        bool keepJobs = default(false);
    gates:
        input in[];
}
```

Appendix F

FIELD DATA AND AUTHORIZATION LETTERS

health and social development
Department: Health and Social Development
GAUTENG PROVINCE

PERMISION FOR RESEARCH

DATE: 14/00/2013

NAME OF RESEARCH WORKER: NGOLE E. ETONDE

CONTACT DETAILS OF RESEARCH (INCLUDE ALTERNATE RESEARCHER):

Mr E.E. NGOLE - 0710166994, email: etonde.ngole@gmail.com

Prof. Turgay Celik - 011 717 6168, email: turgay.celik@wits.ac.za

TITLE OF RESEARCH PROJECT Simulation and Visualization of Large Scale Distributed Health System Infrastructure of Developing Countries

OBJECTIVES OF STUDY (Briefly or include a protocol): The study aims to find out the best possible ways of routing patients within and between health facilities to reduce patient waiting time and queue lengths to its minimum.

METHODOLOGY (Briefly or include a protocol): This study will be done by way of a simulation (computer simulation) where by various health facilities will be simulated within the system.

THE APPROVAL BY THE SUPERINTENDENT IS STRICTLY ON THE BASIS OF THE FOLLOWING:

(i) CONFIDENTIALITY OF PATIENTS MAINTAINED: Yes

(ii) NO COSTS TO THE HOSPITAL: Yes

(iii) APPROVAL OF HEAD OF DEPARTMENT: Yes

(iv) APPROVAL BY ETHICS COMMITTEE OF UNIVERSITY: n/a

SUPERINTENDENT PERMISION

Signature: _____ Date: 10/10/13

SUBJECT TO ANY RESTRICTIONS: _____

Helen Joseph Hospital
Perth Road
Tel: 011 489 1011

Private Bag X47
Auckland Park
2006

health and
social development
Department: Health and Social Development
GAUTENG PROVINCE

PERMISION FOR RESEARCH

DATE: 14/00/2013

NAME OF RESEARCH WORKER: NGOLE E. ETONDE

CONTACT DETAILS OF RESEARCH (INCLUDE ALTERNATE RESEARCHER):

Mr E.E. NGOLE - 0710166994, email: etonde.ngole@gmail.com

Prof. Turgay Celik - 011 717 6168, email: turgay.celik@wits.ac.za

TITLE OF RESEARCH PROJECT Simulation and Visualization of Large Scale Distributed Health System Infrastructure of Developing Countries

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(i) CONFIDENTIALITY OF PATIENTS MAINTAINED: Yes

(ii) NO COSTS TO THE HOSPITAL: Yes

(iii) APPROVAL OF HEAD OF DEPARTMENT: Yes

(iv) APPROVAL BY ETHICS COMMITTEE OF UNIVERSITY: n/a

SUPERINTENDENT PERMISION

Signature: _____ Date: 10/10/13

SUBJECT TO ANY RESTRICTIONS: _____

Helen Joseph Hospital
Perth Road
Tel: 011 489 1011

Private Bag X47
Auckland Park
2006

Helen Joseph
06/11/2013

1.2 Data Capture Form

No.	Arrival Time (HH:MM:SS)	~~Inter-arrival~~ Time (τ) (HH:MM:SS)	Departure Time (HH:MM:SS)	Service Time (μ) (HH:MM:SS)	Queue Length (L)
mother and child	8:01	8:01	8:09		
young mother	8:01	8:10	8:19		
mother in pink	8:01	8:20	8:34		
old man	8:03	8:34	8:49		
grey top	8:04	8:51	8:52		
pink shoes	8:04	8:53	9:07		
yellow top	8:05	9:09	9:16		
tiger skin	8:09	9:16	9:23		
old lady	8:09	9:24	9:34		
jeans and white	8:10	9:34	9:51		
yellow jersey	8:12	9:52	10:10		
top in green	8:12	10:12	10:23		
white socks	8:15	10:23	10:41		
~~standing~~ slender	8:18	10:41	10:53		
green head	8:21	10:54	11:09		
blue top & black	8:28	11:09	11:20		
red t-shirt	8:36	11:21	11:29		
old pants	8:37	11:29	11:42		
colored girl	8:43	11:43	12:00		
old man & wife	8:49	12:01	12:14		
zeelu boy	8:52	12:15	12:31		
yellow jersey	8:59	12:34	12:41		
Other back	9:10	12:41	12:59		
Red shoe ~~Mean Value~~	9:12	13:02	13:08		
blue eyes ~~Standard Deviation~~	9:12	13:09	13:20		

Helen J
04/11/2023

1.2 Data Capture Form

No.	Arrival Time (HH:MM:SS)	~~Inter-arrival~~ Start Time (τ) (HH:MM:SS)	Departure Time (HH:MM:SS)	Service Time (μ) (HH:MM:SS)	Queue Length (L)
	9:03	11:51	12:08		
	9:13	12:09	12:13		
	9:23	12:14	12:20		
	9:41	12:22	12:34		
	9:43	12:34	12:51		
	9:52	12:53	13:09		
	9:58	13:10	13:20		
	10:09	13:21	13:28		
	10:20	13:29	13:41		
	10:23	13:41	13:43		
	10:24	13:44	13:50		
	10:31	13:51	13:58		
	10:43	14:00	14:17		
	10:45	14:18	14:21		
	10:48	14:23	14:41		
	10:58	14:42	15:05		
	10:59	15:06	15:09		
	11:03	15:10	15:24		
	11:15	15:25	15:31		
	11:18	15:31	15:48		
	11:23	15:49	16:09		
	11:29	16:10	16:20		
	11:39	16:20	16:29		
Mean Value	11:43	16:30	16:43		
Standard Deviation	11:48	16:43	16:51		

1.2 Data Capture Form

No.	Arrival Time (HH:MM:SS)	~~Inter-arrival~~ Start Time (τ) (HH:MM:SS)	Departure Time (HH:MM:SS)	Service Time (μ) (HH:MM:SS)	Queue Length (L)
girl ∧ child	9:03	9:52	10:14		
old woman	9:09	10:15	10:42		
thin guy	9:13	10:43	10:59		
colored boy	9:17	11:01	11:13		
mother in pink	9:22	11:13	11:27		
woman in shorts	9:23	11:28	11:40		
Nigerian boy	9:23	11:41	11:58		
Nigerian woman	9:30	11:59	12:11		
fair girl in blues	9:31	12:11	12:21		
old lady and child	9:34	12:23	12:40		
black stoned lady	9:35	12:41	12:51		
skinny boy	9:38	12:51	12:59		
man in suit	9:43	13:01	13:12		
young sisters	9:43	13:12	13:24		
girl in jeans jacket	9:44	13:24	13:42		
girl and twins	9:51	13:42	13:54		
old sister woman	9:59	13:55	14:13		
colored girl with ring	10:10	14:13	14:24		
man in black	10:12	14:25	14:38		
young mother	10:17	14:40	14:50		
short girl in blouse	10:26	14:51	14:59		
mother and child like	10:27	15:00	15:12		
Man in uniform	10:39	15:14	15:30		
~~Mean Value~~	10:50	15:33	15:58		
~~Standard Deviation~~	10:52	15:53	16:11		

girl with dress
girl in pink

1.2 Data Capture Form

No.	Arrival Time (HH:MM:SS)	~~Inter-arrival~~ Steert Time (τ) (HH:MM:SS)	Departure Time (HH:MM:SS)	Service Time (μ) (HH:MM:SS)	Queue Length (L)
Light skin	9:03	9:05	9:22		
fat girl and child	9603	9:23	9:39		
woman in black	9:04	9:42	10:09		
man in lie	9:07	10:10	10:27		
albino girl	9:09	10:28	10:51		
little mum	9:14	10:53	11:15		
fat girl in blue	9:18	11:16	11:41		
redcloud girl	9:19	11:43	11:57		
yellow dress	9:26	12:00	12:18		
white shoes	9:39	12:20	12:31		
no hair	9:42	12:31	12:47		
big man	9:54	12:47	12:51		
nigerian girl	9:56	12:53	13:10		
nigerian girl2	10:08	13:11	13:36		
big mama	10:11	13:36	13:57		
blue shirt	10:20	13:59	14:18		
dirty jeans	10:31	14:18	14:21		
blue skirt lady	10:48	14:22	14:56		
old man	10:51	14:51	14:59		
crippled guy	10:52	15:00	15:09		
fat man and lad	11:09	15:10	15:27		
bright skin man	11:18	15:27	15:44		
over head cover	11:26	15:45	16:01		
green shirt ~~Mean Value~~	11:38	16:01	16:21		
Standard Deviation					

1.2 Data Capture Form

No.	Arrival Time (HH:MM:SS)	Steent ~~Inter-arrival~~ Time (τ) (HH:MM:SS)	Departure Time (HH:MM:SS)	Service Time (μ) (HH:MM:SS)	Queue Length (L)
orange top	9:03	11:21	11:43		
Zebra skin	9:12	11:44	11:56		
Zara girl	9:16	11:57	12:10		
lady in heat	9:17	12:11	12:24		
skinny man	9:24	12:25	12:34		
lady in jean	9:29	12:35	12:51		
woman in gown	9:31	12:53	13:10		
student	9:31	13:12	13:24		
child and walker	9:43	13:26	13:39		
rainbow top.	9:54	13:41	13:46		
striped shirt	9:55	13:49	14:03		
man in green	9:59	14:05	14:12		
colored lady	10:09	14:15	14:21		
old man	10:09	14:23	14:39		
young boy in the	10:16	14:40	14:58		
child and lady	10:31	14:59	15:17		
small man	10:44	15:17	15:31		
nigerian	10:58	15:32	15:50		
yellow top	11:04	15:51	16:03		
green skirt	11:16				
short skirt/blue	11:41				
Zenith man	11:57				
green shirt	12:10				
Suit ~~Mean Value~~	12:16				
pink dress ~~Standard Deviation~~					

1.2 Data Capture Form

No.	Arrival Time (HH:MM:SS)	~~Inter-arrival~~ Start Time (τ) (HH:MM:SS)	Departure Time (HH:MM:SS)	Service Time (μ) (HH:MM:SS)	Queue Length (L)
lady in black	7:48	8:09	8:16		
old woman	7:49	8:16	8:26		
child & mum	7:49	8:27	8:89		
man in jeans	7:53	8:39	8:48		
fat man	7:54	8:44	8:55		
blue dress	7:54	8:55	9:14		
yellow shirt	7:58	9:15	9:20		
man in skinny	7:59	9:20	9:32		
girl and friend	8:01	9:33	9:48		
woman head	8:03	9:49	9:56		
booth	8:03	9:57	10:14		
worker	8:04	10:15	10:26		
~~lady~~ only abb	8:09	10:27	10:42		
man in helmet	8:10	10:43	10:49		
sky blue t-shirt	8:11	10:51	10:59		
check shirt	8:11	11:02	11:17		
black shorts	8:13	11:18	11:29		
sports wear	8:14	11:29	11:36		
woman in green	8:15	11:37	11:49		
light man	8:15	11:50	11:58		
skinny girl	8:17	11:54	12:09		
ocean man	8:19	12:11	12:21		
big woman	8:22	12:22	12:34		
~~Mean Value~~	8:23	12:35	12:48		
~~Standard Deviation~~	8:28	12:49	13:03		

Authorization

On behalf of the management of **Johannesburg Hospital**, NGOLE E. ETONDE, A masters student at the University of the Witwatersrand in Johannesburg has been granted permission to collect the data mentioned in this letter from this health-care facility.



Signature/Stamp



14/10/2023

JHB clinic

1.2 Data Capture Form

No.	Arrival Time (HH:MM:SS)	Start ~~Inter-arrival~~ Time (τ) (HH:MM:SS)	Departure Time (HH:MM:SS)	Service Time (μ) (HH:MM:SS)	Queue Length (L)
black and white dress	10:12	11:26	11:41		
blue dress	10:15	11:42	11:58		
big girl	10:27	12:59	12:09		
big man	10:28	12:09	12:17		
yellow shoes	10:42	12:17	12:28		
black dress	11:08	12:29	12:40		
jeans and white	11:06	12:40	12:58		
blue tights	11:11	13:00	13:10		
yellow hair	11:20	13:10	13:21		
child and mum	11:23	13:22	13:26		
old woman	11:29	13:27	13:41		
couples	11:34	13:48	13:58		
green boy	11:40	14:00	14:09		
blue jeans	11:42	14:10	14:22		
jeans and brown top	11:46	14:33	14:41		
black dress	11:53	14:41	14:51		
pink dress	12:07	14:52	15:03		
red top and shoes	12:16	15:05	15:16		
light green	12:17	15:18	15:29		
yellow pants	12:17	15:31	15:48		
huge and tall	12:30	15:50	16:03		
broken bone	12:34	16:05	16:09		
left side jeans	12:51	16:10	16:20		
moon ~~Mean Value~~	12:59	16:22	16:29		
~~Standard Deviation~~	~~13:08~~				



1.2 Data Capture Form

No.	Arrival Time (HH:MM:SS)	Start ~~Inter-arrival~~ Time (τ) (HH:MM:SS)	Departure Time (HH:MM:SS)	Service Time (μ) (HH:MM:SS)	Queue Length (L)
~~bright~~ dress	8:01	8:14	8:41		
big man	8:01	8:43	8:50		
cry baby	8:03	8:52	9:17		
blue top shapes	8:04	9:18	9:28		
dress & jeans	8:10	9:31	9:50		
old man	8:11	9:52	10:19		
couple & child	8:12	10:21	10:31		
striped t shirt	8:12	10:38	10:53		
jeans & yellow	8:14	10:57	11:11		
girl & child	8:15	11:15	11:23		
girl and mother	8:15	11:25	11:32		
boy in suit	8:21	11:33	11:47		
x-ray card	8:32	11:49	12:01		
traditional	8:33	12:02	12:09		
boy in pink	8:41	12:10	12:14		
Girl in locks	8:52	12:15	12:23		
Limp lady	9:03	12:24	12:31		
old dying man	9:10	12:32	12:41		
big man	9:22	12:41	12:56		
Mean Value					
Standard Deviation					

RECEIVED CEO
22-01-2014
CMJAH

1.2 Data Capture Form

No.	Arrival Time (HH:MM:SS)	~~Inter-arrival~~ Start Time (τ) (HH:MM:SS)	Departure Time (HH:MM:SS)	Service Time (μ) (HH:MM:SS)	Queue Length (L)
Seam	10:08	10:06	10:32		
red dress	10:20	10:34	10:50		
colored lady	11:15	11:16	11:33		
guy in jeans	11:30	11:35	11:42		
lady in blue	11:30	11:43	12:10		
red dress & shoes	11:53	12:15	12:37		
big boots shoes	12:03	12:40	12:54		
	~~12:05~~				
old lady (white)	12:15	12:59	13:32		
lady & child	~~12~~:45	13:35	13:51		
Mean Value					
Standard Deviation					

RECEIVED CEO
22-01-2014
CMJAH

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