ASHESI UNIVERSITY

INTELLIGENT HEALTHCARE FOR EFFICIENT BED OCCUPANCY

UNDERGRADUATE THESIS

BSc. Computer Science

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Intelligent HealthCare for Efficient Bed Occupancy

UNDERGRADUATE THESIS

Thesis submitted to the Department of Computer Science of

Ashesi University College in Partial Fulfilment of Science Degree in

Computer Science

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April 2020

DECLARATION

I hereby declare that this Undergraduate Thesis is the result of my own original work and that no part of it has been represented for another degree in this university or elsewhere.

Candidate's Signature: …………………………………………………………………

Candidate's Name: ……………………………………………………………………..

Date: …………………………………………………………………………………….

I hereby declare that the preparation and presentation of this Undergraduate Thesis were supervised in accordance with the guidelines on supervisors of Undergraduate Thesis laid down by Ashesi University

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Abstract

Hospital occupancy describes the number of hospital beds engaged by inpatients as compared to the total number of beds in the hospital. Knowledge of accurate occupancy is essential to very hospital in determining whether the hospital is under-occupied and wasting resources or over occupied such as that they may not be providing proper patient care. It is also very imperative especially in emergency situations that the current bed occupancy is known such that incoming patients experience reduced wait times which lead to improved patient outcomes.

This thesis explores a model which uses IoT sensors and a triage framework to actively calculate the number of occupied as against the number of beds available and efficiently schedule waiting patients unto these beds according to the severity of their cases.

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1 Chapter 1: Introduction and Background

1.1 Introduction and Background

Ghana has a universal healthcare system called the National Health Insurance Scheme and it was effected in 2004. In 2019, the government's implementation of the National Health Insurance Scheme (NHIS) had enabled over 12 million Ghanaians (about 40% of the population then) to be able to access free basic healthcare across multiple public healthcare providers nationwide [1]. Healthcare in Ghana is largely administered by the Ministry of Health and the Ghana Health Service. There are five main levels of healthcare dispensary in Ghana namely; health posts, health centres and clinics, district hospitals, regional hospitals and tertiary or teaching hospitals. Health posts being majorly found in rural areas lack adequate medical staffing as well as bedding and equipment.

As of 2014, Ghana spent 3.6% of its GDP on healthcare causing an appreciable improvement in the sector[2]. Nonetheless, in Accra which is the country's capital, there are about 3,400 beds across seven major hospitals serving a population of five million[3]. The country has an estimated hospital bed capacity of 25,950 nationwide [4]. In 2011, Ghana had a hospital density of 0.9(beds/1000). This entry provides the number of beds per one thousand people; meaning that for every 1,000 people in Ghana there was less than one hospital bed available to service them [5]. Included in this study were hospital beds from public, general, private, specialized hospitals and rehabilitation centres. In most cases, bed for both acute and chronic diseases is included. There is no set standard or target for the number of beds a country should have per 1000 people because of the variation in demographics and intensity of outbreak. Thus, while 1 bed per 1000 in country may be sufficient, the same in a different country may be woefully inadequate due to the number of people requiring medical attention.

Globally, the rural population constitutes about 50% of the world's entire population [6]. Similarly , the Ghanaian context provides an almost identical case with 49.1% of the population living in rural areas[7]. The lack of modern healthcare in the rural areas can however be found in the urban areas which are well served with modern hospitals including regional hospitals and tertiary hospitals. Due to this, the number of referrals from rural areas to urban centres especially in emergency situations have skyrocketed in recent years. Emergency referrals is critical in improving outcomes especially in time sensitive conditions. Linking to a district or tertiary hospital in a timely fashion could improve chances of survival and possibly save lives. However, to be effective and efficient receiving facilities must be ready and have the necessary resources and space available to take on the extra numbers.

The success of a hospital depends largely on its ability to have a good reaction time in response to emergencies, effectively treat patients and efficiently manage their resources. Due to financial constraints especially in developing countries, strategies to maximize existing resources will have to be adopted and the use smart IoT systems will afford this. Proficient bed management is particularly of critical concern as the last thing a busy hospital would need is overcrowding which could promote the spread of other diseases or under-utilization which would deprive patients of healthcare access as well as the for-profit hospitals of income. Consider a pregnant woman in labour arriving at a hospital only to wait for a long stretch of time to be allocated a bed or even worse, be informed the department is at maximum capacity. This can pose serious threats such as prolonged labour complications which may eventually result in further serious impediments. Efficient bed management forms part of operational capacity planning and control which is a part of a wider spectrum concerned with the efficient use of resources. Even outside the context of health, activities such as scheduling and workflow to enable throughput meet demand and maximizing resource utilization is at the core of every organization[8].

Dimitridas et al [9] concluded that a major cause of surgery cancellations is due to the scarcity of beds. Typically, hospitals in Ghana especially tend to be reactive instead of proactive when it comes to responding to a fluctuation in occupancy. For instance, in the case of a demand surge, hospital managers may react by immediately increasing the number of beds opened. However, reactions such as this might not necessarily be the most effective in the long term as these new opened beds will also have to be staffed which will incur extra cost. Since beds are a limited resource at hospitals, proper management strategies are required to make effective utilization. According to [10], most hospital departments may face the miserable reality of turning patients down due to the lack of beds to accommodate these patients. Thus, the emergence of decision support tools and technology is imperative to advance the bed management system in Ghanaian hospitals.

Smart systems such as IoT integrate functions of sensing and actuation in order to manage situations. Internet of Things (IoT) is a recent communication paradigm that envisions a near future where devices and objects of everyday life embedded with microcontrollers and suitable protocols would be able to communicate with each other and other users [11]. IoT in recent times has found applications in many fields including industrial automation, home automation, mobile healthcare, proficient energy management and traffic management. The paradigm encourages machine to machine communication (M2M) further reducing the chance of human error which is of critical concern in healthcare. Physical devices are able to stay in touch with one another leading to a greater scale of efficiency. IoT enables everyday tasks to be automated which leads to a better monitoring of task and progress with very little to no human intervention. In healthcare, IoT allows real time monitoring and simultaneous reporting via connected devices that can save lives in the event of a medical emergency such as asthma attacks and heart failure. IoT devices are able to collect and transfer health data such as blood pressure, blood levels and oxygen levels.

These data are stored in the cloud and can be shared with authorized personnel such as physicians or an external consultant to look at them regardless of their location and time. With IoT, remote medical assistance is now possible where in the case of an emergency, patients can contact a doctor who may be miles away for help through smart apps. Mobility solutions have also enabled patients to be checked for ailments on the go. IoT is changing the way facilities are being delivered to the health industry. The prevalence of IoT systems in healthcare will transform systems from reactive to proactive allowing them to schedule effectively and increase the overall efficiency in the delivery of healthcare in Ghana.

1.2 Motivation

The lack of efficient systems to automatically monitor and report on hospital resource utilization in most Ghanaian hospitals leads to numerous status updates that escapes management majorly due to the manual approaches they employ. In 2018, the Korle Bu Teaching hospital inaugurated a new Accident and Emergency centre which has a bed capacity of over 60 beds - twice the number at the previous centre[12]. Patient statistics prove that the outpatient attendance is averagely 32,000 per annum. The Casualty Reception alone receives about 52% out of which 40% are admitted. Even though the number of patients being received per time would put enormous pressure on hospital beds, with the right technological systems to accurately predict the number of beds at any particular point in time, the beds could be efficiently managed. Management teams who have very little to no knowledge of effective assessing techniques tend to rely on simple mathematical equations and past experiences to inform their decisions which can be detrimental to the hospital's progress [13].

The problem addressed by this research is that of accurately assessing the number available inpatient beds in hospitals at any point in time to improve long patient wait times especially patients in critical condition, treating patients with the needed care as well as making the maximum profits by not turning patients down. The problem of efficient bed utilization is important because delays, overscheduling, under scheduling, overcrowding, transfer of patients are all situations that can be fatal to both the patient and the hospital as a whole.

On the 28th of March 2020, Ghana had 139 COVID-19 cases and in light of this the Minister of Health announced that 200 Intensive Care Unit (ICU) beds would be available across the country to admit patients[14]. As at 9th May 2020 Ghana's COVID-19 case count is 4263 which renders the number of beds available woefully inadequate to support the spiraling case count [15]. It is therefore imperative that decision support technology is adopted to manage the bed resources available as increasing the number of beds without having any effective management tools may not be the most efficient course of action.

1.3 Research Hypotheses

This research paper is being written under the following assumptions which are subject to modification after research methodology is carried out.

(i) H_0: The emergency departments of most Ghanaian hospitals face enormous congestion during peak times. There are limited number of beds and resources than desired.

(ii) H_1: In an emergency situation, it may take the Ghanaian hospital a longer period than necessary to find a critical patient a bed or turn them away.

(iii) H_2: Private and public hospitals alike face congestion and thus would be needy of a model that would alleviate the burden of bed management.

1.4 Research Objective

The main objective of this research is transforming hospitals from reactive to proactive by asking one major question, "**Can the bed availability of a hospital be calculated at any point in time to efficiently schedule patients to improve clinical outcomes?"** The aim is to be able to access the knowledge of the number of available beds at every point in time per day. This information will support and inform management decisions accurately.

This proposal will describe the approach to a model with the use of smart IoT systems to assess the availability of hospital beds better than the current methods in Ghanaian public health facilities.

2 Chapter 2: Review of Literature

2.1 Access to HealthCare Systems in Africa

The third Sustainable Development Goal (SDG) highlights good health and wellbeing in reducing mortality rates and the access to healthcare is imperative in order to achieve this goal [16]. This study primarily focuses on the apt delivery of healthcare as healthcare access is still a very serious challenge for Africa. The healthcare industry is undoubtedly a requisite sector for every country and comprises providers of remedial diagnostic, preventive services such as doctors and nurses. The principal aim of healthcare systems is to provide the population with efficiency in their health needs. Thus, the population being able to access the health services is very important.

Access to healthcare describes the coverage ability of the health care system. It is defined as the capacity of healthcare system to reach the population without excluding any part of it in order for health services to be dispensed [17]. It is particularly clear that while some countries enjoy a very fair access to quality healthcare as included in their rights, others can only deem it a luxury. [18] indicates that if there is one main area that sums up the Africa's pool of developmental issues, it would be healthcare. According to [19], less than 50% of Africans have access to modern healthcare facilities. This is partially due to the fact that most African countries spend less than 10% of their GDP on their healthcare sectors[19]. WHO reports that approximately 25% of global diseases occur in Africa, however the continents contribution towards the global health budget is less than 1% [20]. On the other hand, countries such as Finland, Canada and France to mention a few, are amongst the best countries with regards to healthcare access and good quality of life in general[21]. Such countries will generally enjoy better health and a longer life span due to their stable healthcare systems.

Africa displays the symptoms of a crisis in healthcare technology management which has devasting effects on healthcare delivery. According to [22], Africa is under immense internal and international pressure to adopt healthcare technologies in the form of support systems, devices and equipment to strengthen the efficiency and coverage of our healthcare systems. Improved healthcare management systems have been identified by the Harvard Business School is identified as a key factor to improving healthcare[23]. African countries have to close this healthcare gap by adopting cutting edge technologies into the field to optimize our current systems. Even though the continent has a long road ahead in bringing its healthcare frontlines up to par, recent times have witnessed an appreciable increase in the use of technology for healthcare on the continent. The advent of flying medical aid via the use of drones, remote healthcare systems as well as smart lockers is steering African healthcare unto the right path [24].

2.2 IoT Technology

Internet of Things (IoT) is a term that was coined in 1999 although the idea actual idea of IoT connected devices dates back to the 1970's [25]. The world today is in an age of smart technologies which represents a new era of ubiquitous computing[26]. Internet of Things (IoT) while not the only technology in this field, has proven to be a very compelling force in expressing the paradigm of ubiquitous computing. IoT is defined by [27] as the interlinking of physical devices, building and vehicles sometimes described as "smart"– embedded with sensors, actuators and network connectivity to aid these objects to collect as well as exchange data. IoT allows entities to be detected or sensed and remotely controlled over an existing network. This invariably creates more potential for our physical world to be integrated into computer systems to improve accuracy and efficiency. Linking up all these different objects and adding sensors to them emerges a level of digital intelligence to these objects that are rather taciturn on their own, enabling them to communicate and share information without human intervention [28]. In reports made by [28], tech analysts predict that by 2025, there would be of approximately 41.6 billion IoT devices connected to each other. This cements the fact the world as we know it would become more interconnected making data very easily accessible. IoT is currently making strides in the fields of healthcare, industrial automation and energy management.

The benefits of IoT in today's society are immense however it all boils down to enabling organizations be agile and efficient in their operations and this is materialized through the access to more data about their own internal systems such that they are able to make prudent and decisions based on the data. It is for this reason that this research employs IoT to be able to gather information from a set of sensors connected to the beds concerning how many patients are occupying a hospital bed. This vital data is then used by the hospital to determine how many more patients to admit within a prescribed time frame.

[redacted] Use of IoT Sensor Technology in Occupancy Detection

According to [29], sensors are devices used to identify incoming signals. It is used to detect the presence of any physical object in the vicinity and send information about it. Physical quantities such as light, force can all be converted into the required signals in order to be used by sensors. They can be either analogue or digital. There are many types of sensors some of which are motion sensors and pressure sensors.

In healthcare, pressure sensors are used in anesthesia delivery machines, oxygen concentrators, ventilators and kidney dialysis machines just to mention a few. To measure the exact duration of patient-physician interaction over a long period of time, [30] developed a sensor system to detect the number of people that enter the door and their direction. The time between two separate measurements could be reduced to 50 ms, to enable the system measure walking speeds up to 2 ms^{-1}. The accuracy of the time stamp for each event is less than one second which ensures a precise documentation of the consultation time. In this research a motion sensor is joint to two flight sensors on a particular side of the door frame.

[31] researched into low cost wireless occupancy sensors for beds to be able to alert health professionals when patients got out their beds in order to prevents falls. In this study proximity sensors and accelerometer sensors were assessed as the focus was on a low-cost system. The downside in relation to our current study is that although accelerometers are motion sensors and may be used to detect human presence, these alone are not enough to conclude that the entity detected is a human. To be able to streamline the classification of presences, object detection and activity recognition algorithms are applied in that project.

The research undertaken in [32], describes a wireless occupancy sensor system in a nursing home that is used to alert caretakers of possible falls and tumbles of the residents in the home. It is reported that these residents easily fell when getting out of bed which is highlighted as a serious health issue and the main cause of deaths in nursing homes. The research employed pressure sensors in conjunction with a ZigBee network to alert the nurses of when patients got out bed so they could go offer them assistance. The disadvantage in relation to our current research is that the use of ZigBee networks however is mainly short range and thus is not suitable for a large public health facility. Its maintenance cost is also very high considering it has a low data speed [33].

2.3 Computer Simulation in Healthcare

Computer Simulation is explained as approximating a system's behaviour abstractly by the use computer to imitate a real-world system or process. A computer simulation is a program which runs on a computer and employs step-by-step algorithms to explore the approximate behaviour of a mathematical model. The field is slowly gaining grounds in the technology industry as it currently provides assistance in the design, creation and evaluation of complex systems.

Computer simulation's dynamism allows it to be applied in a wide range of industries including healthcare. In the *Patient Wait Case Study*, computer simulation is used to analyse and improve patient waiting times [34]. Due to a heightened increase in patient complaints about waiting times, two methods were channelled to understand and subsequently reduce patient waiting times. However, it was discovered that piloting these two methods to find out which would be most suited to curb the problem would be very time consuming and expensive. The researchers then turned their attention to computer simulation which offered a cheaper and more convenient way to evaluate the effect of process changes on patient wait times. In a different study, [35] runs a study which aims to explores examples of computer simulation models that support decision making support tools. The main purpose of this review is to suggest a system of healthcare topics assessed with the aid of simulation models due to how useful simulation had proved in healthcare per their research.

2.3 Summary of Literature Work

Thus far from the research, it is evident that the access to proper healthcare in African countries in this case Ghana, can be improved by providing better equipped systems for devices to be able to access pools of data that for making timely and effective decisions. The literature work reveals that a lot of work has been done with sensor systems to relief agitation of bed occupants however the literature also reveals a gap in knowledge in the use of sensors systems to optimize hospital bed allocation and patient scheduling which this research proposes.

3 Chapter 3: Research Methodology

3.1 Introduction

The general aim of this study is to find the generate a cost effective and efficient mechanism by which bed availability can be assessed at any point in time throughout the day to improve patient wait times and ultimately save lives. This section describes the conceptual framework that the research study is built on.

This chapter shall discuss the research methods available for the study and what is applicable for use in response to the statement of the problem in chapter one. It mainly describes the research design employed and validation process of the headlining topic. This research aims to describe a technique that Ghanaian hospitals could possibly employ to assess bed availability in a more accurate manner as opposed to guesswork and natural inferences. The significant themes to be considered under this chapter would be specifies the method of research used, research design, respondents of the study, data collection and data analysis.

3.2 Research Method – Quantitative Versus Qualitative Research

One of the foremost points in the approach is about information/data gathering. How should information be gathered in the best way possible to ensure its consistency and completeness? The research design method deemed appropriate for this research work is qualitative research.

Quantitative research is the process of assembling observable data to answer a critical research assertion. It is often done using statistical, computational or mathematical technicalities. On the other hand, qualitative research which leans more towards non-statistical measures. It focuses on words rather than numbers and depth as opposed to breadth. Its methods are investigative as they seek to unearth opinions, thoughts and feelings of the participants. It enables the researcher to gain more understanding into the underlying reasons and opinions as to a problem or particular phenomenon exists. The main methods of collecting data in qualitative research is through organized interviews and focus groups where people retell their stories and experiences, observation of participants in their natural setting as well as analyzing documents and conversations.

Both qualitative and quantitative research strive for reliability and validity of their data and both have a systematic way of carrying out the process. Thus, the choice is not about one being more accurate or objective than the other but depends wholly on the information the researcher seeks to unearth. For this study, qualitative is preferred to quantitative analysis because the researcher seeks to understand the frustrations and feelings of the health professionals at hospitals that face over congestion and the methods, they currently employ to deal with their bed management. It is worth mentioning that quantitative research was not undertaken in this study due to the difficulty the researcher faced in assessing government hospital data to aid in the simulation process. However, there is a general lack of depth in the knowledge of the underlying causes and impact of the problem on healthcare personnel and patients alike hence qualitative research being chosen.

3.3 Research Design and Data Collection Tools

A research design is the plan or sequence of actions that the researcher has to take in order to collect and analyze data. In this study, qualitative methods would be used to collect data from Ghanaian hospitals. The data collection tools employed are:

i. Organized In-depth Interviews - Doctors and other health personnel would be interviewed to enable the researcher to catch a better scope and understanding of the problem and methods being adopted currently to mitigate it. Interviews were chosen because they can be succinct enough for the busy doctors and health professionals taking into consideration how hectic a hospital can get. Interviews will provide the necessary answers to aid this research asked without putting our participants under any extra tension. It also allows for intimate time where critical questions to be asked to those who matter the most or are most affected in the situation (In-depth interviews). The main advantage of interviews is that they eliminate nonresponses and will also allow the interviewer the chance to perceive the emotions of the interviewees. The type of interview structure adopted was semi-structured where a list of open-ended questions is asked to the respondent allowing the researcher to probe further.

ii. Observation – Once at the research grounds (hospital), the researcher will observe the space to pick up any other information the interview could be silent on to better inform the study and reduce biases. Observational research may prove resourceful in highlighting any lurking variable partly contributing to the problem at hand.

iii. Analyzing documents – Online journals, articles and news reports would be analyzed by the researcher to uncover more information in relevance to the issue in comparison to the information received from interviews and observation.

3.4 Research Setting and Sample Selection

The sampling strategy implemented in this research is non-probabilistic sampling. Non-probabilistic sampling is deliberately chosen to reflect particular features of the population. This strategy is chosen also because non probabilistic sampling is used mostly in exploratory and qualitative research. It also provides a wide range of sampling techniques such as purposive sampling which was chosen for this study.

For this study, the researcher selected two hospitals both in the capital city of Ghana, Accra. According to [36], for qualitative sample sizes, they should be relatively small. They argue that a qualitative study is rich in detail and respondents are more likely to give more information than even necessary. Hence, the sample sizes must remain small in to enable the researcher meticulously to analyze the data. The researcher reduced the scope to Accra because the literature review of healthcare in the country revealed that most patients end up being referred to hospitals in Accra predominantly and other major cities for treatment.

For privacy and security purposes the actual names of these hospitals have been withheld and would be labelled as 'Hospital A' and 'Hospital B'.

i. Hospital A – This hospital is classified as a **highly resourced – low capacity private hospital**. It has a bedding maximum of about 60 beds. It is a medium facility in the Tema West District with a minimum of four doctors on duty per every shift. The entire hospital has approximately seven wards and four consulting rooms. It is well resourced with high tech laboratories and equipment such as an MRI scanner, CT Scanner among others. The hospital's outpatient attendance is approximately 8,000 people per annum. Three doctors are interviewed in this hospital including one hospital director.

   The interview process took place for Hospital A on 13th February 2020. The initial consultation to seek approval from the hospital the research took place on 7th February 2020. Three doctors on duty were interviewed including a hospital administrator. Each doctor was interviewed for approximately 20 minutes.

ii. Hospital B – This is hospital is classified as **highly resourced – high capacity public hospital**. It is a principal health facility in Ghana, receiving a high influx of referrals from less equipped hospitals and health centres. It has a total bed capacity of approximately 2,000 beds with about 17 clinical departments. The hospital has an average daily attendance of 1,500 and 250 patient admissions. The clinical department this study will focus most on is the Accident and Emergency department which has a bedding total of approximately 60 beds and an outpatient attendance of 32,000 per annum. Three doctors are interviewed at this department and each doctor was interviewed for approximately 15-20 minutes. The interview process for Hospital B begun on 5th February 2020. The research lasted for two days.

3.5 Data Analysis

In analyzing the data collected from the in-depth interview, thematic content analysis and narrative analysis is used. Content analysis is preferred to other methods of qualitative data analysis due to its ability to enable the researcher find meaningful trends and patterns from responses. Content analysis is "any qualitative data reduction and sense-making effort that takes a volume of qualitative material and attempts to identify core consistencies and meanings" [37]. The data is organized into themes and sub-themes such that the data can be comparable. A main advantage is that it helps in the reduction and simplification of the data into meaningful information while producing results that can be manipulated to suite the particular assertion. Permission was sought from respondents to record their responses on paper.

This section entails an analysis of the data that was collected for this study in relation to the research objectives. It contains the analysis of the in-depth interview, findings from the observation as well as findings from analyzing online news articles and journals.

3.5.1 Content Analysis of In-depth Interviews

Content analysis provides the opportunity for the researcher to be able to generate codes for the participant responses to generate meaning out of them. The data is coded using selective coding where keywords, concepts and ideas are collected together to create meaning. Table 3.1 provides a detailed breakdown of the respondents with their coded identification that were interviewed at both hospitals that participated in the research.

Table 3-1 Summarised Table of Respondents

	Hospital A	Hospital B
Respondent 1 (R1)	R1A	R1B
Respondent 2 (R2)	R2A	R2B
Respondent 3 (R3)	R3A	R3B

Table 3.2 provides a summarized table of the coding analysis that has been performed on the responses of the participants to some interview questions which can be found in the appendix. Codes which are the dominant ideas and labels from responses provided by participants were generated and a description of the codes were added to the table to provide more context and insight.

Table 3-2 Summary of Coding Analysis

Stakeholder Type	Qualitative Data (Responses)	Code	Question	Description of Code
R1A	There is no system we employ to predict our occupancy levels. The number of available	Automation Desire	4	Comments about the desire for a system that

	beds is counted manually on the daily basis. A system that monitors the number of beds being occupied currently would be very helpful.			eliminates the manual work of counting beds.
R2A	This hospital is barely ever at full capacity.	Availability	3	Discussion on assigning limited number of beds to increasing number of patients
R3A	Patients are rarely turned away due to the lack of beds but turned away to public hospitals due to their inability to afford treatment here	Destitution	6	Comments on if a patient is ever turned away due to a shortage of beds or any other reason
R1B	When the hospital is at the capacity, patients in dire condition have to be treated in plastic chairs and sometimes on the ground	Frustration Unpreparedness	8	Comments on the alternatives ways in which patients are treated and the feeling accompanied with this
R2B	We currently do not employ any technical systems especially to aid us in knowing the bed availability status of this hospital. It is done manually but any form of automation would be a great effort.	Automation Desire	3	Discussion on any technologies the hospital employs in handling their patient admission and bed allocations
R3B	Surgeries are sometimes rescheduled due to a shortage of beds and patients are turned away to come back at a later date when more beds may be available.	Dissatisfaction Setback	6	Comments on patients being frustrated because they cannot be admitted due to a shortage of beds.

After the coding process, themes were generated from the stakeholder interviews to shed more light on the findings of this research. Themes are a higher level of categorization of the ideas generated from coding usually used to highlight a major element. Themes can be split into two types which are primary and secondary themes. Fig 4.3 provides a list of themes that surfaced from the coding strategy as well as their descriptions as per the interview response contexts. There were four main themes identified through the coding process.

Table 3-3 Summary of themes generated from coding analysis.

Theme	Description
Theme 1	Need for automated systems - All respondents from the two hospitals expressed the desire or need for systems that would automate certain practices such as manually counting the number of occupied or available beds at intervals to be able to make better decisions and improve reaction times during emergencies or surges.
Theme 2	Unpreparedness to accommodate influx of patients during peak times. - Respondents mainly from Hospital B expressed their concerns during peak times when hospital beds are all occupied and thus incoming patients in dire conditions must be treated on chairs and sometimes on the ground.
Theme 3	Patients dissatisfaction with being turned away due to shortage of hospital beds - Respondents pointed how disappointed some patients felt in situations where they had to be turned away in very critical condition to other hospitals.
Theme 4	Public hospitals are more susceptible to the problem of bed shortage as compared to private hospitals. - Respondents from Hospital A which is the private hospital clearly expressed that they had no problems with bed availability and that the main reason for which patients are mostly turned away is due to their inability to pay for treatment. Nevertheless, they expressed interest in a system that would replace the manual counting of beds in use in their facility

The first theme is the need and desire for automated systems. This theme run across all interviews conducted at both hospitals. Both of the hospitals did not have any advanced systems that managed their bed management. In fact, the interviews revealed that both hospitals did not employ any systems that managed any other part of the hospital but their records. The interviews conducted in Hospital B (public hospital) revealed that the appropriate systems that could keep track the number of available beds as well as those occupied by patients were very necessary and would help reduce the congestion of patients especially in the Accident and Emergency center. It could also reduce the number of patients in critical condition who receive care in plastic chairs in the corridors as more beds could be allocated to them more promptly. Respondent R2B stated "*if there was a system in place to allow us accurately check the number of beds occupied or unoccupied in the wards then we could efficiently admit other patients in the waiting queue and reduce the waiting times and congestion*".

The second theme highlighted the unpreparedness of the of the hospital to cater for an influx of patients during peak times. This theme run through the interviews of mainly Hospital B (public hospital). This corresponded with the first research hypothesis that states that "The emergency departments of most Ghanaian hospitals face enormous congestion during peak times. There are limited number of beds and resources than desired". Since there were not enough hospital beds to treat every single patient neither were there any potent technical systems put in place to efficiently manage the beds that were available, it was difficult for the hospital to effectively administer treatment to patients that urgently needed it. Respondent R1B explained that due to the fact that available beds are manually counted sometimes there may be errors in the numbers reported back. Also, because these manual checks are done at intervals of a couple of hours, they are only updated periodically and thus patients will continue to wait for the bed report to be updated in order to be admitted even when a new bed may have bed available hours ago.

The third theme highlights the dissatisfaction patients faced after being turned away due to shortage of beds. Again, this theme run through the interviews conducted at Hospital B (public hospitals). This validates this research's second hypothesis which stated that "In an emergency situation, it may take the Ghanaian hospital a longer period than necessary to find a patient a bed or turn them away". Respondent R3B explained the disappointment some patients faced when they are told to seek help from other hospitals or are transferred there due to the shortage of beds. In some cases, the lack of immediate attention causes the patients' case to worsen. In some cases, immediate medical attention is given to a sick patient to alleviate pain but then they are told they cannot be admitted and thus given a later date to return.

The fourth theme is that public hospitals may be more susceptible to the problem of bed shortage as compared to their counterparts in the private hospital setting. This theme contradicts with this research's third hypothesis which claims that "Both private and public hospitals both face congestion and thus would be needy of a system that would alleviate the burden of bed management". This theme run across the interviews conducted at Hospital A (private hospital). Respondent R2A indicated that the hospital was ever rarely at capacity and that there were enough beds available to patients who could afford to come to the hospital. Respondent R3A also explained that patients were rarely ever turned away due to the hospital being at maximum capacity but mostly due to the financial issues on the part of the patient. Regardless of the fact that Hospital A did not experience to the issues of congestion and turning away of patients due to limited beds, all the respondents at the hospital did harmonize on the need of a method or system to aid in tracking the number of occupied and available beds in the hospital more efficiently. This conclusion enables Theme 1 to be proposed as the primary theme whiles the other three themes support it.

Table 3-4 Summary of primary and secondary themes.

Primary Theme	Sub Themes (Secondary)
Need for automated and potent smart systems (Theme 1)	Unpreparedness to accommodate an influx of patients during peak times (Theme 2)
	Patients dissatisfaction with being turned away due to shortage of hospital beds (Theme 3)
	Public hospitals are more susceptible to the problem of bed shortage as compared to private hospitals (Theme 4)

3.6 Research Limitations

This research was very insightful however there were a few challenges faced by the researcher that took a toll on the process. Here are a few limitations to the research process:

i. Willingness to provide important but confidential information – A good number of the hospitals that were initially contacted to be participants of this research were very reluctant in providing any information concerning their processes to help in the research. Emails sent went unanswered for a very long span of time forcing the researcher to reduce the sample size to the hospitals that were willing to fully engage and participate.

ii. Availability of respondents - Some respondents were unavailable on days of the interview which prolonged the process and others were very busy thus could not spare too much time to delve into particular detail.

iii. Time – A lot of time was spent trying to finalize the number of hospitals willing to participate in this research. Time was wasted visiting hospitals who constantly did not reply to emails or provide any helpful information via their websites or hotlines.

3.7 Ethical considerations

This study was carefully curated to unearth insights and opinions of the frontline workers who worked in hospitals that were deemed to have challenges in relation to predicting their bed availability efficiently and instantly and thus presents very little to no risk in any way to participants. Some measures taken to ensure the above assertion holds are:

i. Purely voluntary participation – All respondents were made to understand and have an overview of the study and entire project beforehand. Respondents were made to understand that were at liberty to partake in this study or otherwise. Consent forms were signed by the respondents as permissions to the researcher to further the study.

ii. Anonymity of Hospitals and respondents – All hospitals and respondents participating in this research have their identities hidden to protect their privacy and also improve their cooperation.

3.8 Modifications to Hypotheses

Insights from this qualitative analysis partially validated two of this research's hypotheses and disproved one which is finetuned.

- H_0 stated that the emergency departments of most Ghanaian hospitals face enormous congestion during peak times. There are limited number of beds and resources than desired. This was validated in the public stream of the Ghanaian hospitals.
- H_1 stated that in an emergency situation, it may take the Ghanaian hospital a longer period than necessary to find a critical patient a bed or turn them away. This was validated in the public stream of the Ghanaian hospitals. The private hospital did not experience this as their bed occupancy was rarely ever at a maximum.
- H_2 stated that private and public hospitals alike face congestion and thus would be needy of a model that would alleviate the burden of bed management. This hypothesis is disproved from the qualitative analysis and thus this hypothesis is modified by placing the context of this research in the Ghanaian public health system.

4 Chapter 4: Methodology – Implementation

4.1 Implementation Overview

This chapter contains the implementation of a simulated system of sensors that aims to assess the bed availability of a ward as well as schedule patients effectively on the number of available beds retrieved. The simulation is divided into two parts; the human detection simulation which aims to find the number of occupied beds in a ward to determine the available beds in the same ward and the patient scheduling simulation which aims to efficiently schedule patients unto the available beds found from the first simulation by applying a triage framework.

4.2 Implementation Resources

This section the simulation model was developed using one main package in python - SimPy. SimPy is a process-driven discrete events simulation framework based on standard Python. This package provided a highly optimized environment to enable simulations to be run. It enabled the model this research proposed to be simulated by manually stepping through events. Since many developers and researchers make use of SimPy, adopting it makes it easier for other researchers to verify the results. The Triage framework presents a priority generation system employed in hospitals that is able to rank patients according to their severity level in order to effectively allocate resources to them.

4.2.1 SimPy vs. Tortuga vs. SSim

Simpy is a library for python that provides the platform for simulation of discrete events. It uses Python's generator class instead of threads which provides an advantage as compared to its competitors [38]. This provides more flexibility as well as elegance in its implementation where the command *yield* is used the entities and processes to interact with the rest of the simulation. The framework comes with good documentation with very recent updates and also has a very active user community thus sharing and verifying information is simpler. The disadvantage is that Python is generally slower than Java and C++.

Tortuga is framework for discrete event simulation in Java. A simulation in Tortuga can be modeled as a list of scheduled events or a set of interacting processes [39]. Tortuga simulations are able to hold thousands of entities per simulation. These entities are represented by threads and thus this frame has a relatively higher speed. However, the framework has not had any recent updates and lack a comprehensive documentation.

SSim is a library for C++ and Java. This library is hardly used by developers to its incomprehensive documentation although there have been some recent updates.

The Simpy framework was chosen due to it being a very active and the most used library which has the requested functionality this research model proposes. Again, Python is platform independent, widely used and supported by various post-processing programs. The simple syntax of Simpy and Python in general makes it a suitable match to implement this model.

4.2.2 Triage

Triage is the most important factor in emergency conditions[40]. According [41], triage defines the process of sorting patients based on their need for immediate medical care or attention and their likelihood of recovery with and without treatment. Triage is normally done in an emergency centres at hospitals, during disasters and wars when medical resources are very limited and thus must be allocated with proper precision to maximize the number of survivors. Triage should be done within about 15 minutes of arrival to the Emergency department. In triage, some vital physiological signs including heart rate and blood pressure are measured and assessed using a triage tool in order to prioritize patients. Triage is very important because it efficiently rations patients when resources do not allow all patients to be treated immediately at a time. Careful triage is of immense importance as it prevents under-triage which is the situation where high risk cases are not given enough medical attention or over-triage, a situation where non-critical patients are offered the highest level of care.

The use of triage begun in World War II by French soldiers to treat wounded soldiers behind the front [42]. As medical advances have been technology, modern applications of triage have been developed into many Emergency Medical Centres (EMS) systems worldwide such as the START model which is algorithm based. In a nutshell, triage demands patients are rapidly classified in order of their injuries or complications to establish how quickly they need care [43] and for this reason it is applied in this simulation to schedule patients effectively after the number of available beds have been found through the first simulation (human detection).

4.2.2.2 The Triage Tool

The tool that is used by triage to rate the urgency of clinical care among patients in some countries Ghana, South Africa to mention a few is called the Triage Scale (TS). According to [44], to The Triage Scale is designed for use in hospital-based emergency services across Ghana. The TS is used for assessing and rating medical urgency in emergency situations. Triage scales aim to optimize the waiting time of patients according to the gravity and urgency of their medical condition. [45] supports that global advancement in the triage scales in the past two decades has revealed creditable research on the validity and reliability of these scales. There are three versions of the TS scale depending on whether the patient is an adult, child or infant. For this study, the focus is on the Adult Triage Scale.

The Triage Scale is divided into two parts; the Triage Early Warning Score (TEWS) and the Discriminator List.

4.2.2.2.1 Triage Early Warning Score (TEWS) Calculator

The TEWS calculator is used to generate a general score for patients on which they prioritized. There are seven vital signs that are assessed using the TEWS calculator in order to be given an overall score. Each vital sign monitors a different physiological system and these vital signs are:

- **Blood Pressure** which monitors the cardiovascular system.
- **Heart Rate** monitors the cardiovascular system.
- **Respiratory rate** which measures the respiratory system (lungs).
- **Temperature** which measures the thermoregulatory system.
- **Alertness, Verbal Response, Reaction to pain and Unresponsiveness (AVPU)** which measures the central nervous system (brain).
- **Mobility** monitors the musculoskeletal system (bones and muscles).
- **Trauma** indicates the presence of any physical injury or bumps.

Figure 4-1 An example of TEWS Score Calculator

ADULT TRIAGE SCORE © South African Triage Group 2008								
	3	2	1	0	1	2	3	
Mobility				Walking	With Help	Stretcher/ Immobile		Mobility
RR		less than 9		9-14	15-20	21-29	more than 29	RR
HR		less than 41	41-50	51-100	101-110	111-129	more than 129	HR
SBP	less than 71	71–80	81-100	101-199		more than 199		SBP
Temp		Cold OR Under 35		35-38.4		Hot OR Over 38.4		Temp
AVPU		Confused		Alert	Reacts to Voice	Reacts to Pain	Unresponsive	AVPU
Trauma				No	Yes			Trauma
over 12 years / taller than 150cm								

Wallis, P & Gottschalk, Sean & Wood, Darryl & Bruijns, Stevan & De Vries, Shaheem & Balfour, C. (2006). The Cape Triage Score - A triage system for South Africa.

By observing the basic vitals of a patient with a parameter on the TEWS calculator (horizontally), it can be assessed, and the appropriate score read off vertically. After assessing all the vitals, the individual scores are added up to give a total TEWS score for the patient. With these scores, the patients are categorized into distinct triage codes declaring their urgency levels with the use of the Discriminator List. It is important to note that, the TEWS will only identify and classify a patient into an appropriate triage code if the physiology of the patient is altered. Thus, if the patient's physiology vitals are healthy after the initial assessment, they will not be categorized into a code.

4.2.2.2.2 Discriminator List

The second part of the triage tool named the Triage Scale is the discriminator list. The discriminator list sorts the triaged patients into categories by generating a triage color (red, orange, yellow, green and blue) which will determine the patient's urgency level and ultimately how fast they would be attended to. As with the TEWS calculator there are separate versions of the discriminator list for adults, children and infants. For the purpose of this research only the adult discriminator list is considered.

Figure 4-2 Discriminator List presentation as used in Ghanaian hospitals.

Colour	Red	Orange	Yellow	Green	Blue
TEWS	7 or more	5 - 6	3 - 4	0 - 2	Dead
Target time to treat	Immediate	Less than 10 min	Less than 60 min	Less than 240 min	
Mechanism of injury		High energy transfer			
Presentation		Shortness of breath – acute		All other patients	Dead
		Coughing blood			
		Chest pain			
		Haemorrhage – uncontrolled	Haemorrhage – controlled		
	Seizure – current	Seizure – post ictal			
		Focal neurology – acute			
		Level of consciousness reduced			
		Psychosis/aggression			
		Threatened limb			
		Dislocation – other joint	Dislocation – finger or toe		
		Fracture – compound	Fracture – closed		
	Burn – face/ inhalation	Burn over 20%	Burn – other		
		Burn – electrical			
		Burn – circumferential			
		Burn – chemical			
		Poisoning/overdose	Abdominal pain		
	Hypoglycaemia - glucose less than 3	Diabetic – glucose over 11 & ketonuria	Diabetic – glucose over 17 (no ketonuria)		
		Vomiting – fresh blood	Vomiting – persistent		
		Pregnancy and abdominal trauma or pain	Pregnancy and trauma		
			Pregnancy and PV bleed		
Pain		Severe	Moderate	Mild	
	Senior health care professional's discretion				

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Wallis, P & Gottschalk, Sean & Wood, Darryl & Bruijns, Stevan & De Vries, Shaheem & Balfour, C. (2006).

The Cape Triage Score - A triage system for South Africa.

- A TEWS score of 7 or more put a client at the highest priority with a triage color red. Patients in this domain need to be allocated resources most immediately since they have their cases are more life threatening. Patients at the Emergency Department (ED) with complications such as seizures, burnt faces, gas inhalations and hypoglycemia with a severe level of pain belong in this category.
- A TEWS score of 5 to 6 puts a client at an urgent priority after the red category with a triage color orange. These patients are next in line after the patients in the red category and should ideally be allocated resources within 10 minutes of being triaged.

Patients triaged in this category normally exhibit signs of pregnancy labour, uncontrolled hemorrhaging, coughing blood, uncontrolled breath among others. The pain level in this category is described as severe.

- A TEWS score of 3 to 4 puts a client at an intermediate priority with a triage color yellow. These patients typically are next in line after the patients in the orange category have been serviced. Within 60 minutes of being triaged, the patients in this category should be allocated resources to increase their chances of survival. Patients in this category typically suffer from controlled haemorrhages, dislocated toes or fingers, abdominal pains and persistent vomiting. The pain level in this category is described as moderate.

- A TEWS score of 0 to 2 puts a client at the least priority with a triage color green. Such patients typically have minor cases as compared to the rest and experience mild pain in relation to their complications. Patients in this category are normally serviced or allocated resource within three hours of being triaged.

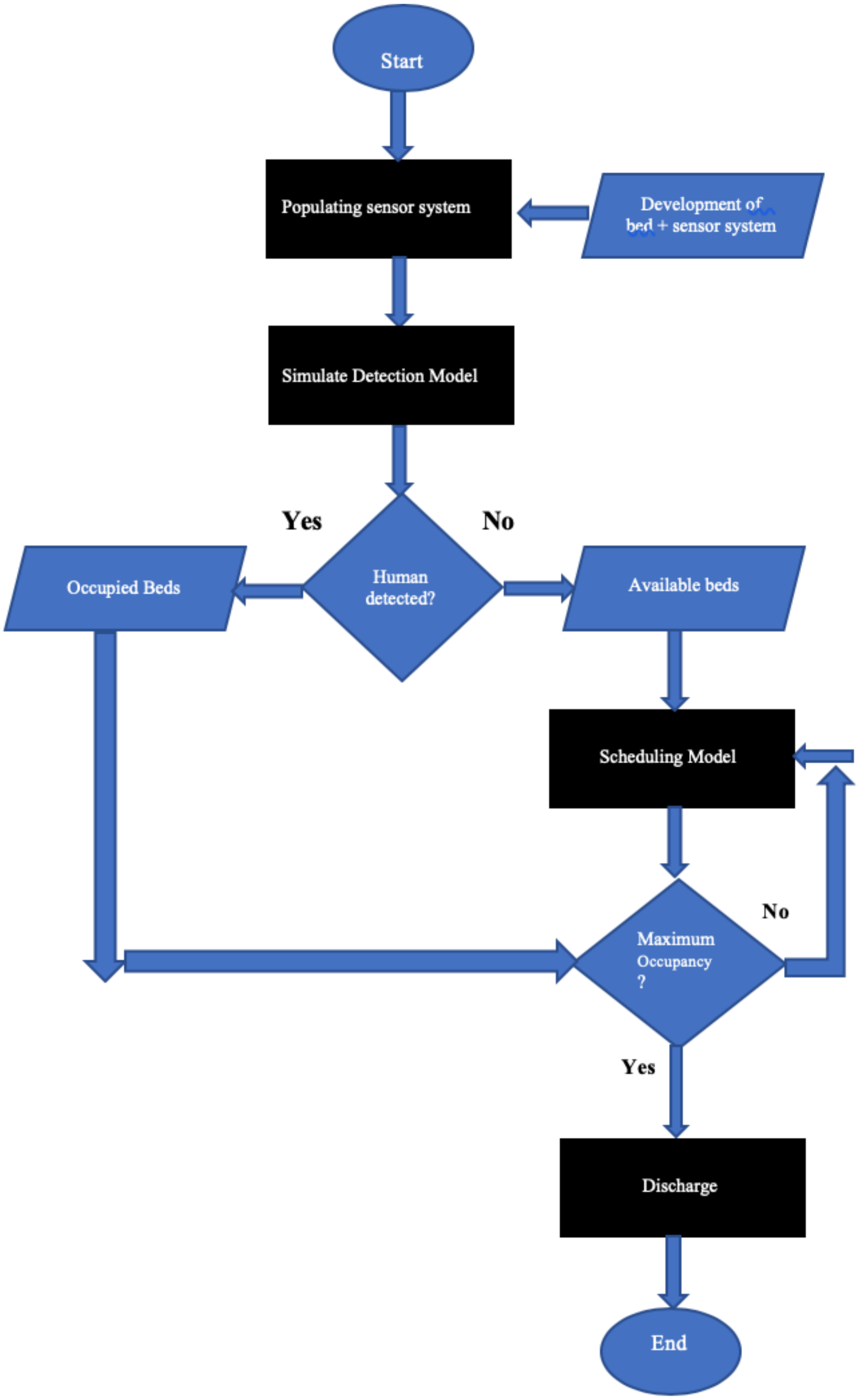
- A patient into the triage color of blue is prioritized because upon triage they are declared clinically dead or very unlikely to survive.

4.3 Simulation Overview

This simulation has two major parts; the detection model and the scheduling model. As expected, the simulation behaves differently for the two parts. In the first part of the simulation (detection model), the number of beds that are occupied in a particular ward is assessed by the use of sensors which are initialized with random values. The simulation is initialized for *x* number of times which is equal to *x* number of beds in the ward. The results provide a numerical output of the number of occupied beds as well the number of available beds.

The second part of the simulation (scheduling model) covers the generation of patient objects and the scheduling of these patients objects into the beds available found from the first part of the simulation as well as the discharge of patients of patients from the simulation by employing the Triage Early Warning Scale (TEWS) score which schedules emergency patients according to the severity of their cases. The discharge section of the simulation randomly discharges a random number of people per a random length of time.

Figure 4-3 Flow chart Diagram of model.



4.4 Simulation Design

There are 5 main classes in this simulation design, and they are:

- g (global variables) -This class stores global variables. No individual object instance is used. Global variables are stored as class variables. The variables are
    - Inter-arrival time (inter_arrival _time) – This is the average time in days between arrivals which is initialized to 1.
    - Average Length of Stay (los) – This is the patient average length of stay in the hospital initialized to 10 days.
    - Duration of simulation (sim_duration) – This is the duration of the simulation in days which is initialized to 500 days.
    - Audit Interval (audit_interval) – This is the interval between audits in days which is initialized to 1 day. Thus, an audit report is generated daily.
    - Hospital Bed Capacity (beds) - Signifies the number of beds in hospitals which is initialized to 100 beds for this simulation.
    - Occupied Beds (beds_used) – This is the number of beds of that are used or occupied before the patient allocation or scheduling.

- Hospital – The Hospital class (one instance created) functions by creating dictionary of patients present, assessing the list of audit times, list of beds occupied per each audit time over a period of days, list of beds, current total beds occupied per given number of days and holds the data for admitted patients. The Hospital class contains methods for audit of beds occupied, summarising audit (at end of run), and plotting bed occupancy over time (at end of run).

- Model - The model class contains the model environment. The modelling environment is set up, and patient arrival and audit processes initiated. Patient arrival triggers a spell for that patient in hospital. Arrivals and audit continue for the duration of the model run. The audit is then summarised and bed occupancy, and number of people waiting for beds (with 5th, 50th and 95th percentiles) plotted.

- Patients - The patient class is the template for all patients generated (each new patient arrival creates a new patient object). The patient object contains patient ID and length of stay.

- Resources - This class holds the all beds resource (could also hold other resources, such as doctors).

4.5 Human Detection Phase

The human detection model in the system is defined under a method called run i.e. def run ()' which controls the main model and at the end of its run signals for an audit summary and a bed occupancy plot. The main class contains the modeling environment and is set up by assigning it to *simpy.Environment().* The run method sets up an instance of the hospital class and then proceeds to determine the resources (beds) used in the hospital object. A set of sensor parameters namely; a motion sensor parameter, a weight sensor parameter, temperature sensor parameter and surface area sensor parameters are all initialized with a range of range of random values with the use of the python built in random int function. For all the sensors, random values for an interval of efficacy are generated. To be able to detect if a living human is present on the bed and not an object, these four parameters were carefully chosen to reflect the basic elements of a living human. Table 5-1 summarizes the ranges with which each sensor is initialized for efficacy as well as the confirmed clinically accepted ranges of human temperature, weight and surface area.

A condition is then generated for these sensors to be able to detect a human being that is, if all sensor parameters receive numbers that fall into the definition of a human body on the same bed then human is identified and thus the number of beds used is increased. After, the class ‘resources’ is initialized with the difference between the total beds available and the beds used from the initial sensor run as a parameter. The setting up of resources which is the number of available beds invokes other processes such as the new admissions and bed audit processes.

```
        for i in range(g.beds):
            motionVal = random.randint(0,1)
            weightV = random.randint(0,100)
            tempSense = random.randint(30,40)
            surfA = random.uniform(1.4,2)

            if(motionVal == 1 and weightV >= 50 and weightV < 100 and
tempSense >= 30 and tempSense <39 and surfA >=1.6 and surfA < 2):
                # a bed is in use hence decrease bed
                g.beds_used += 1

        # Set up resources (beds)
        self.resources = Resources(self.env, (g.beds- g.beds_used))

        # Set up starting processes: new admissions and bed  audit
(with delay)
        self.env.process(self.new_admission(g.inter_arrival_time,
g.los))
        self.env.process(self.audit_beds(delay=20))

        # Start model run
        self.env.run(until=g.sim_duration)
```

Snippet 1.0: Code showing how sensors are initialized and the ranges in which they operate.

4.6 Patient Scheduling Phase

Patients are set to arrive in this simulation using the Poisson process where the average time of arrival between patients is known however the exact timing of events is random. On the onset of new available beds being determined from the first part of the simulation, the processes of new admissions and bed audit are set up. The bed audit function is given an initial delay to enable the model set into place fully before any beds are counted. The model class contains a function called new admission that generates admission of new patients given their expected length of stay and the inter arrival time which is the time between two arrivals of patients. Each patient’s vital signs including temperature, heart rate, blood pressure, mobility, trauma and AVPU are collected by scoring each vital sign on a scale of three using the TEWS calculator.

```
while True:
        # Increment hospital admissions count
        self.hospital.admissions += 1

        temp = random.randint(0,3)
        BP = random.randint(0,3)
        RR = random.randint(0,3)
        AVPU = random.randint(0,3)
        Mob = random.randint(0,3)
        Trauma = random.randint(0,3)
        weight = random. randint(40,100)

        base  = (temp+BP+RR+AVPU+Mob+Trauma)

        if(base >= 7):
            g.redS+=1
        if(base >= 5 and base < 7):
            g. orangeS+=1
```

```
if(base >= 3 and base <5):
    g.yellowS +=1
if(base > 0 and base <3):
    g.greenS +=1
if(base == 0):
    g.blueS +=1
```

Snippet 1.1: Code showing how the triage calculator works and how triage color assignments are done.

The collated TEWS score is a base on which the patient is then categorized into a triage color based on their condition's level of urgency. The higher the TEWS score the more priority is given in being allocated a bed. Based on the new information concerning the patient's health vitals a new length of stay (new_los) according to assignment 'newLos =1+ base' is then generated for each patient depending on the severity of their case. The *expovariate()* function is used to determine the ultimate length of stay according to *los=random.expovariate(1/ newLos)* and as such the number '*1'* is added to the base in the new length of stay generation such that the number zero is never generated. The patient class contains the patient ID, their priority on the queue and their triage color. After the vitals of the patient is taken, a new patient object is now created the patient is then appended unto a hospital patient dictionary in the hospital class.

A method in the model class called spell_gen generates the analytics of the patient's stay in the hospital. Every time the spell_gen method is called it takes the patient object which includes information on their length of stay as parameter and places a bed request to the hospital resources. This request then increases the hospital queue count by adding the patient to the dictionary of queueing patients and signalling that the new patient object will also need a bed. The resource request is now yielded. The simulation still continues after the yield request so there is there is no delay in scheduling if resources are available. After the resource is available and allocated to the patient, the hospital queue is decremented by 1 and the patient is deleted from the dictionary of in the queued patients using the code *del self.hospital.patients_in_queue[p.id]* . The patient is removed from those queues to be added to the list of patients with beds and the count of such patients is increased.

```
yield self.env.timeout(p.los)
```

Snippet 1.3: Code showing how patients are discharged after their length of stay expires.

env.timeout() signals simpy to trigger an event after a certain amount of time has passed[46]. In this case, the event is that the patient's length of stay has elapsed. Once this happens, the patient is removed from the occupied bed count and the dictionary of patients with a bed.

5 Chapter 5: Results

In this section, the results obtained through the simulation using the approach defined in the implementation section is analysed. Each simulation result is explained in the following subsections:

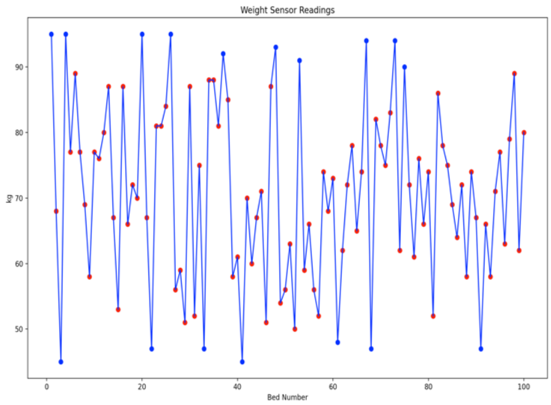
5.1 Bed Detection Analysis

This section displays the result of the first part of the simulation which aims to detect the number of beds in use in order to deduce the number of available beds.

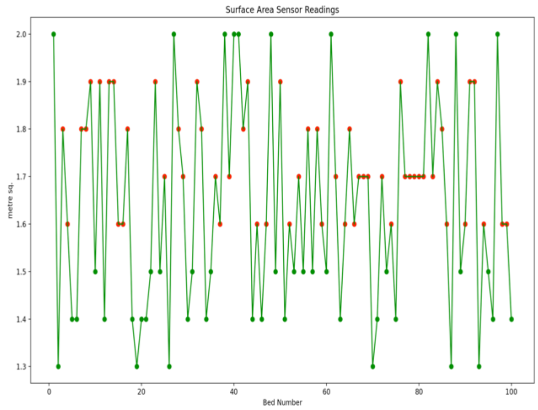
According to [47], the average human temperature is 37^{o}C. However, in extreme illnesses such as hypothermia, the human body temperature can drop as low as 34^{o}C. Also, in some cases such as hyperthermia when the body gets dangerously hot the human temperature can rise as high as 40^{o}C. As stated by [48], the average human surface area for an adult male is approximately 1.92m^2 whereas that of an adult female is 1.6m^2. [49] reports that although the weight of a human depends largely on factors such as height and race the average weight for an adult male is 69.2 kg whiles that of an adult female stands at 62.0kg. For the motion sensor, a binary mode is generated to detect motion where '1' signifies motion detection and '0' staticity. Assessing this information, a range of values was developed for the sensors in this this system to detect the human ranges in their respective parameters. Table 5-1 presents a summary of the ranges assumed in this research. The simulation is run on 100 beds for a day in the first part of the simulation model.

Table 5-1 Summary of Intervals for Sensors.

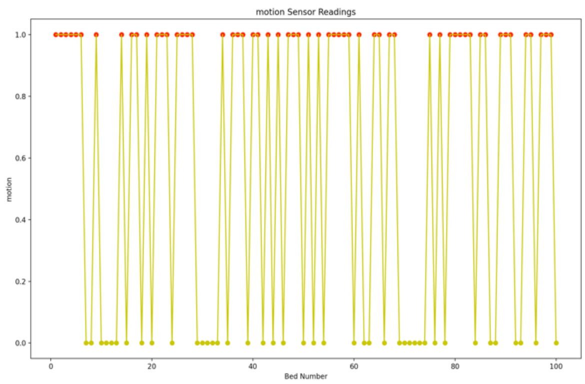
	Min	**Max**
Temperature(°C)	33.0	40.0
Surface Area (m^2)	1.6	2.0
Weight (kg)	50.0	100.0



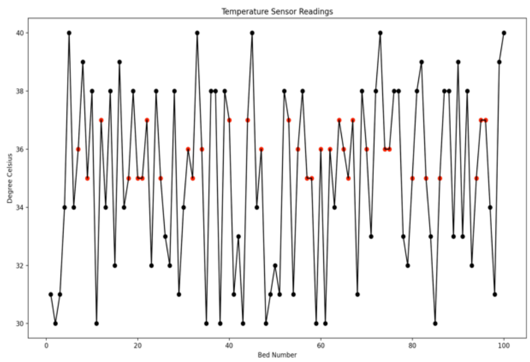
(a) Results of weight sensor readings for the number of beds checked in the hospital for a day.



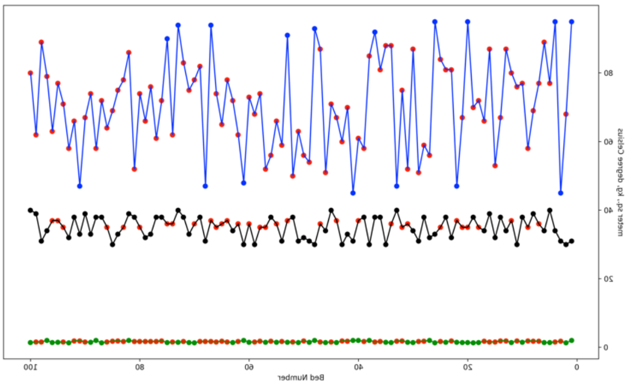
(b) Results for the surface area sensor for all beds checked in the hospital for a day.



reading checked at the hospital for a day.



d) Results of the temperature sensor readings or all beds checked at the hospital for a day.



e) Results for all sensor readings for all 100 beds simulated per day.

Figure 5-1 Graphs of readings for all sensors used.

The diagrams above in Figure 5-1 summarizes all the sensor readings taken per bed in the first part of the simulation to determine the number of beds available. The red points consist of all beds whose sensor values fell into the defined human interval whiles the black dots show the other sensor values generated on beds that did not fall into the category of the human definition this research suggested. In Figure 5-1 graphs (a), (b), (d) show the randomness of the system alternating between various points whereas graph (d) which the motions sensor graph depicts that the motion sensor is either detects movement or not. When all fours sensors attached to a bed collide in their readings, meaning that they hit the numbers for their respective human domains in the same run then a human being is suggested to have been detected on that particular bed and thus the bed count of occupied beds is increased and that of the free beds is reduced. With this understanding the simulation is run with this dynamic for 500 days with 100 beds for the second part. In Figure 5-2, the results for the bed availability per day when the simulation run for 500days is shown.

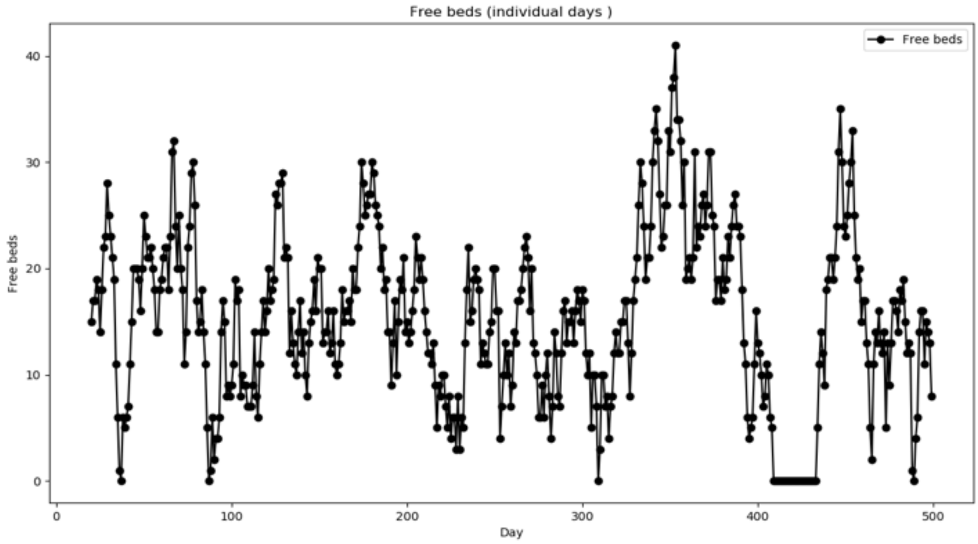


Figure 5-2 Graph showing the number of free beds per day over a 500-day period.

5.2 Patient Scheduling Analysis

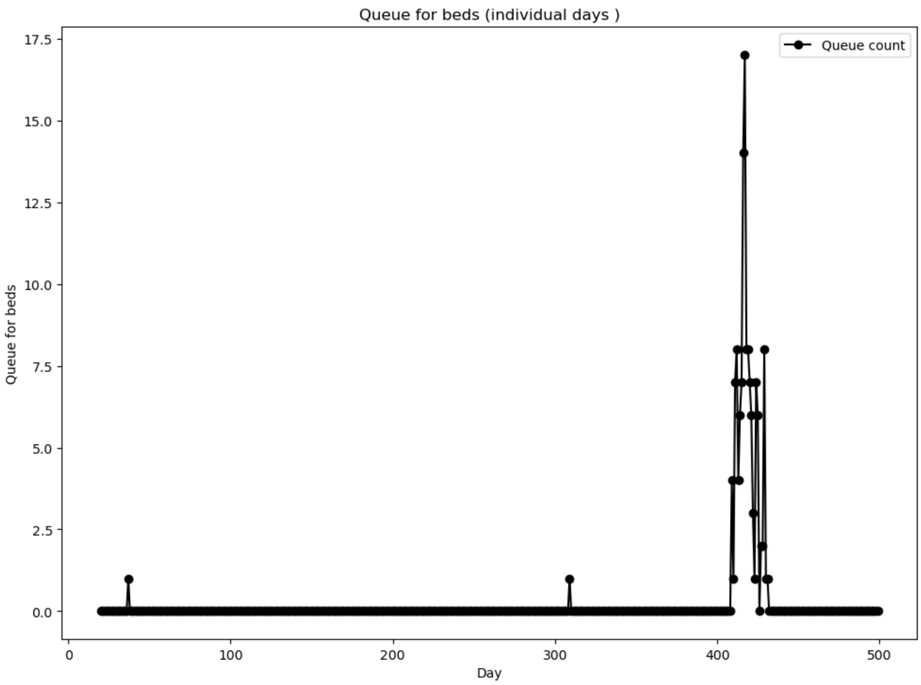


Figure 5-3 Graph showing the measure of patient queues per day over a 500-day period.

The bed availability graph in Figure 5-2 clearly shows the number of available beds for each day. The trend over the 500-day period shows a constant fluctuation in the number of available beds until approximately the 410th day, where the unavailability of free beds lasts for a prolonged number of days - until approximately the 430th day. In Figure 5-3, the patient queues at day 410 to 430 validates the lack of beds in those days by detailing a significant upshot in the patient queue on those very days. Thus, it can be explained that on the days there were less beds available, the patient queue increased and vice versa.

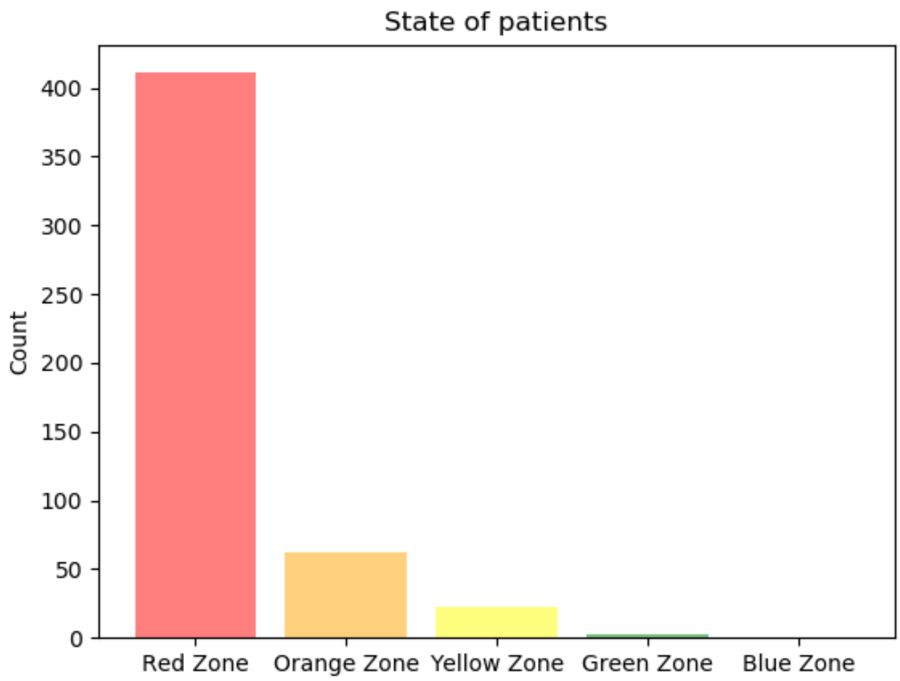


Figure 5-4 Graph showing the patient count for each triage colour code(category).

The patient count in Figure 5-4 shows the patient triage codes that were allocated based on the TEWS scores for a duration of 500 days. It shows that an upwards of 400 patients were in the red zone which is the most critical code in the triage framework. These patients are to be given the most priority with shorter wait times and have beds allocated to them before any other colour code's patients. The orange zone had a patient count of approximately 55 patients, approximately 20 patients for the yellow section and approximately less than 10 patients in the green zone. This graph presents the assumption that most cases reported to the Emergency department during the period were all high-risk cases involving patients who were critically ill. In the normal Ghanaian public hospital system, some of these patients could possibly be treated the in corridors and on chairs whiles patients with less grave conditions occupy the beds due to the lack of smart systems to classify patients based on the severity of cases. However, this model affords a detailed analysis such as the that average Ghanaian public hospital could employ to determine to allocate its bed resources to improve patient outcomes.

Chapter 6: Conclusion and Future Work

6.1 Summary

This research explored and proposed an efficient way to improve patient outcomes in emergency situations in public hospitals, primarily their Accident and Emergency centres. This research proposed a sensor system applied in conjunction with a triage framework to detect the number of beds available by deducing the number of occupied beds and then scheduling patients on these free beds in their order of priority.

The application of the sensor model would allow bed availability to be calculated in fractions of the time it takes when its being manually counted from ward to ward. As every second in the Emergency Department is of critical importance, it is necessary that a bed count be easily accessible to the hospital staff at any point in time in day. This model also reduces if it not eliminates completely the chances of an inaccurate count as opposed to human error that is associated with the manual count.

With the inclusion of the triage framework into this model, all emergency cases will be categorised with the most urgent cases in queue of patients given a priority of a bed first. This would ultimately reduce the long wait time of patients with comparatively worst conditions and pain. Such patients would no longer be treated in corridors and on plastic chairs but would be allocated a bed to increase their chances of survival.

According to [50], the cost of sensors is drastically reducing as an average IoT sensor in 2004 costed approximately $1.30 as opposed to the average price of $0.30 in 2020. This appreciable decrease in price means that the intelligence and precision that IoT systems provide can now be accessed by more people as well as organisations. With the decline in cost of IoT sensors, more imperative data can be collected to enable decision making at a cheaper cost. In this light, public hospitals can apply this IoT driven model to effectively schedule their patients to reduce casualties in the emergency department by maximizing the use of the number of available beds. In for profit hospitals, the application of this model will increase profits as patients are less likely to be turned away due to congestion.

6.2 Limitations

This section discusses the aspects of this research which were latent enough to adversely affect the accuracy of the proposed model.

- The model was simulated and not actually built as initially planned due to the sudden outbreak of the virus and the lockdown of Accra. The inability to visit and maintain communication with partner hospitals led to the system being simulated to represent a similar emergency setting in the Ghanaian public hospital.

- Finding actual data from Ghanaian hospitals proved very difficult. Numerous communication tactics were futile and the outbreak of the COVID-19 pandemic made the requests for data very secondary to hospitals who were at the centre of the chaos. Thus, the data for the system was randomly generated with medically approved intervals, in terms of patient vitals and sensor readings. The randomness of the generation appreciably represented a Ghanaian hospital emergency system as the arrival of patients and capacity is unplanned.

6.3 Future Works

This section of this chapter suggests extensions to this study to optimize the research aside the limitations.

- A refined version of the triage system is necessary to provide shorter wait times to all emergency patients and not just those in critical condition. A separate queue could be created for patients in the yellow and green triage code section to allocate them resources separately outside the main queue in order to increase patient satisfaction in the event that more patients with red and orange priorities keep being added to the front portion of the queue.
- The initial idea for this thesis was to be able to apply some sort of intelligent algorithm to the model such that efficient decisions could be made with very little human intervention. However, the lack of substantial data needed to train and tests these algorithms could not be made available to due to disruptions of the COVID-19 pandemic. Thus in an extension of this study , a model could be that applies intelligent algorithms to make decisions.
- The hospital being able to assess the bed availability of hospitals close by to aid in quicker patient referrals and transfers is a viable extension to explore.

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Appendix

In-depth Interview Questions

1. Tell me about the current state of bed availability and patient demand in this facility.
2. What are your thoughts on infrastructure particularly, increasing the number of beds?
3. How do you cope in assigning limited number of beds to increasing no of patients?
4. What measures are put in place to currently to predict bed occupancy levels?
5. What technologies are you currently employing here if any and what for?
6. Can you tell about any incident where a patient has been turned away due to shortage of beds?
7. Can you tell me if there are incidents where a patient's surgery has been rescheduled or cancel due to availability issues?
8. Normally, what is done if the hospital is overbooked?
9. Can you describe any known mechanisms you use to predict patient discharge times?