UNIVERSITY OF NAIROBI

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OPTIMIZATION OF THE BLOOD BANK MANAGEMENT USING A DISTRIBUTED WEB APPLICATION

By

CATHERINE MWANGI

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SUPERVISOR

DR. MICHAELINA ALMAZ YOHANNIS

A project report submitted in partial fulfillment of the requirements for the award of Master of Science in Distributed Computing of the University of Nairobi

DECLARATION

I, Catherine Wanjiru Mwangi, do hereby state that this research project report is my original work and any contribution of other researchers has been acknowledged accordingly. To the best of my knowledge, this research work has not been previously submitted or presented to any other academic forum or institution.

Signature.. Date. 25th/08/2023

Catherine Wanjiru Mwangi

I, Dr Michaelina Almaz Yohannis, do hereby certify that this Master's research has been presented for the award of Master of Science in Distributed Computing Technology with my approval as the University of Nairobi Supervisor.

Signature................................ Date. 11th/09/2023

Dr Michaelina Almaz Yohannis
Department of Computing and Informatics
University of Nairobi, Kenya

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ABSTRACT

A major problem facing blood banks is how to optimally forecast the amount of blood to collect and how to allocate the blood collected to reduce wastage. Currently, each blood bank manages blood allocation manually which lacks the transparency of the blood units available. Further, blood is perishable hence after a certain period blood is no longer safe for consumption. At the same time, the collected blood is not adequate to serve the blood demand. Previous researchers have suggested and developed solutions to address the blood shortage by facilitating more blood donations. However, the issue of forecasting blood order quantity and the efficient use of blood collected has not been addressed which means blood collected is still prone to expiry before usage. This research addresses this problem by developing a web-based solution that uses a stochastic algorithm and FIFO strategy to ensure optimal blood is collected and used before expiry. The web-based solution is developed using distributed technologies that include REST API process requests using the FIFO strategy and MongoDB which is a distributed database that is open source and uses a format compatible with REST. The developed blood bank system was then evaluated and tested in terms of performance to ensure it ensured optimal blood management.

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ABBREVIATIONS

KTTA - Kenya Tissue and Transplant Authority

GA - Genetic Algorithm

API - Application Programming Interface

SOA - Service-Oriented Architecture

WSDL - Web Services Description Language

UDDI - Universal Description, Discovery, and Integration

FIFO - First in First Out

HTTP - Hypertext Transfer Protocol

ICT - Information and communications technology

DEFINITION OF TERMS

REST API - an application programming interface comprising of ~~f~~ rules that programmers follow to create their APIs.

First in First out - An approach where goods acquired first are disposed first.

CHAPTER ONE: INTRODUCTION

1.1 Background

In healthcare, services such as childbirth, surgeries, cancer treatments, trauma care, and other chronic medical conditions, need safe blood as a prerequisite. All these lifesaving procedures require safe blood (Ministry of Health, 2019). According to the Ministry of Health, Kenya needs an estimated 1,000,000 blood units annually. The World Bank (2022) stated that in Kenya at least 1,100 patients need blood daily yet the country collects merely 16% of the blood needed. However, the blood donated annually is way below the required amount (Ministry of Health, 2019). In the year 2021/2022 the Kenya Tissue and Transplant Authority collected a total of 348, 507 units of blood, which is significantly below the annual target as per World Health Organization (WHO) recommendations of at least 1% of the total population (Ministry of Health, 2019). Consequently, there is a blood shortage in the hospitals and at the same time, some blood collected is wasted. According to a performance audit report by the Kenyan parliament, 50% of the blood collected in 2020 expired before usage. There is a need to automate blood inventory management to facilitate efficient usage of blood collected.

In Kenya, blood transfusion is managed by the Kenya Tissue and Transplant Authority (KTTA). The blood collected is then processed in Kenyatta National Hospital and distributed to blood banks across the nation. The regional blood banks then avail blood for use in hospitals. Currently, each regional bank manages its records manually. Consequently, the regional blood banks don't have transparency on the blood units available and their expiry dates. This makes it impossible to manage blood and distribute it before expiry. When the blood overstays in the blood banks it becomes unfit for human use resulting in resource wastage and blood wastage whereas some hospitals requests have barely enough blood.

1.2 Problem Statement

The blood distribution chain in Kenya is not optimized for efficiency hence there is wastage of the few blood resources collected and inadequate blood collection. Blood products have a short shelf life that calls for efficient management of the blood inventory to reduce wastage and shortage. At the same time, the blood banks need to maintain a desirable blood inventory to meet the blood demand.

1.3 Research Objectives

The specific objectives of the study are:

1. To identify and review blood bank management models.

2. To determine the suitable blood assignment model for Kenya.
3. To design a model that assures optimal and dynamic allocation of blood products.
4. To develop and test the prototype that optimizes blood allocation.

1.4 Research Questions

The research seeks to answer the following questions:

1. How can blood allocation be optimized?
2. What algorithms help regional banks manage blood effectively?
3. What are the features of an optimal, dynamic blood allocation model?

1.5 Project Scope

The scope of this project is to identify the inefficiencies in blood bank management in Kenya. Secondly, this project seeks to address these challenges faced regarding blood management by determining the optimal solution for blood allocation that reduces wastage. Finally, this project entailed implementing the solution and testing its application for adaptability by users.

1.6 Project Justification

Kenya collects inadequate blood leading to blood shortage. Consequently, getting blood for specific blood groups is a challenge. At the same time, the few blood units collected are still not used optimally. For instance, in 2020, 46% of the blood collected expired before usage. There is a need to create a system that facilitates optimal usage of the blood units collected so that there is minimal wastage.

To address the blood shortage problem, previous researchers have suggested various ways to leverage technology to mobilize more people to donate blood. This research seeks to provide a solution to facilitate the forecast of the blood demand and optimal usage of the few blood units collected. The goal is to facilitate the collection of only the needed blood units and efficient usage of these collected blood units before expiry.

1.7 Limitations

1. Minimal research done on blood optimal models for blood bank management
2. Insufficient data on KBTS since minimal information is provided on their website and none of the 6 regional blood banks has an office.

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

This chapter presents a review of past literature related to blood donation challenges. According to Berg-Schlosser & De Meur (2009), a good literature review should present an overview of the knowledge currently available in a certain research area. This is important in revealing what has been done in a research area and what research gaps still exist. By so doing, one can establish the scope of a study. This chapter starts with an explanation of the cause of the blood shortage in Kenya. Secondly, this chapter discusses blood products and their usage in healthcare. Thirdly, this chapter discusses the application of ICT in blood donation through social media, blood donation, among others. Fourthly, related applications used in blood donations are discussed. Moving forward blood donation in Kenya is discussed followed by the challenges Kenya faces regarding blood donation. Finally, a conceptual framework is presented.

2.2 Background

Some of the reasons why Kenya has a blood shortage are;

1. Organizations tasked with the mandate to collect, store, and distribute blood are underfunded and understaffed. In February 2019, Kenya Tissue and Transplant Authority (KTTA), the organization which collects and processes blood for hospitals for transfusion was nearly empty. In the year 2021/2022 KTTA collected an estimated 348,000 units against a target of 1,000,000 units annually. Worse still, the critical organization is seriously understaffed and some crucial machines have broken down. The lack of enough funding and staff limits the ability of KTTA to mobilize blood donations in hospitals.
2. Kenya Tissue and Transplant Authority's (KTTA) over-reliance on school children for blood donations has exposed Kenya to grim risks of blood shortage since when children are on holidays there is inadequate blood supply. Further, blood cannot be collected in large quantities when children are in school since it has a limited shelf life (Adepoju, 2019).
3. Many Kenyans are ignorant of the need for blood donation since they are not sensitized about the dire need for blood facing the country.
4. Commercialization of blood provision (OAG, 2022).

Finding blood remains a challenge in almost all countries. Traditionally, when a patient needs blood, he/she has to find compatible donors in his family and friend circle or contact a blood bank. However, finding suitable donors at a given time within a small group of people is difficult. Blood banks also do not guarantee to have blood for all blood groups. The current blood deficit calls for a sustainable blood system. The Ministry of Health suggests establishing a pool of regular voluntary non-remunerated blood donors, to ensure the blood shortage is a thing of the past. With broad internet coverage, blood banks can collaborate through a web application to share limited blood units (Torrado & Barbosa-Póvoa, 2022).

2.3 Application of ICT for Blood Management

The WHO recognizes the potential of ICT in transforming the face of health services delivery globally (Harmening, 2018). Although evidence on user preference and feasibility of mobile health is relatively limited, various attempts have been made both locally and globally regarding integrating ICT in blood donation management. The potential of ICT or mobile applications depends on the scalability and adaptability of the technology to be attractive and acceptable to diverse groups of users (Takanagane et al., 2017). An investigation of various blood management in various parts of the world provides an in-depth perspective of the success of ICT applications in this area.

2.3.1 Blood Donation Management through Social-Media

Guglielmetti et al. (2021) studied the usage of social media by the Red Cross in the US and established that services such as Twitter and Facebook are used by blood donation mobilizers to recruit and create relationships focused on creating a database of volunteer donors, updating potential donors about disasters, and engaging the media. Although the US Red Cross has a dedicated Facebook page to provide information about blood donation and engage the blood donor community, there are similar initiatives across America to help in blood donation mobilization. For example, Life South Community Blood Centers in Florida utilize a Facebook application named "I Give Blood" to enable donors to share with friends about their donation history (Sood et al., 2019). Similarly, *Social Blood*, a Facebook application, connects potential donors with respective compatible blood recipients over Facebook. Although it initially covered the US, the application has become a global sensation, providing a social space to connect thousands of donors to nearby recipients. The application utilizes web services and Facebook functionalities to create connections between donors and recipients through the infusion of location-aware technology. A cross-sectional study performed in Saudi Arabia to investigate the role social media played in blood donation showed that social media plays a significant role in donor mobilization. Out of the 297 participants, 82% said they received notifications to participate from social media platforms (Alanzi & Alsaeed, 2019). These notifications were; 61% through Whatsapp, 13% through Twitter, 10% through Snapchat, 6% through Facebook, and 1% through YouTube and Telegram. The study also established that 43% of the blood requests were from friends, 28% from family, and 29% from other people (Alanzi & Alsaeed, 2019). Countries such as Sweden have also been utilizing a massive social media campaign to reach out to more potential donors to address the shortage of blood and blood products. Social media has been a successful tool since offers the benefit of accessing multiple potential donors near locations where they are needed. However, concerns about the privacy of data in such a large community with third parties handling the massive user information remains a major concern for donors and stakeholders (Sümnig et al, 2018).

2.4 ICT for Blood Bank Management Applications

Web applications and Smartphone applications have become quite popular and many organizations across the globe are utilizing them to link donors with recipients.

2.4.1 GPRS Smart App in India

A smartphone-based virtual blood bank utilizing General Packet Radio Service (GPRS) has been proposed in India. The application has centralized storage to store data about donors and information about blood banks (Singh & Jain, 2016). Individuals seeking blood send a request to the server through mobile devices by specifying the type of blood or blood product needed and their location. The smart application then matches the recipient request and location with the blood banks or registered donor profiles, retrieves the information and sends it to the user through GPRS.

2.4.2 India: Lions Blood Bank

The Rotary Blood Bank is an organization established in 1984 to collect and distribute blood in India. Being the largest and most modernized blood bank organization, Lions Blood Bank has both physical and technical infrastructure to support blood donations. The organization organizes regular voluntary blood donation camps within and around Delhi to allow donors to participate. Although the blood shortage in India supposes the Kenyan levels, the Lions Blood Bank provides technology-banked blood donation drives in learning institutions, corporate offices, and other areas where there is high donor concentration. Besides, the organization has an online system that allows donors to register and donate blood. The system allows users to book an upcoming camp or become a donor through the online platform. Also, visitors can view available blood and blood products from the system. The patients or hospitals can also request blood or blood products available based on the chart. Another important feature is accessible to users in the upcoming camps with dates and venues.

2.4.3 Bank South Africa: Western Cape Blood Service

Western Cape Blood Service is a non-governmental organization that collects, processes, and distributes blood and blood products in South Africa. The organization has both a web-based system and a mobile application to facilitate blood donation. The system makes it easier for donors to donate blood and save lives. It is one of the best web-based systems with rich features for donors. The application allows users to create a personal profile detailing their blood type and tracking their donation. It also provides updates about blood levels so that donors can get to know when the organization is facing a shortage. Within the system, users can view nearby donation camps and centres. Besides, the application has reminders for donors who are due to donate blood based on their last blood donation. The registered donors also get personalized alerts when there is a mobile donation clinic in their local areas. Another important feature is the easy map navigation to all available camps and clinics. The registered users also receive event alerts and invitations. Donation recipients also get to provide their real, moving stories that encourage donors to continue with their noble course. The system allows users also to invite friends through a link to ensure the donor list grows larger. Through their referral system, donors receive some incentives for every successful referral.

2.4.4 Nigeria: Redbank

Redbank is a web-based service that enables patients and hospitals to search for and find safe blood quickly and easily in real time through voice calls and short message services. The web-based system provides multiple functionalities for various users. For example, patients and hospitals wishing to get blood or blood products have to send an SMS with a certain format outlining the blood type, number of pints, and location. The system then sends an SMS with details of the nearest blood bank that has the blood required. With the information about blood availability, the hospital or patient can then arrange a call to purchase and collect the requested blood. Figure 4 below shows the Redbank application.

Furthermore, the system allows hospitals and patients to register to access blood bank services. The blood banks can also register by providing the required information such as name, location, and contact information as shown in Figure 5. This allows the hospitals and users to locate the blood banks near them as well as those that have the blood or blood products needed. There is also an important component of the system that manages donors and donor information. The donor management module provides information about the blood donation drives, available camps, and dates. The availability of alerts and reminders also ensures that the donors get informed about the blood situation in the area so that they can voluntarily participate in blood donation.

2.5 Blood Donation in Kenya

Details about research in the area of blood donation in Kenya remain scanty. Ireri (2014) surveyed 224 respondents in a randomized cross-sectional study to understand the gap between the demand and supply of blood and blood products in Kenya. The study examined donor information needs to enhance the recruitment and retention of donors through ICT solutions. In the study, only 4.9% of the respondents were regular donors and only 19 of 81 donors had been contacted by the KTTA. More than 70% of the respondents had received communication through SMS and emails regarding blood donation dates and venues. While the study provides useful insights about donor awareness and education, it does not focus on raising awareness of potential recipients. The effort by the KTTA is also geared towards ensuring a continuous supply of blood to match the demand. The KTTA coordinates and manages the Kenya national blood transfusion initiative through its manual Blood Bank Management System. Other organizations such as Red Cross Kenya and Blood Life Initiative Kenya (BLIK) also offer support to the KTTA to ensure the country has sufficient safe blood for transfusion.

2.5.1 ICT for Blood Donation in Kenya

Various initiatives have been undertaken to facilitate the increased donation of blood to meet the demand. The use of social media has become quite popular in the country as a way to reach out to donors, especially during disasters or even when an individual needs a blood transfusion. The use of hashtag allows users to apply dynamic tagging that help other users easily find messages based on the content or theme. These hashtags have helped the recipients to link up with donors during blood appeals. Organizations such as KTTA and Red Cross also partner with media to publish blood donation appeals to a wider population. Thus, social media has been a great success as an ICT tool for facilitating the connection between donors and recipients and addressing blood shortage.

Nevertheless, there have been several mobile applications designed and developed for blood donation in the recent past. In October 2019, an application was launched in Mombasa to address the blood shortage. Named Red Splash, the application allows donors to search for nearby blood donation camps or blood banks. It also allows the registration of voluntary donors who can receive periodic blood appeals as well as organizing mobile blood drives in collaboration with blood banks (Kabale, 2019). A similar application named Life Buddy was also created by a team of innovators in Kenya to help blood recipients to connect with donors. The application allows blood recipients to connect with blood donors by posting a request on the application. The recipient must specify the blood type then the application sends a notification to nearby donors.

2.5.2 Challenges

While many initiatives have been made to enhance blood donation, challenges still exist in the country. The Health Cabinet Secretary noted that the country requires one million units of blood annually but only 348, 507 units were collected in the year 2021/2022 (World Bank, 2022). The main challenges identified regarding blood donation include a lack of awareness about donation camps, venues, and dates by the potential donors. This lack of information makes it difficult even for willing donors to fail to avail themselves when needed. Other challenges identified by Nzoka & Ananda (2022) included a lack of donor education, a lack of feedback and motivation to donors, and psychological issues such as fear. Besides, the over-reliance on school children means that during a year like 2020 when schools were closed down the blood shortage was aggravated. The shortage is also aggravated by the fact that the recipients lack a popularized, KTTA-backed application that they can use to link up with donors. When the recipients cannot find the required blood in the blood banks, they are forced to reach out to relatives or use other tools such as social media which have proven quite time-consuming and often ineffective if the willing donors are not near the recipient.

2.5.3 Donors Perspective

Recruitment and retention of donors are significant challenges for blood collection agencies globally. Although there has been limited literature on the psychological aspects of the lack of interest in blood donation, knowledge of the reasons behind the problem can help in the effective management of the problem by attracting and retaining donors. Lack of knowledge about blood donation or familiarity with the importance of blood donation is a key issue that affects blood donation and the recruitment of donors (Raivola et al., 2019). The low donor recruitment rate demonstrates inadequate information regarding the need for blood donation in the country. Organizations involved in blood donation should promote knowledge of prospective donors about the donation of blood. For such organizations to run effective donation drives, they should utilize blood donors as informative references for peers and colleagues to attract new donors. Lack of awareness on the side of donors can only be effectively addressed through an education program that targets current donors and also prospective ones.

Also, a survey by Lynch and Cohn (2018) established that 67% of people believe that blood donation could endanger their health. This is also compounded by fear of needles which has a significant impact on the willingness of donors to participate in such procedures. Some people are also afraid of the sight of blood or pain. Besides, the belief that there is enough blood donated and available for patients inhibits the participation of donors. Many donors wait until an appeal is made or in an event of a disaster to avail themselves. Unfortunately, blood is perishable and has a limited shelf-life of about 42 days (whole blood) while platelets have only a 5-day shelf-life. This makes it difficult to meet the national target at any given time. Another donor perception is that once a year is a safe way to donate blood. However, one can donate blood every 56 days so long as they lead a healthy life since blood replenishes shortly after donation.

2.5.4 Role of Technology in Blood bank management

Disruptive digital technologies have the potential to optimize blood management. It can aid in the recruitment and retention of blood donors, keep the donors motivated in the long term, and shorten or simplify access to blood by those in need of it. From social media to mobile applications, a web-based system, and an augmented reality application, the evolution of technology allows the automation of various stages of the blood donation process (Kabale, 2019). Recruiting and retaining donors is a major challenge due to the lack of tools to motivate them in the long term (Shokouhifar et al., 2021). This is an area that can be addressed through technological intervention to raise the blood donor return rate. The use of distributed technology can also be exploited to create a web-based system to streamline the recruitment and retention of donors, as well as manage usage and access to blood and blood products in blood banks (Razavi et al., 2021).

2.6 Service-Oriented Architecture (SOA) and REST Architecture

Service-Oriented Architecture (SOA) is the key concept of distributed computing that involves creating applications which use network services such as the web. This architectural approach enables loose coupling between application components for better reusability. The SOA applications are created based on services. A service can be an implementation of clearly defined functions which can be consumed by clients in another application or process. Leveraging the technology entails building software components that have defined interfaces independent of implementation. A crucial aspect of SOA is that it separates the service interface from the implementation details. The services can then be consumed by clients that do not care about the specific implementation that executes these services requested. SOA can be realized through web services. Web services can be any software system built to support interoperable interaction between machines over a network. The interoperability can be achieved through XML-based standards such as Web Services Description Language (WSDL), Simple Object Access Protocol (SOAP), Universal Description, Discovery, and Integration (UDDI) (Avila et al., 2017).

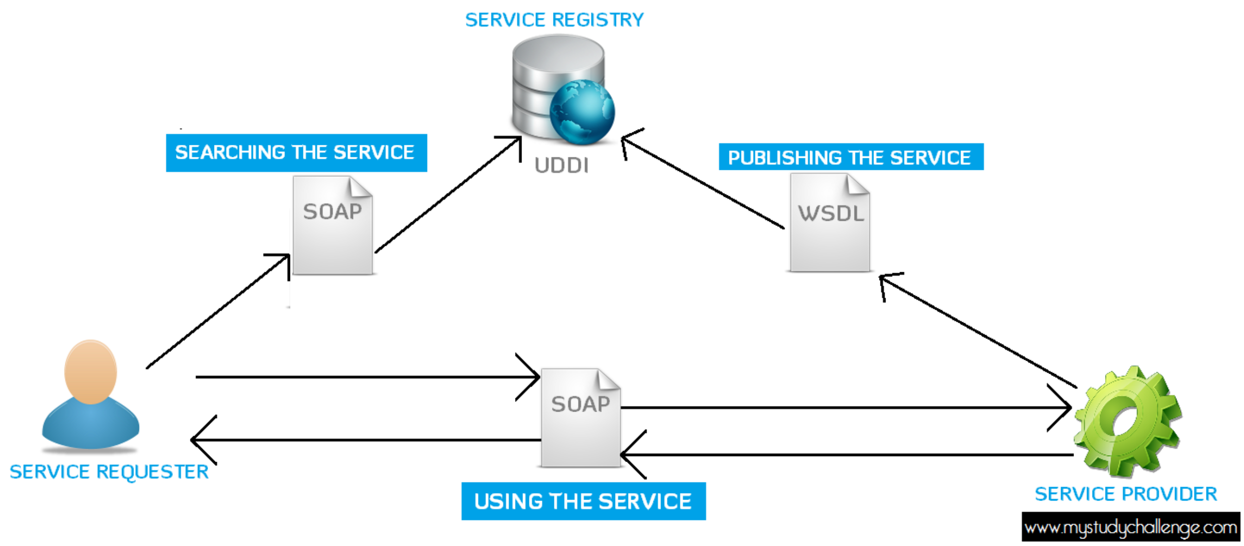


Figure 1: Web services architecture.

Ideally, a web service describes an interface through an automatic language such as the WSDL as shown in Figure 1 above. The service can then be accessed in a public directory named UDDI through the use of the defined protocol, SOAP, which facilitates communication with other software components. Web services use XML for data serialization since it (XML) is independent of programming language or operating system. In the web service architecture, service providers implement services and publish them in a service directory (UDDI) while service requesters can be any entity that needs the service. The requester uses SOAP to send and receive messages (Madeira et al., 2022).

However, RESTful web services shown in Figure 2 below exist and work best on web-based software systems. A REST (representational state transfer) specifies constraints which may include uniform interfaces (Garriga et al., 2016). The constraints induce properties such as modifiability, scalability, and performance, allowing the services to function best in web systems. The architecture utilizes Uniform Resource Identifiers (URIs) to allow access to resources, mostly links to web services (Madeira et al., 2022).

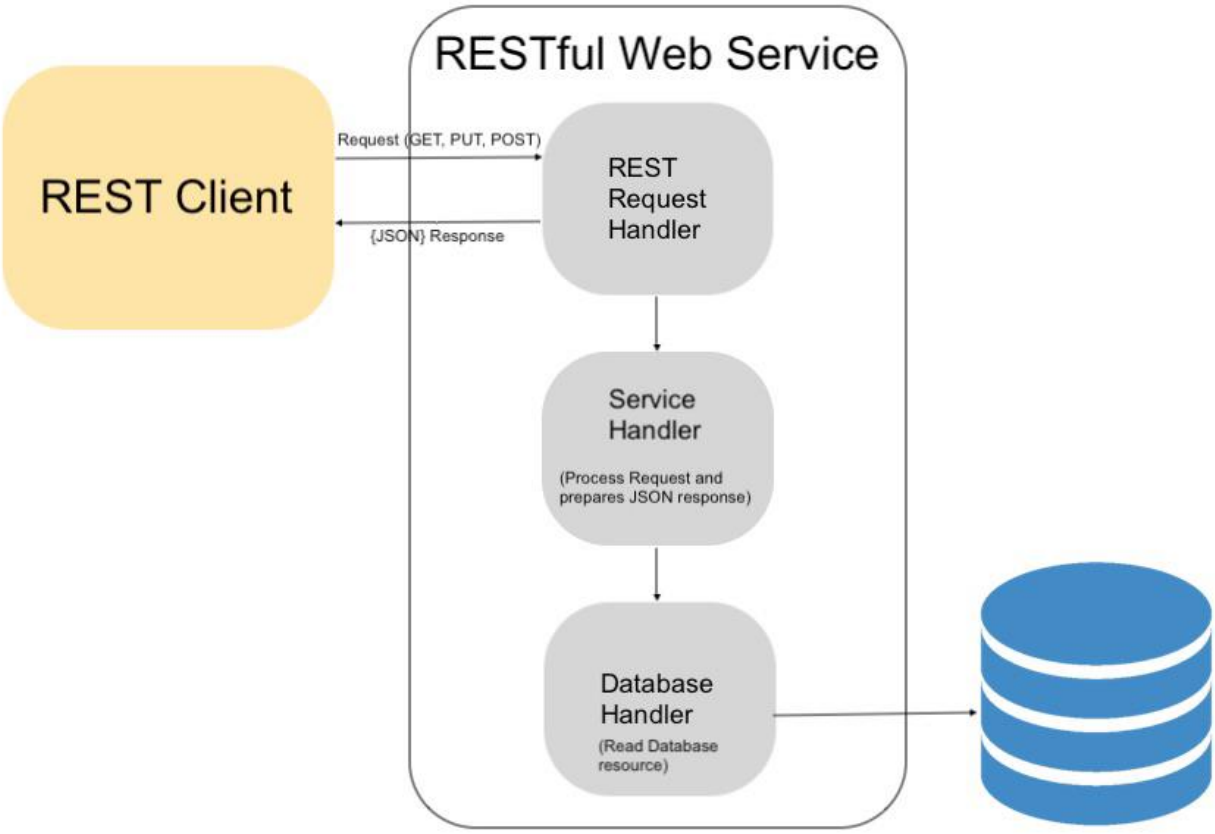


Figure 2: REST Architecture.

2.7 Genetic Algorithm

A genetic algorithm is a search heuristic inspired by the natural evolution process that is used to solve optimization problems. In simulation, genetic algorithms evaluate and modify the set of solutions simultaneously in a direct and parallel manner (Soman & Malinowski, 2019). The genetic algorithm starts by creating a population of random bitstrings of fixed size. This population of bitstrings is then evaluated using the defined objective function. The algorithm then repeats the main loop for a fixed number of iterations until there is no further improvement in the outcome. Each iteration is perceived to be an evolutionary generation and an optimal outcome is produced when evolutions no longer produce an improvement.

The genetic algorithm has 5 elements: initial population, fitness function, selection, crossover, and mutation as shown in figure 3 below. The search process starts with a set of individuals called a population. The population is comprised of individuals which are characterized by a set of variables (parameters). These variables are known as genes and are joined to form a chromosome. A set of genes of an individual form a string in a genetic algorithm. Fitness function determines the fitness of an individual compared to other individuals. The fitness function determines the fitness level of each individual. The selection process entails determining the ways to choose possible solutions based on the individual's fitness levels. Fitness in this case refers to the capability of the individual to survive in an environment based on its characteristics (Lambora et al., 2019). The selection process produces a new population from the older one based on the fitness level. Crossover facilitates the mating of each pair of parents. It entails choosing a crossover point at random within the parents' genes. Upon exchange of the genes, new offspring are generated until the crossover point is reached. Mutations entail subjecting some genes to mutation based on a low random probability. Mutation aims to maintain the diversity of the population and prevent premature convergence. Termination happens when a termination criterion is met such as the population no longer producing new offspring and at this point, it is when the optimal solution is produced (Soman & Malinowski, 2019).

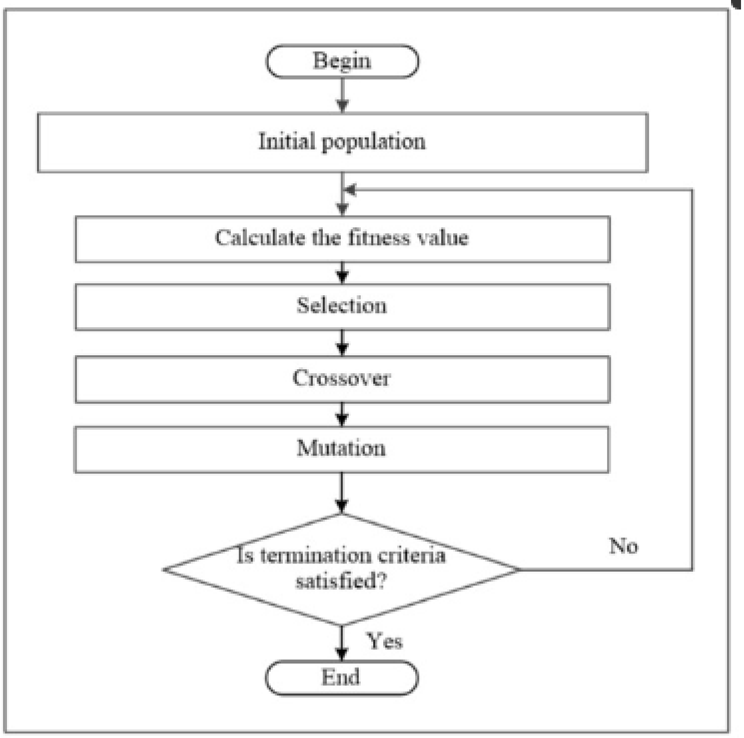


Figure 3: Genetic algorithm process.

2.8 Conceptual Framework

The conceptual framework below in Figure 4 shows the relationship between the different variables in a blood supply chain and the optimization opportunities. It helps answer the research question of how the blood management can be optimized. As shown in Figure 4 below there are two areas where blood management can be optimized namely: (1) collecting blood informed by the blood demand and blood stock levels; (2) blood allocation strategy informed by blood compatibility and the blood available in stock. This research focused on blood allocation and proposed genetic algorithm to predict the number of blood units that should be ordered informed by the blood demand. The research also discusses how FIFO strategy while taking into consideration blood compatibility can help allocate blood effectively and reduce blood expiry.

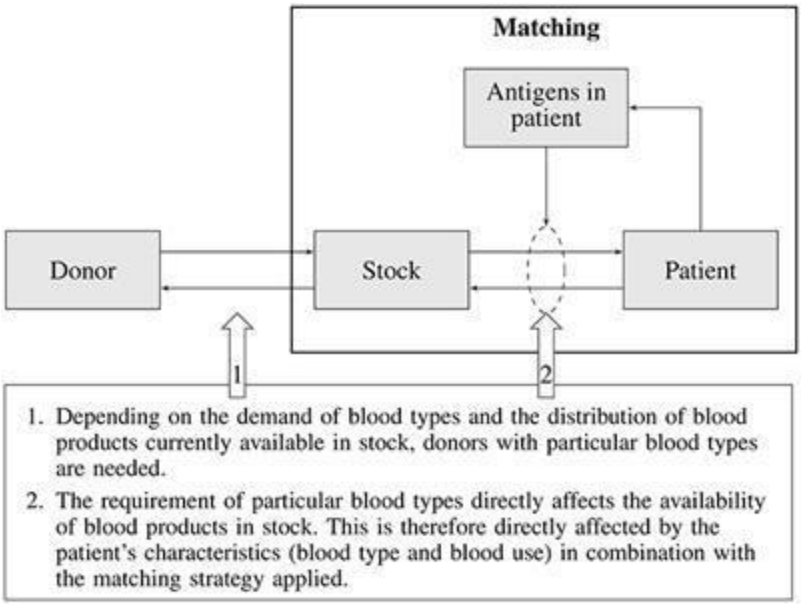


Figure 4: Conceptual Framework (Van Sambeeck et al., 2018).

CHAPTER THREE: RESEARCH METHODOLOGY

This chapter provides an overview of the research methodology used for the project. The chapter discusses how qualitative research through document review was conducted to fulfil objectives 1 and 2 then explains how the waterfall model was used to fulfil objectives 3 and 4 of this project.

3.1 Research

The researcher conducted qualitative research. Qualitative research entailed collecting and analyzing non-numerical data which in this case was research journals to understand the concepts and methods proposed for optimizing blood management. Qualitative research is suitable for this research since it allowed the researcher to break down a complex issue into meaningful inferences. Johnson et al. (2020) state that qualitative research is recommended when generating an idea or developing a new product. In this case, the qualitative research conducted provided insights that inform the development of a blood assignment algorithm suitable for Kenya.

3.1.1 Data Collection

Data collection entailed identifying the documents to use in the research. The aim was to identify journal articles that discuss blood bank, management models. The researcher selected articles that were published in the last 10 years simply because most of the articles published recently focus on sustainable blood supply and most of the articles that address blood bank optimization were published between 2012 and 2015. The second research criterion was evaluating if the research articles were peer-reviewed since the goal was to get quality findings. Thirdly, the researcher evaluated if the article addressed the research subject and was written in English. To do so, the researcher filtered articles by their subject using keywords such as blood assignment algorithm, blood management, optimal blood assignment, and blood distribution models. In the end, these six article journals were identified. Below is Table 2 showing the journal article used and their details.

Table 2: Selected research articles.

	Authors	Issue Addressed	Published in
1	Ben Elmir et al., (2023)	Proposes a smart blood management system that uses forecasting and machine learning	Information Journal
2	AlZu'bi et al. (2021)	Intelligent and machine learning optimization methods for blood donation	2021 International Conference on Information Technology (ICIT)
3	Van Sambeeck, et al. (2018).	Optimal blood matching strategy	Frontiers in medicine
4	Silva Filho et al. (2013).	Forecasting of blood demand	IFAC Proceedings Volumes
5	Chinnaswamy et al. (2015)	Automation of blood classification and automation techniques	International Journal of Applied Engineering Research
6	(Rusman & Rapi, 2014)	Cost optimization model according to blood bank location.	Proceedings of the Asia Pacific industrial engineering & management systems conference

3.1.2 Data Analysis

Data analysis is referred to the processes by which data is inspected, cleansed, transformed, and modelled to derive useful information and inform insights (Aguinis, Hill & Bailey, 2019). Data analysis for this research entailed mapping and linking data from different documents. During this state, the researcher evaluated and reviewed various documents to elicit the meaning. To further collaborate on the meaning derived multiple data sources were used. Using multiple journals reduced the impact of potential biases that may arise from a single study.

The researcher took a deductive approach in research whereby the research questions were the main guide for analyzing data. The deductive approach was suitable for the project since the researcher had some idea about the subject. A Nvivo data coding system was used to analyze the data. In particular, deeply assessing the insights presented by each article journal. The first step was initial coding by reading through the articles and assigning codes to parts of the article that address concepts that relate to the topic. The codes assigned were informed by the research questions and included: the assignment model/algorithm, risk factors in handling blood, factors to consider in blood assignment, and features of an optimal blood assignment model as shown in Figure 5 below.

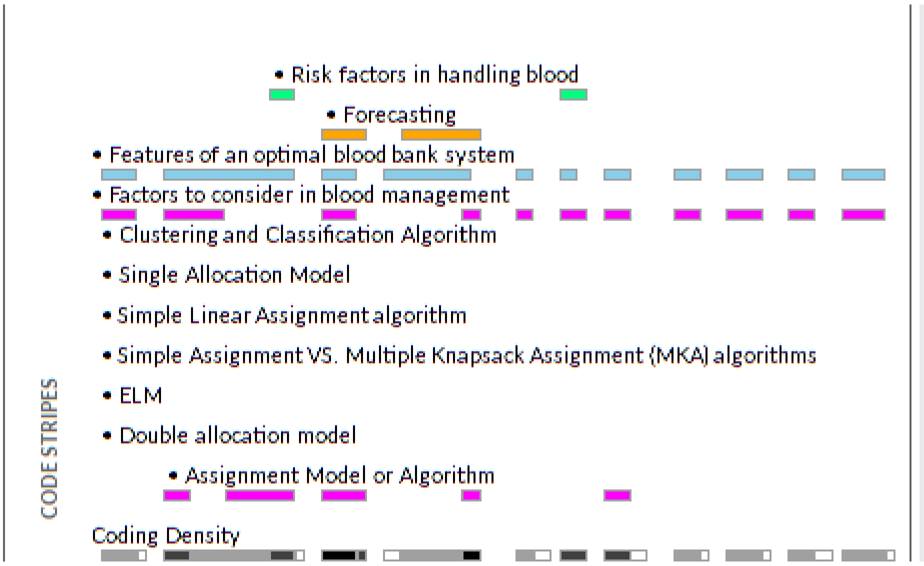


Figure 5: Data coding process.

3.1.3 Document Review Results Presentation

The results derived were presented descriptively whereby in addition to presenting the findings the researcher interpreted and analyzed the data from a personal lens. Descriptive data presentation helped in explaining the data in an understandable and meaningful way. Further, the descriptive presentation provided a simplified interpretation of the data in question. The results are further organized to address the research question on the assignment algorithms used to manage blood and the features of an optimal blood allocation model. The findings presented from the research inform the blood bank management algorithm tested.

3.1.3.1 Forecasting Algorithms

Findings from the document review showed that some of the assignment algorithms that can be used to help manage blood are machine learning and data mining algorithms, time series forecast algorithms, Box Jenkin procedure, or linear assignment algorithms. AlZu'bi et al. (2021) discuss machine learning and data mining algorithms that can be used to manage the blood donation process. Intelligent systems can help predict the number of blood donations that can fulfil future blood demands. Further, these systems can accurately predict adequate blood storage hence reducing the expiry of blood units and wastage as well as the need to import blood from outside. AlZu'bi et al. (2021) discuss various optimization methods to optimize blood donations and the supply of blood to hospitals. One of the methods is the particle swarm optimization (PSO) algorithm proposed by Olusanya et al. (2015) to help distribute blood effectively among the blood banks and the blood types. PSO uses queueing technique and multiple knapsack assignment technique to match blood types to the requests. Another method is the symbiotic organisms search (SOS) optimization algorithm proposed by Govender and Ezugwu (2018) that generates accurate percentage bound values to predict the demand and supply of blood units each month. On the other hand, Priya et al. developed a web and mobile application that updates information about acceptors, patients and donors and maintains records of blood donated and available blood for each blood type. Other methods proposed include the use of fuzzy sequential pattern mining and classification data mining algorithm (AlZu'bi et al., 2021).

Similarly, Ben Elmir et al., (2023) developed an information system for managing blood supply from blood donation to usage. The information system uses time series forecasting model and machine learning to forecast future blood demand. Further, the system uses blood donor classifiers that help predict donors' behaviour such as return donors. Further, blood demand prediction data is used to determine the amount of blood collected in sequential order hence reducing blood shortage and wastage (Ben Elmir et al.,2023).

Silva Filho (2013) proposes a forecasting model for the blood supply chain to avoid the expiry of blood components and stockout. Forecasting in blood management entails estimating the amount of blood that should be collected and the blood that will need the hospital's demands. Silva Filho (2013) proposes using Box and Jenkin procedure to forecast the blood components required. Silva Filho (2013) states that blood forecasting should be based on previous information about blood component use by hospitals. Forecasting helps address the challenge of how to plan and control inventory levels. The forecasting algorithm should predict blood components that should be sent to the hospitals with accuracy by relying on past demand and predicting possible emergencies. Models used to predict the future include regression models and parametric models. Other more effective models are the multiplicative seasonal autoregressive integrated moving average (SARIMA) and the BJ procedure. Silva Filho (2013) proposes using BJ-SARIMA. An automated BJ algorithm is used to reduce time and cost related to identification, estimation and validation. Implementing the BJ SARMA algorithm entails data entry, statistical analysis and data transformation, automatic order and type identification, parameter estimation, and finally diagnostic check of the model (Silva Filho, 2013).

Van Sambeeck et al. (2018) propose an integrated approach that takes into account all the factors involved in blood management. These factors include available blood units to match, storage of blood units, targeted donor recruitment, blood storage, and the cost of blood units and screening. Van Sambeeck et al. (2018) state that any blood management algorithm should start with a blood-matching strategy while taking into consideration the patient mix which determines the blood demand. Further, Van Sambeeck et al. (2018) state that the availability of the blood products in the inventory is dependent on the donor's availability. The assignment algorithm should further consider the transfusion complication risk. Further, the assignment algorithm should consider the fluctuating demand for blood units. Van Sambeeck et al. (2018) argue that with all this information the resulting cost of inventory, material handling, and transport can be estimated. Van Sambeeck et al. (2018) further argue that in addition to inventory management increasing donor recruitment can increase the availability of blood in the inventory.

Chinnaswamy et al. (2015) on the other hand designed a blood bank management model shown in Figure 6 that allowed crossmatching using multiple knapsack solutions. To benchmark, the performance of this model, Chinnaswamy et al. (2015) designed a model based on a simple linear assignment that did not allow cross-matching. Using multiple knapsacks compatible blood types were cross-matched. This meant that blood types compatible could be used to fulfil compatible blood requests. The aim was to stabilize blood usage in the blood bank and at the same time minimize the need to import blood units (Chinnaswamy et al., 2015). To achieve cross-matching the blood bank model had the blood types assigned compatibility values. The figure below shows the optimized model using multiple knapsacks. The results derived from this model showed that cross-matching was more efficient in managing blood banks than blood banks without cross-matching. It reduced the need to import blood outside (that is from other hospitals and blood centers).

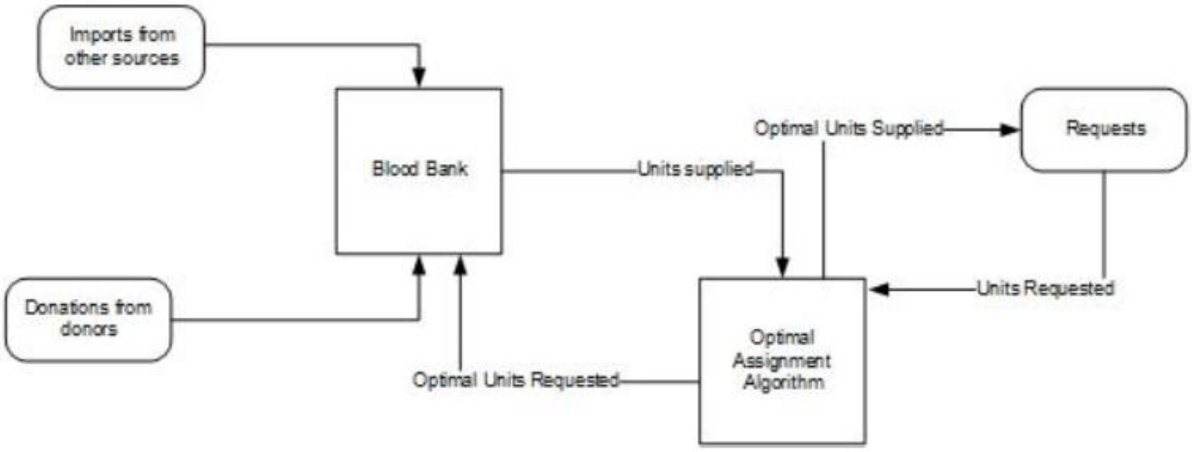


Figure 6: Crossmatching by Chinnaswamy et al. (2015).

Rusman & Rapi (2014) proposed a location optimization model shown in Figure 21. The motivation was to find an optimal solution to optimize blood distribution of blood. Considering that blood shortage is a problem affecting 80% of the hospital this seemed to be a viable solution. The model is based on Makassar City in Indonesia. Makassar City has 2 regional blood banks and 17 hospitals. Rusman & Rapi (2014) proposed using either a single-allocation model or a double-allocation model (Rusman & Rapi, 2014). The single allocation model assumed that a hospital's blood demand can be supplied by one blood bank. Consequently, this model reduced delivery costs. Under this model, a hospital was only allowed to specify blood units available in the single blood bank. Conversely, the double allocation model assumed that a hospital's blood request could be satisfied by both blood banks. The hospital was allowed to request a maximum number of blood units available in both blood banks. Both of these models were based on integer programming to calculate the costs of each model (Rusman & Rapi, 2014). Below is a chart showing the efficiency of these two models based on computations to determine the efficiency of both models in terms of cost.

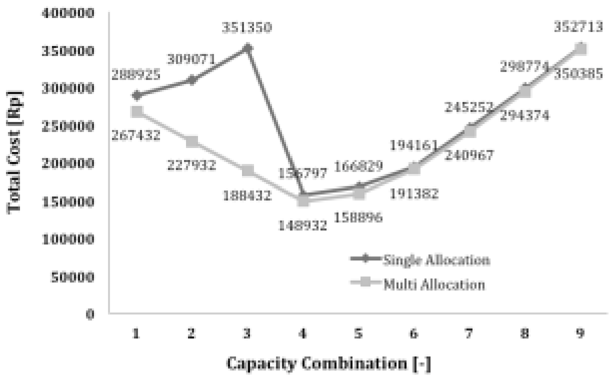


Figure 7: Single and Double Allocation Model by Rusman & Rapi (2014).

As seen in Figure 7 above, the model can be useful in determining the blood models to use to distribute to the different hospitals in the city at an optimal cost.

3.1.3.2 Features of an Optimal Blood Management Model

AlZu'bi et al. (2021) state that there is a need for an effective blood donation supply chain that meets the demand for blood required in hospitals. Adequate blood donation is needed to meet the blood demand of hospitals. Also, blood is perishable and has to be discarded after its maximum shelf life passes hence there should be stable blood supply to the hospitals. Besides, the blood management process is expensive hence blood collected should be efficiently used before expiry. Another consideration to make is that blood transfusion is based on compatibility (AlZu'bi et al., 2021).

Rusman & Rapi (2014) states that the location and availability of blood banks is an important feature of blood distribution. Poor location decision impacts capital costs, expenses, and customer experience. Strategic location decision is important to reduce anomaly that may cause morbidity or mortality. Rusman & Rapi (2014) argues that blood banks can be organized in a centralized or decentralized manner.

Additionally, Chinnaswamy et al. (2015) argue that it is important to retain blood donors and increase blood donation. Chinnaswamy et al. (2015) state there is a need for an intelligent automation mechanism to monitor blood stock levels and select suitable blood donors to be notified and requested to donate. Using an intelligent system can decrease the workload in blood centres. Further, Chinnaswamy et al. (2015) recommend taking into account emergency blood requests and how to address them. Chinnaswamy et al. (2015) propose a notification system to communicate with donors hence reducing latency in response and increasing the availability of blood.

Silva Filho et al. (2019) concurs with Chinnaswamy et al. (2015) by advocating for forecasting to estimate aspects of the blood supply chain that include finances, production and inventory, distribution, and marketing. In particular, a blood centre can use forecasting to plan blood collection schedules, manage inventory using an inventory system, and manage distribution following a distribution policy. Forecasting is important in blood supply to facilitate reliable decision-making. The blood centre forecasting should predict blood supply and demand to minimize shortage and excess of blood units in storage. Forecasting can minimize uncertainties in the blood supply chain. Forecasting can minimize uncertainties in the blood supply chain.

Van Sambeeck et al. (2018), argue that an optimal matching strategy should balance the risk of alloimmunization complications and costs associated with blood supply. The risk of alloimmunization complications is present in red blood cell transfusion. The reality of blood transfusion is that only a portion of blood group antigens are matched which introduces a risk of alloimmunization. According to Van Sambeeck et al. (2018), an optimal blood management approach should balance the cost of donor typing, donor recruitment, inventory management, blood product logistics, alloimmunization complication and patient blood typing.

3.2 Genetic Algorithm

The two variables that can provide optimal blood management are: reorder point and order quantity. The order quantity is the number of goods an organization should order at a given time. On the other hand, the reorder point is the inventory level at which new order should be made. Setting a reorder point ensures there is a sufficient stock level to fulfil clients' demands before the blood is resupplied. Having a reorder point facilitates the efficient running of an organization by balancing supply and demand needs. Currently, the formulas used to determine the reorder point either lead to high levels of inventory if the maximum daily demand is multiplied by maximum lead time or low service levels when the average daily demand is multiplied by average lead time. Subsequently, the uncertainty of demand and supply makes it challenging to predict inventory levels and service levels.

To solve this challenge the genetic algorithm was used to simulate the blood demand and lead time along with the uncertainties. To perform the simulation, the researcher defined the inventory strategy by inputting the ordering quantity and the reorder point into the genetic algorithm simulation model and defined the genetic operators. The genetic algorithm sends multiple inventory strategies to the model in iterations to find the optimal values.

To use the genetic algorithm in this simulation, the researcher used a Python library called geneticalgorithm. The geneticalgorithm library implements the standard and elitist genetic algorithm. The geneticalgorithm library solves combinatorial, continuous, and mixed optimization problems with discrete, continuous and mixed variables. Also, to facilitate data manipulation pandas and numpy Python libraries were used.

3.2.1 Implementation Process

Firstly, the research determined the type of data to use. In this case, a free dataset for a blood centre was downloaded from Data.World. Moving forward, the data about the blood inventory levels, blood demand, blood lead times, and blood expiry date were extracted. Also, the data was checked to ensure randomly generated values were generated to fill the blank data values. The data was then aggregated to provide mean lead times and mean demand.

Secondly, the researcher defined the genetic algorithm parameters which include the chromosome representation, population size, mutation rate, and termination criteria. The chromosome representation in this case represents the inventory levels and specifies the quantity of blood needed at different times. The population size refers to the potential inventory levels that are evaluated in each generation of the genetic algorithm. The mutation rate and crossover probability are the parameters that control the variation and combination of solutions in the genetic algorithm. The mutation rate used was 0.1 and a uniform crossover probability was defined. The termination criteria are the stopping condition and in this research, the termination criterion is based on the number of generations.

After the genetic algorithm parameters were defined the initial population for the blood inventory levels and reorder point were randomly generated. The members of the population are then evaluated for fitness and a next generation is generated comprising of the fit individuals. The roulette wheel selection method was used since it allows individuals with higher fitness values a higher probability of being selected for reproduction, while still giving a chance for lower fitness individuals to be chosen. Using the roulette wheel selection, the fitness of the individuals is evaluated using a fitness function measuring how well the blood quantity in the stock satisfies the demand fulfilment while considering the lead times (Lambora et al., 2019). Subsequently, by using this selection method the genetic algorithm has a better chance of generating better solutions. Crossover and mutation were then applied to the selected individual to create a new individual. To determine individuals that form the next generation enlarge sampling selection was used. Enlarge sampling selection provides the parents and the offspring an equal chance of being selected hence ensuring all fit individuals have a chance of being selected (Soman & Malinowski, 2019). The steps of evaluation, selection, crossover, and mutation and selection are iterated for a predetermined number of generations until the termination criterion is met. After the termination criterion is met the best solution for blood quantity to order and reorder point is presented

3.3 Waterfall Model

The waterfall model is a linear-sequential process model in which each phase is completed before proceeding to the next phase. The outcome of one phase is used as input to the next phase. This means the researcher completed requirement gathering then proceeded to system analysis and design, and finally to system implementation and testing. The waterfall model is suitable for this project since there are strict time constraints and hence iterative models may hinder time adherence. However, the limitation of the waterfall model was the inflexibility to accommodate changing requirements.

3.3.1 Requirement Gathering

Requirement gathering refers to the process of identifying and defining the needs of a software system to meet the user's needs. It is about analyzing the user needs and then clearly defining the system specifications (Valacich et al., 2022). The researcher started by analyzing the user needs and crafting the system specifications on how the blood distribution system should work. Under this phase, the problem and potential solutions were identified through a document review in the literature review section and the qualitative research conducted that informs the proposed blood management algorithm. At the end of this phase, the researcher documented the system requirements giving an abstract idea of the blood distribution system.

3.3.2 System Analysis

System analysis entails interpreting facts to identify the specific system components to specify what the system does (Valacich et al., 2022). In the second phase, the researcher studied the requirement specifications identified during the document review to derive functional, non-functional requirements and technical requirements. The functional and non-functional requirements are more detailed and clearly describe the various system functions. The functional requirements defined the features and functions of the system whereas the non-functional requirements defined the quality attributes of the system.

3.3.3 System Design

System design refers to the process of defining the different components, architecture, modules and architecture of the system (Valacich et al., 2022). In this research system design entailed the design of the system architecture, database and interface. The system architecture design defined the components that make up the system as well as the system architecture style. (Valacich et al., 2022). On the other hand, the database design was created to show the database model and how data elements interrelate in the system. It shows how the data is managed within the system. The user interface on the other hand entails defining the system user interface in terms of features, components and appearance. The interface design was done using Figma software.

3.3.4 System Development

The system development phase entails coding a web application that fulfils the second project objective. The researcher used the information gathered previously and more so the project designs to create project components. To accomplish the development phase, heterogeneous technology and tools were used. They include MongoDB atlas database, NodeJS, and React. React was used to create the front end using the node js runtime. MongoDB was used to create the system database.

3.3.5 System Testing

Valacich et al. (2022), state that system testing is conducted to determine whether the system meets the specified business requirements. Further, system testing evaluates whether the user needs and requirements are met satisfactorily (Leotta et al., 2017). The researcher used the developed prototype to assess the feasibility of the web application facilitating dynamic blood allocation and reducing blood wastage. To accomplish this objective, the researcher used dummy data to test the system's usability.

CHAPTER FOUR: RESULTS AND DISCUSSIONS

This chapter presents the system requirements identified in the system analysis part and the system designs created. The system analysis phase help comprehend the details of the blood distribution system.

4.1 Artifact Development

4.1.1 System Analysis

A: Functional Requirements

The functional requirements specifications documents what the prototype should perform. This section also includes the type of data that can be entered into the system, the flow of data, operations, reports, and users and their roles or user groups. The system consists of a variety of functionalities designed to ensure the system works as it is meant to.

1. Users should be able to log in to the system. Note the users, in this case, are hospitals.
2. Users can request blood.
3. The users should be able to see the status of their blood requests. (Approved, declined, pending)
4. Users can view available blood units in the blood banks.
5. The admin should be able to login successfully to the admin dashboard
6. The admin can perform all CRUD (create, read, update, delete) operations regarding blood bank regions.
7. The shelf life of blood products should be visible to the admin (Blood has a shelf life of 42 days).
8. Admin can view blood usage statistics in terms of approved, declined pending requests and as well as blood availability.
9. Admin can manage inventory.

   Technical Requirements
10. The assignment algorithm should use FIFO to determine how blood requests should be addressed.
11. The assignment algorithm should use a stochastic algorithm to forecast the reordering point and ordering quantity.

B: Technical Requirements

1. Use rest APIs technologies
2. Use NodeJS as the runtime environment/compiler for JavaScript.

3. Use ExpressJS which is needed when using NodeJS to create a server-side framework for creating server/APIs.
4. APIs that facilitate the reusability of common components.
5. A user interface
6. Ability to store, retrieve, and edit data stored in the database server.
7. Ability to make requests to the APIs database.
8. Ability to consume the implemented APIs
9. React which is used to create frontend and consume the APIs
10. A Mongo DB server
11. A NoSQL database with various collections and documents
12. Capability for the database to communicate with the APIs

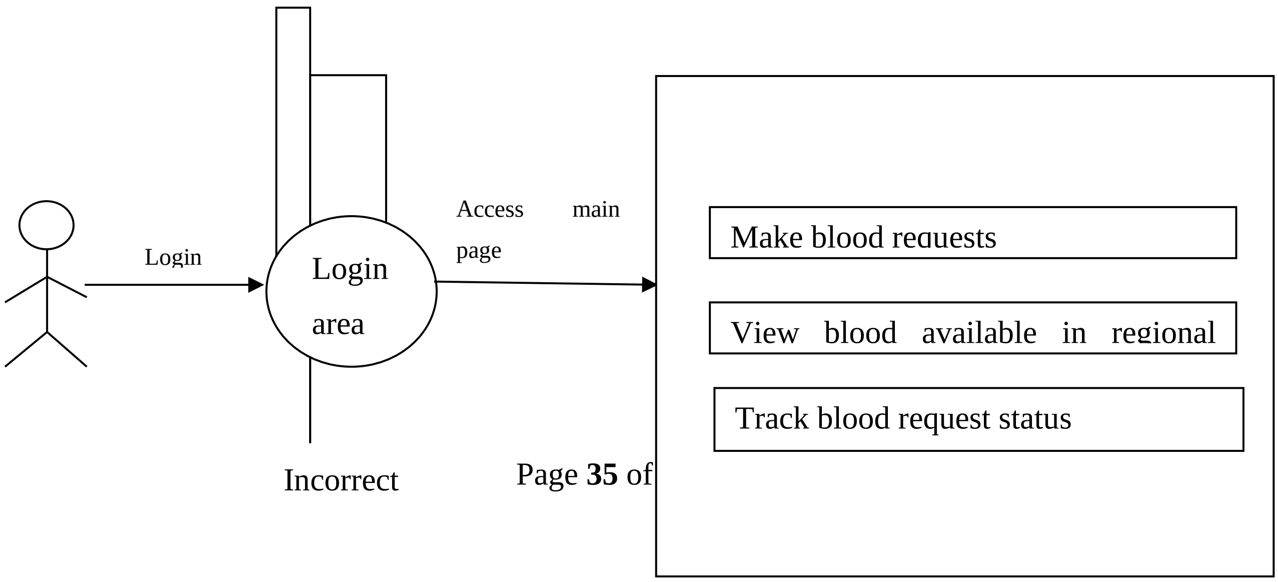
C: Non-Functional Requirements

The non-functional requirements include the requirements that outline the criteria for evaluation of the system operations rather than the specific behaviour. Although functional requirements are important, most requirement-gathering techniques tend to ignore non-functional requirements leading to gaps in non-functional aspects of the system requirements. The main focus of the current project is to create a scalable system with improved performance and reliability hence the non-functional requirements include:

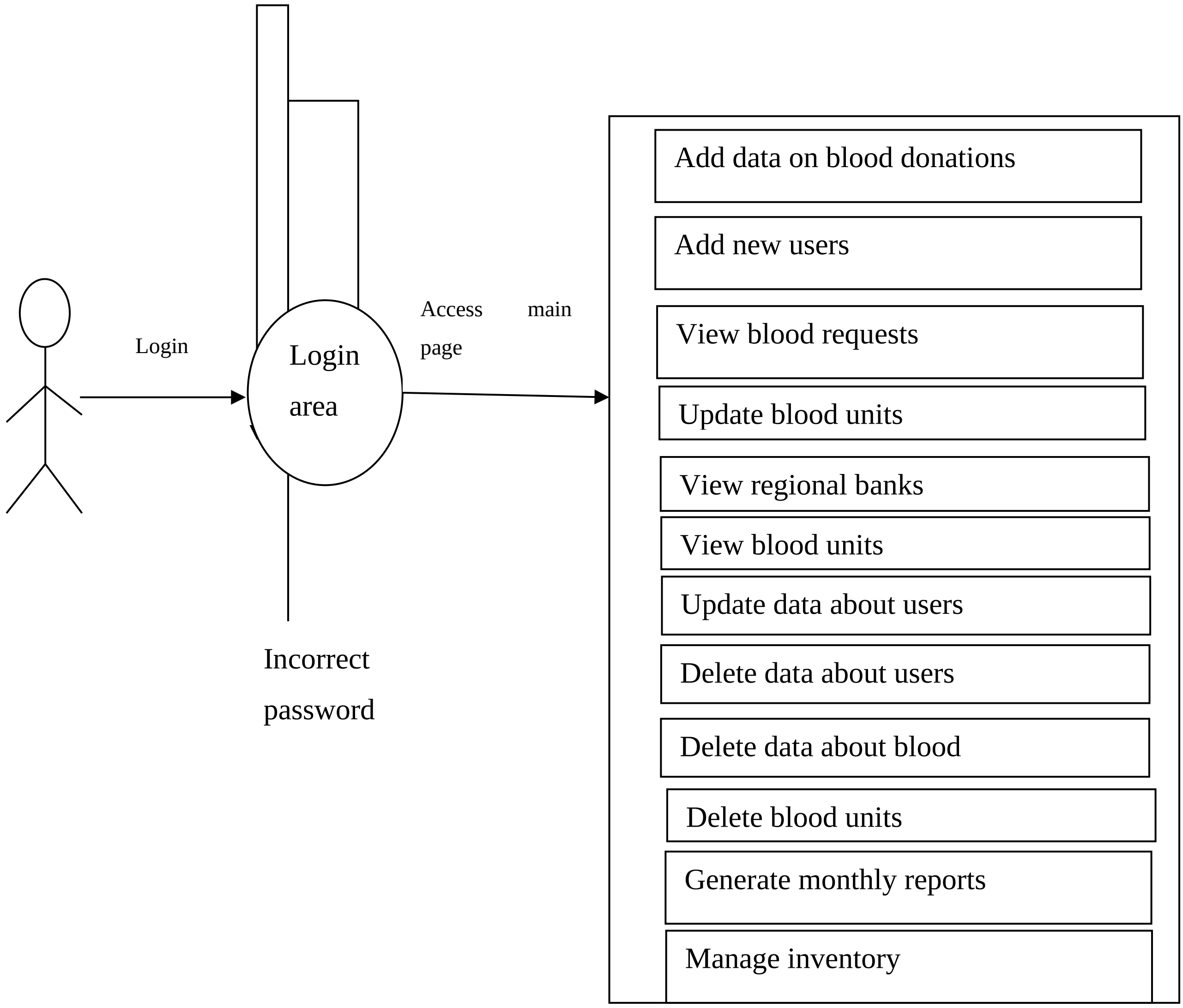
1. The website should be user-friendly.
2. The website load time should have a minimal delay.
3. The website should not have errors.

D: User Activity Diagrams

B: User Login



A: Admin Login



4.1.2 System Design

System design entailed creating the architecture for different system components, modules, and interfaces. The system design provides the system business logic. The researcher designed three visual components of the system namely: system architecture, database design, and interface design.

A: System Architecture

The system has a client-server based on the API concepts as shown in figure 10 below. The client can send GET, PUT, or POST, requests; the requests are sent to the request handler that determines the requested route or rather the API to address the request; the service handler/ the API handles the specific request; data to be posted or retrieved from the database is processed by database handler.

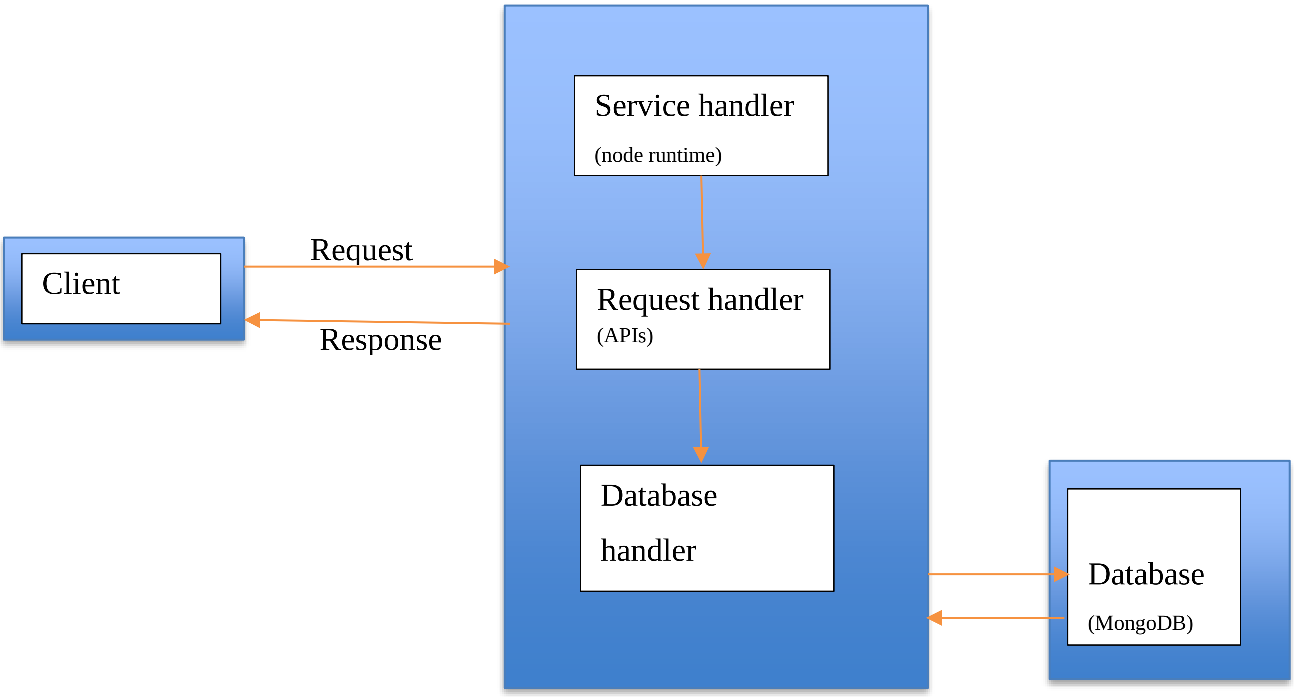


Figure 10: System architecture.

B: Database Schema

Figure 11 below the database design illustrates the organization and relationship of collections and documents in the database.

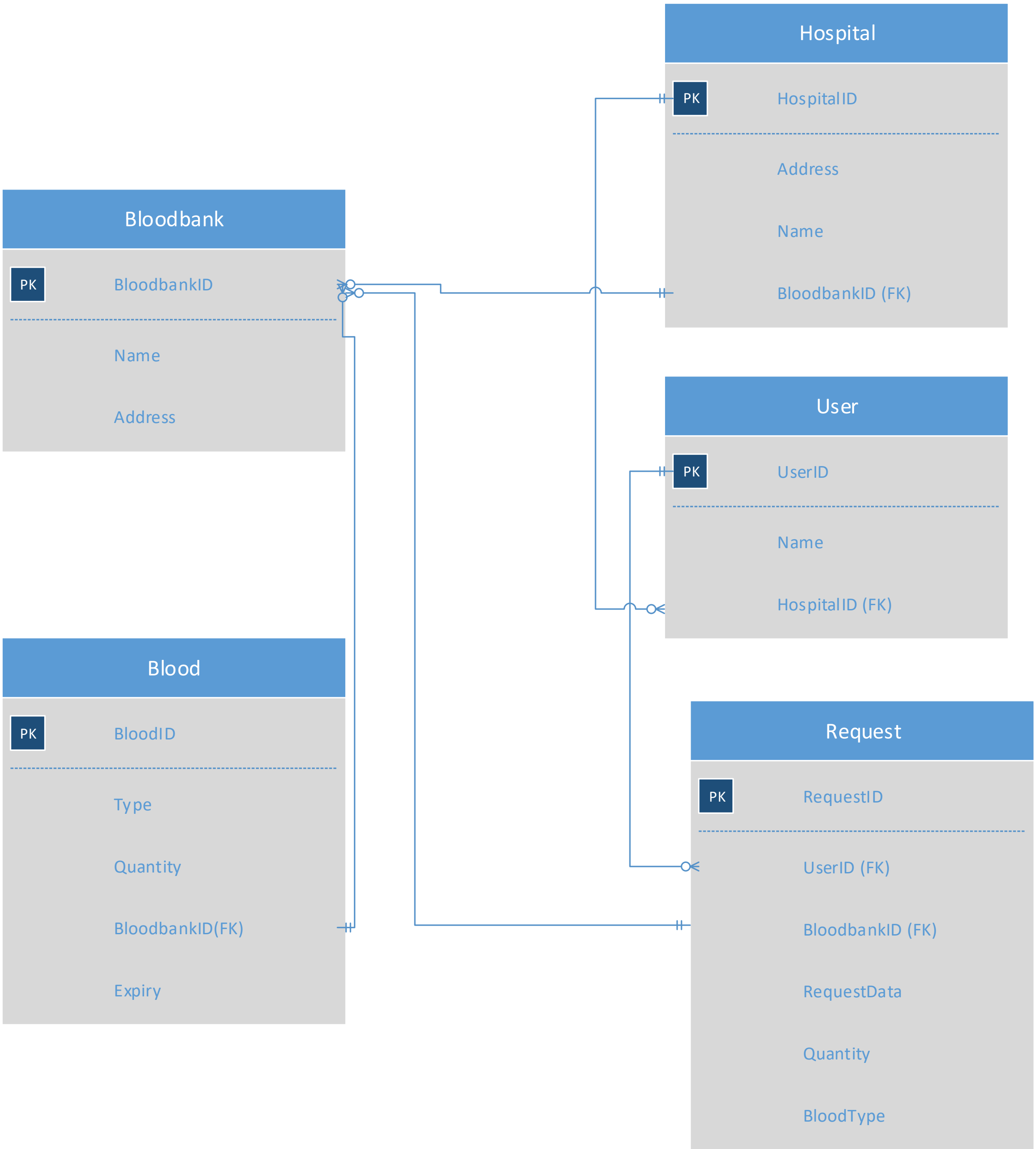


Figure 11: Database Schema.

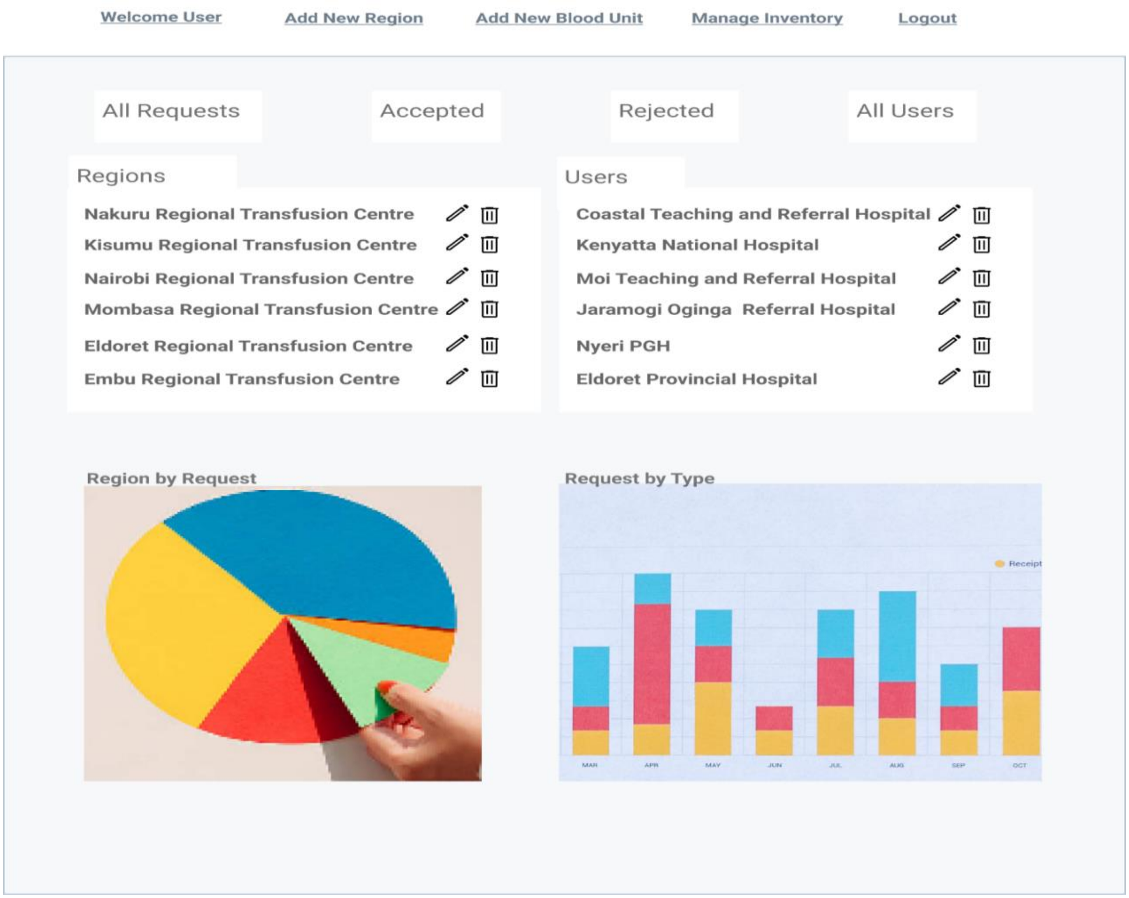
C: Interface Design

The diagrams below present the user and admin system interface designed using Figma.

Client interface design

Type	Quantity	Expiry Date	Action
O+	8	in 13 hours	REQUEST
O-	6	in 2 days	REQUEST
A+	11	in 5 days	REQUEST
A-	13	in 21 days	REQUEST
AB+	6	in 24 days	REQUEST

Admin interface design



4.1.3 Model Implementation

A: Model Evaluation

The genetic algorithm model was used in foresting the number of blood units the blood bank should order at a given point and the reorder point. A genetic algorithm simulation is a tool that provides joint outcomes for a set of independent variables. The genetic algorithm models calculate and forecast an outcome based on variability and volatility. The random values can be random data sets, continuous values, or discrete values. Genetic algorithm simulation is appropriate for this project since it can predict the outcome even with certain levels of randomness and unpredictability associated with the variables.

The two variables to optimize are order quantity and reorder point. Consequently, the chromosomes of the genetic algorithm should include both of these variables. After defining the genes in the chromosomes, the next stage was generating a random population of 100 initial chromosomes from the experimental data. However, when generating this initial population, the constraints associated with order quantity and reorder point are considered. The constraint of order quantity is related to the demand for the blood units whereas the constraint for the reorder point is related to the lead time. To get the constraints, a free dataset for a blood centre was downloaded from Data.World. The data about the blood inventory levels, blood demand, blood lead times, and blood expiry date were extracted. Also, the data was checked to ensure randomly generated values were generated to fill the blank data values. The data was then aggregated to provide mean lead times and mean demand.

The next step was the selection process done using the Roulette Wheel Selection. The roulette wheel selection method gives the genetic algorithm a better chance of generating better solutions. After the selection of fit chromosomes, the next step was recombination through crossover and mutation. The chromosomes include a set of structures referred to as genes. Each gene is a potential solution to the optimization problem. The process to optimize the solution is maximized by exploiting the available search space. These chromosomes are subjected to genetic operators, crossover, and mutation. The crossover type used is the uniform crossover, chromosome probability of 0.3, and a mutation probability is 0.1 as shown in appendix 5.

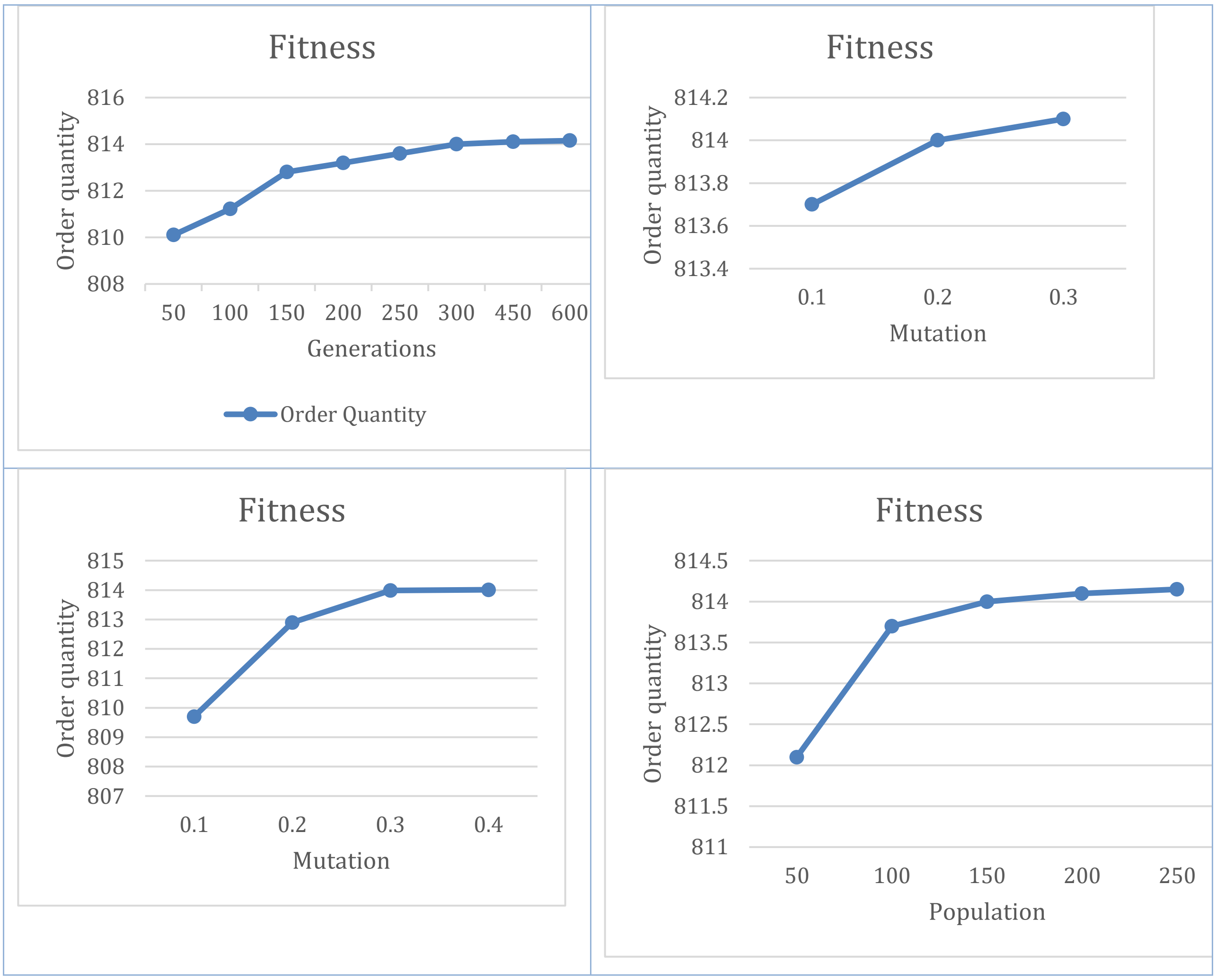
Moving on to the mutation process, the chromosomes are mutated based on the mutation rate. After the recombination process, a new population is created. Enlarge sampling selection was used to determine which parent and offspring have a chance of creating the new population. The benefit of using enlarge sampling selection is that it gives an equal chance of being selected to the parents and offspring. After the recombination process that entails crossover and mutation a new population is formed. Using enlarge sampling selection, the parents and the offspring have an equal chance of being selected based on their fitness level to form the new generation.

Further, the blood bank will take into account the number of blood units requested daily and determine the requests that can be addressed daily. At this stage, the system will use FIFO to address blood requests. FIFO is used to use the blood collected first to address blood requests hence reducing the chances of expiry. The proposed dynamic blood bank model has the blood bank as the central entity. The diagram also shows that the blood bank provides information about the available blood units and the blood requests made to the assignment algorithm. Using this information, the assignment algorithm determines which blood units to be used to address the blood requests and the units that need to be imported from outside. The blood assignment algorithm introduces the queue-type data structure whereby the oldest blood units are organized on top awaiting preferential processing. the problem of expiring blood units from a data structure perspective. Also, the allocation algorithm takes into consideration the patient mix and the blood compatibility while at the same time implementing FIFO.

C: Model Validation

The parameter sensitivity analysis is one method recommended for evaluating genetic algorithms. The parameter sensitivity analysis evaluates the performance of the algorithm with varying parameter values. Parameter sensitivity analysis is effective at determining what parameters give the most optimal solution (Lambora et al., 2019). In this case, the parameters analyzed were the mutation rate, population size, and crossover rate as shown in table 3 below.

Table 3:Parameter sensitivity analysis results.



Optimal results were achieved with a population size of 220, 300 generations, a crossover rate of 0.4 and a mutation rate of 0.3. These optimal results are: reorder point when the blood units are 814 and the order quantity is 146.

Another method for evaluating genetic algorithms is the convergence test. Lambora et al. (2019) stated that a successful optimization process is achieving a smooth convergence towards a stable fitness value in a graph fitness value against generations. The result from the model shows that the fitness value increases as the number of generations increases as shown in Figure 12 below.

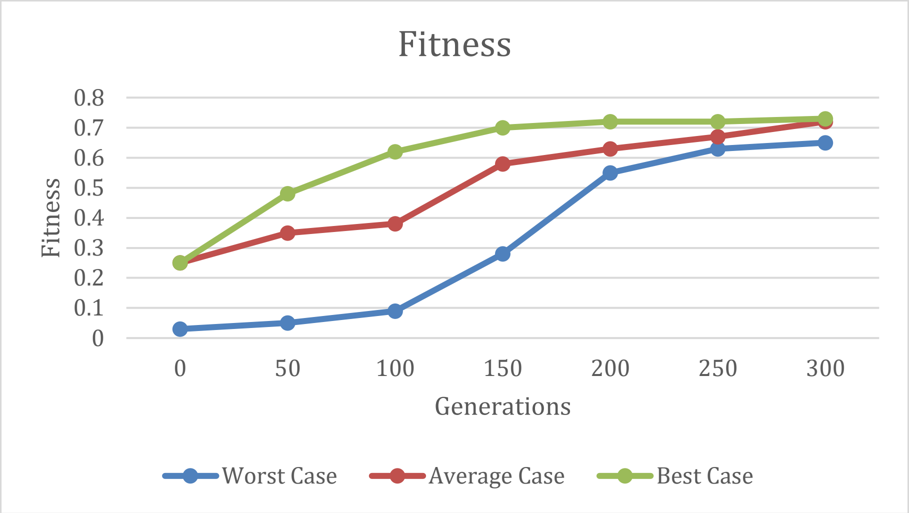


Figure 12: Fitness graph.

4.1.4 Prototype Implementation

The researcher developed the server side using REST API technologies. REST takes advantage of the internet mechanisms used to view web pages. These mechanisms are based on HTTP protocol and the runtime environment used to implement REST API is NodeJS. NodeJS is an open source that allows the developer to run JavaScript on the server. Also, express js was used for creating the server. Express js. provided a flexible and minimal Node js framework for developing a website with robust features. Express js. framework runs on top of node js. functionality to simplify the APIs. An example of a rest API endpoint for processing a blood request is shown in Figure 13 below.

```
 // blood request details
const { blood, quantity, bank, date } = req.body;
  let status = "Pending";
  let rem = quantity;
  try {


// Processing of the request starts by checking whether the available blood is not expired
    const units = await Blood.find({
      bloodtype: blood,
      bank: bank,
```

```
      expiry: {
        $gte: new Date(),
      },
    }).sort("expiry");

// when there are no units of the blood type requested.
    if (units.length === 0) {
      status = "Pending";
    }
//If the quantity of the first entry in the database is greater than the requested units

else if (units[0].quantity > rem) {
      status = "Approved";
      await Blood.findOneAndUpdate({ _id: units[0]._id }, { $inc: { quantity: -rem } });
    } else if (units[0].quantity === rem) {
//If the quantity of the first entry in the database is equal to the requested units
      status = "Approved";
      await Blood.findByIdAndRemove(units[0]._id);
    } else {

//When the request cannot be satisfied by the 1st entry, loop through other entries

      for (let i = 0; i < units.length; i++) {
        if (rem >= units[i].quantity) {
          rem -= units[i].quantity;
          await Blood.findByIdAndRemove(units[i]._id);
        } else if (rem === 0) {
          status = "Approved";
          break;
        } else {
          rem = 0;
          status = "Approved";
          await Blood.findOneAndUpdate({ _id: units[i]._id }, { $inc: { quantity: -rem } });
```

```
        break;
      }

```
Figure 13: Request Processing

To create the front end the researcher used React. React is a JavaScript library used to build user interface components that are reusable. React renders the appropriate components and updates them whenever changes are made. React was selected for this project since it is simple, easy to use, and scalable. Further, React is open source and hence accessible to all developers. Some of the React packages used to create the front end include Material UI, Formik, yup, Axios, styled-components, and Google charts. Material UI library provided customized components that were ready to use in the project such as text boxes, modals, cards, and tables, among others. Axios js. is a HTTP library that helps consume an API service. Axios js. provided the different ways to make HTTP requests that include POST, GET, DELETE, and PUT. For example, the Axios package was for sending requests to the server as shown in Figure 14 below.

```
    try {
/*send a post request to the server with a payload of blood type, blood bank, quantity and date*/
      const res = await Axios.post("/requests", { blood, bank, date, quantity: value });
//server responds with an HTTP status code of 201 //
      const req = await res?.data;
      if (req) {
        toast("Request sent successfully", { type: "success" });
        setUnitsOpen(false);
      }
      setLoadUpdatedRequests(true);
    } catch (error) {
// If there is an error server responds with HTTP status code 500//
      setLoadUpdatedRequests(true);
      console.log(error);
      setUnitsOpen(false);
    }
  };
```
Figure 14: Send request implementation

The database was implemented using the MongoDB Atlas database. MongoDB was the right database to use since it is open source and compatible with NodeJS and Rest technologies because it organized data in JSON format similar to REST as shown in Appendix 1 below. MongoDB Atlas Database allowed the researcher to develop the database faster and more simply. Further, MongoDB also made it easier to create data dependencies using a single API. The database created by MongoDB was a NoSQL database with collections and documents. Mongoose is a document relational model that simplifies the manipulation of MongoDB. Mongoose is an object data model library used for Nodejs and MongoDB. Mongoose is used for the representation and translation of objects in MongoDB, provides schema validation, and manages the relationship between data. It defines the document structure, validators and default values. An example of a mongoose schema is shown in Figure 15 below.

```
const requestSchema = new mongoose.Schema(
 { // A database schema for the request collection//
   blood: {
     type: String,
     required: true,
   },
   quantity: {
     type: Number,
     required: true,
   },
   status: {
     type: String,
     default: "Pending",
   },
   date: {
     type: Date,
     required: true,
     default: false,
   },
   bank: {
     type: mongoose.Schema.Types.ObjectId,
     required: true,
```

```
    ref: "Bank",
  },
  owner: {
    type: mongoose.Schema.Types.ObjectId,
    required: true,
    ref: "User",
  },
 },
 {
  timestamps: true,
 }
);
```
Figure 15: Mongoose Schema.

4.2 Discussion

The conceptual framework shows that the blood management chain can be optimized in 2 areas: (1) blood supply from donors to the blood banks; (2) blood allocation from the blood bank. The research addresses the forecast of the order quantity and the optimization of blood allocation using the FIFO strategy. FIFO is an optimal allocation strategy because it minimizes the expiry of collected blood. It provides an optimal sequence to remove blood units from the inventory with units of varying shelf life. The blood bank inventory has n blood units which are associated with i^{th} units with a shelf life of S^{i} (1,2,....n). The shelf life of the blood units in the inventory (LS) is dependent on the sequence used to remove blood units from the blood bank. Using FIFO, a blood unit is issued only after the previous units have been issued. The L(S) function requires consideration of all factors that can impact the optimal blood allocation. FIFO assignment of blood units is appropriate since the issuance of blood units is controlled by the users and the expiry for the different blood units is different.

On the other hand, data about inventory management in the past shows that on average 22,685 blood units were requested monthly whereas the blood collected was on average 10,512 meaning there was a deficit of 46% (OAG, 2022). Further, hospitals order blood as and when needed and have no limits on reorder levels. Subsequently, most hospitals have no stock to deal with emergencies. By forecasting the optimal amount of blood that blood banks should collect the research provides a way to avoid collecting excess blood than the demand. With the proposed blood management system, the blood centres and hospitals can determine the optimal reorder point and the optimal number of blood units to order. The introduction of an inventory management system can significantly reduce the deficit in fulfilling blood demand and reduce the expiry of blood products before usage.

CHAPTER 5: CONCLUSION AND RECOMMENDATION

The project achieved the objectives of identifying and reviewing previous blood bank management models and designing and developing an optimal blood allocation model. After reviewing previous studies, the forecast of ordering quantity and reorder point using genetic algorithm and FIFO queuing approach were found to be optimal blood allocation techniques to solve the blood allocation processing problem. Since the order quantity and reorder point are forecast early in advance the blood bank can efficiently manage the inventory. The blood banks can determine when to make new blood orders and the optimal amount of blood to order. Also, blood units collected first are allocated first hence reducing the chances of expiry before usage. FIFO facilitates the effective use of the blood units collected. To put FIFO into practice the researcher designed a REST API to process requests from hospitals using the FIFO strategy. The API was created using JSON and Python. The system database was created using MongoDB which is a distributed NoSQL database that uses the JSON format compatible with REST API. Using these technologies made it possible to develop a distributed web-based system that can be used by blood banks to facilitate the allocation of blood units optimally hence reducing blood wastage.

Future research can compare other prediction models that can be used to forecast blood supply and demand hence facilitating the selection of the most efficient prediction technique. the collection of optimal blood units needed within a specific time. Further, future research may also look into lean inventory management practices that can be used to reduce blood wastage and improve blood management processes. Lean can be used to eliminate non-value-adding activities, streamline processes and accelerate workflow.

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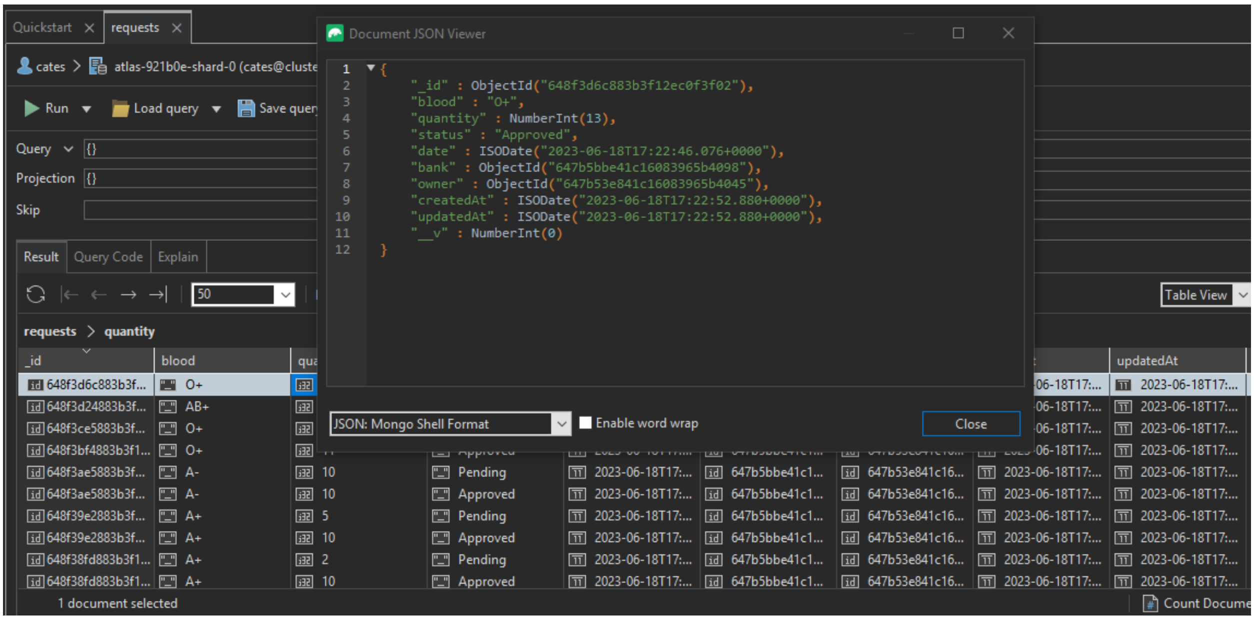
Appendixes

Appendix 1: MongoDB JSON Format



Appendix 2: Make a blood request

This functionality allows hospitals to make blood request from the regional blood banks. The hospital is required to fill out a form that enquires about the hospital details and the number of units required along with the urgency of the blood units as shown in figure 24.

A+	8	in 20 days	REQUEST
A-	8	in 20 days	REQUEST
O+	12	in 20 days	REQUEST
O-	6	in 20 days	REQUEST
O+	14	in a month	REQUEST
AB+	14	in a month	REQUEST
AB-	14	in a month	REQUEST
B+	14	in a month	REQUEST

Appendix 3: Track Blood Request

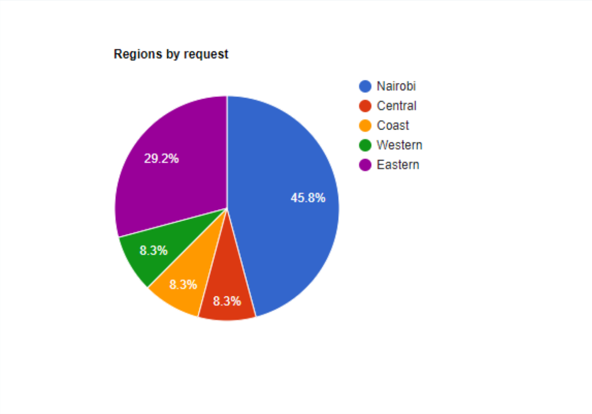
Upon filling the request, the hospital can track the progress of the blood request as shown in figure 25.

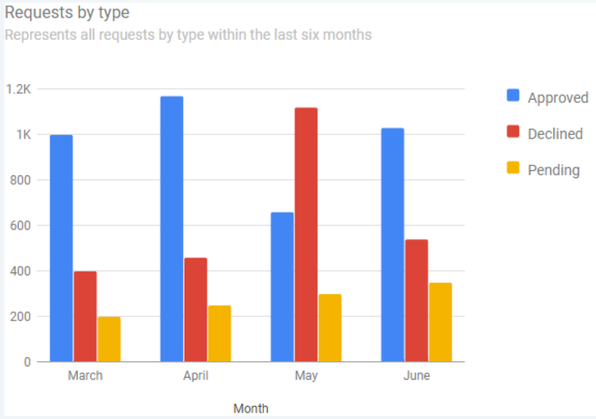
All Blood Banks
Requests
Approved
Pending
Rejected

Requested Blood Type	Blood Bank	Quantity	Date	Status
A+	Nairobi National Blood Transfusion Center	4	June 11, 2023	Approved
A+	Nairobi National Blood Transfusion Center	8	June 11, 2023	Approved
A+	Nairobi National Blood Transfusion Center	2	June 11, 2023	Approved
A+	Nairobi National Blood Transfusion Center	1	June 7, 2023	Approved
A+	Nairobi National Blood Transfusion Center	2	June 7, 2023	Approved

Appendix 4: Generate Graphical Reports

The functions allow the regional bank to access reports on the blood units allocated to each hospital in the previous months as well as the number of blood units used and those that expired as shown in figure 26.





Appendix 5: Genetic Algorithm Parameters

```
algorithm_param = {'max_num_iteration': 1000,
                   'population_size':220,
                   'mutation_probability':0.3,
                   'elit_ratio': 0.01,
                   'crossover_probability': 0.4,
                   'parents_portion': 0.3,
                   'crossover_type':'uniform',
                   'max_iteration_without_improv':200}
```