

MAKERERE UNIVERSITY
COLLEGE OF COMPUTING AND INFORMATION TECHNOLOGY

**Ubiquitous Computing for Mobile Based Payments in Localised
Intelligent Transportation Systems**

By
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DEPARTMENT OF COMPUTER SCIENCE

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Abstract

Traffic congestion is a major issue in many developing world cities, including Kampala, due to limited infrastructure and traffic management resources. Governments in these regions have attempted to address this issue by constructing toll express highways as part of embracing intelligent transportation systems. However, this approach has led to challenges, such as long queues and delays at tollgates. One proposed solution is the use of RFID technology, but this approach is cost-prohibitive.

This research proposes a low-cost solution tailored to the local context of Uganda. The proposed solution leverages techniques from the field of ubiquitous computing where a secure, reliable mobile application for prepaid payment of toll fees. These payments are recorded and in a cloud server and can be verified using a linked embedded QR code scanner. The proposed system can serve as an example of how intelligent transportation systems can be implemented in a developing city like Kampala, utilizing techniques from the field of ubiquitous computing. In the long run, such a project could help Kampala evolve into a smart city that is clean and self-sustaining.

Keywords: Intelligent Transportation Systems, Ubiquitous Computing, Mobile Based Payments, Smart Cities

Chapter 1

Introduction

1.1 Background and motivation

Traffic systems in developing-world cities such as Kampala tend to have issues such as limited infrastructure, as well as traffic management resources. Increase in vehicle ownership for both private and personal use among residents in these regions has also played a part in this[?]. These factors have an aggregate effect and result in traffic congestion in most of these cities[?].

One solution that has been put in place in efforts to improve the existing infrastructure is the construction of express highways that use a toll system, and studies have shown that such projects are of great significance spurring economic growth in the region[?]. The highways are less congested and are constructed as alternatives to any already existing routes. Motorists arrive at the tollgates found at the entrance to these roads, pay the toll fees, charged on a vehicle size basis in some cases and are then granted access to the highway.

Challenges have however risen with this solution, a major one being congestion and queues as motorists wait to pay their toll fees, thus defeating the road's intended purpose. These challenges can be attributed to issues such as finding cash change as well as limited manpower to attend to the various vehicles accessing the gates[?].

This research therefore explored how techniques from the field of ubiquitous computing can be used along with mobile commerce tools to create a localised low-cost solution to streamline this payment process. Such a system

can serve as a demonstration of how intelligent transportation systems can be implemented in Uganda, and in the long run, ultimately aiding in the development of cities like Kampala into smart cities.

1.2 Problem Statement

Toll payment checkpoints at the toll gates often experience queues and delays as motorists try to pay their toll fees. These queues occur due to issues such as:

- Limited manpower to handle the number of vehicles using the station causing congestion especially during moments such as peak hours of morning and evening, but there is limited labour to service them.
- Delays as tollgate employees try to find change for motorists since current payment system employs cash payments.

From our interviews with the owners of the current system we were also able to determine that the current system has a variety of limitations. Motorists who lose their tickets foreexample are required to pay 50000shs. fine, an amount that far exceeds what most of them would have paid. Additionally are also cases of breakdown of the ticketing machines due to low maintenance works particularly in the parking system context such as the one at Makerere University.

1.3 Objectives

1.3.1 Main Objective

To develop a low-cost secure reliable system, based on ubiquitous computing and mobile commerce techniques, to ease and quicken payment of toll fees.

1.3.2 Specific Objectives

The project's specific objectives include:

- To understand the existing payment approach used at Makerere University toll gates.
- To design a system prototype for the proposed solution.
- To implement the proposed mobile application and confirm whether it solves the highlighted problems within the current payment system.
- To demonstrate how embedded QR code scanners can be used in the toll payment context as an alternative to long range RFID scanners in low-resource settings



Figure 1.1: Makerere University main gate where the projected will be implemented

1.4 Scope of the project

This project is limited to building a cross-platform mobile application to enable motorists to pay their toll and parking fees. This application will be used with an embedded microcontroller with QR code reading capabilities.

Implementation of the project was done at Makerere University.

1.5 Significance of the project

The biggest significance of this research project is demonstrating how intelligent transportation systems can be applied in Uganda. This project will also quicken the toll payment process for motorists eliminating the congestion from the queues and delays that arise from the current system.

Additionally, the project is a step in the right direction towards achieving one of the UN Sustainable Development Goals, SDG13, that is concerned with climate action[?] as paper wastage in printing tickets, and vehicle emissions as they wait in queues are both reduced significantly by the proposed solution. In the long run, such a system can be scaled to various parts of the

country paving the way for development of smart cities in Uganda

Chapter 2

Literature Review

In this chapter we discuss similar projects that have been done and how they relate to the project development and execution in relation to our project. We also look at their shortcomings and how they are addressed in our project.

2.1 Intelligent Transportation Systems

Intelligent Transportation Systems are technologies that work with applications and are built with the intention of improving safety in the transport sector, and raising productivity for people

Initially proposed in the United States in the twentieth century, a great deal of research is currently going on in this domain as these systems not only improve traffic conditions but are also likely to improve safety, and sustainability in the transportation sector by limiting the inconveniences caused by traffic congestion[?].

These systems leverage information and communication technologies, such as embedded sensors, IOT devices[?]. They're used in efforts like real-time data collection from sensors placed in vehicles or infrastructure, and are able to aggregate this data that can then be used to gain insights in information concerning a given city or region. This information can then be used for services and applications aimed at improving the management, plus improving traffic flow in cities by reducing traffic congestion, which helps lower consumption of fuel and carbon emissions[?].

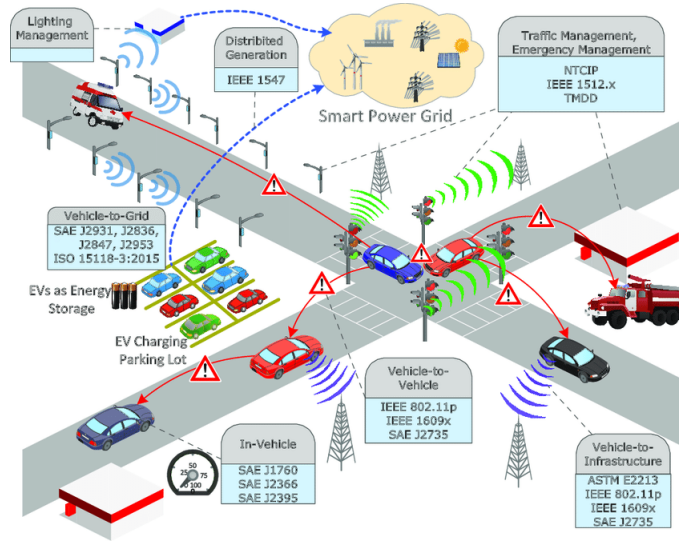


Figure 2.1: A sketch of an intelligent transportation system

2.1.1 Uganda National Roads Authority Express Highway and Makerere University Kampala

Attempts to put in place a project of this nature in the Ugandan setting have been made though limited by the resources and technology available in the region by the Uganda National Roads Authority through the construction of the Entebbe Express Highway. This implementation is however limited as cashless payments on this road are made electronically through an UPESI RFID card that's scanned as one tries to access the road[?]. At Makerere University, individuals who are exempted from paying the parking fee are also given a RFID tag that they place inside their vehicles. This is then scanned by a long-range RFID camera and they're instantly granted access thereafter[?].

Project Gap

The systems mentioned above are not as feasible because:

- Cash payments are the commonest way to pay , and these take up time in terms of trying to find change
- The alternative payment is an UPESI card, and the process of getting out of the vehicle to scan it is time consuming.



Figure 2.2: Gen. Katumba Wamala showing an UPESI payment card on the launch of the Entebbe Express Highway

- The implementation at Makerere University only accounts for vehicles with RFID tags and the rest have pay with tickets.

2.1.2 Use of GPS Software and Cell Towers

Research on how this can be leveraged in easing toll fee payment has been done by others. In 2020, Danang Dismantoro, Istas Pratomo and Surya Sumpeno also proposed a mobile application that allowed payment of these fees via GPS software[?, ?]. The system was tested through simulations in Vissim software [?], which they believe was able to simulate the real world condition at tollgates. Cell phone towers and GPS technology are used to identify the motorist's location and if the motorist happens to be within the toll's gate vicinity, the money is automatically deducted from their personal account.

Research Gaps

- No physical implementation of this system was realised
- The researchers acknowledge the need for a deeper feasibility study and the fact as it has some shortcomings.
- Some scenarios are unaccounted for such as if one is near a cell tower but does not necessarily intend to access the tollgate, they'll have their money deducted even without actually using the gate.

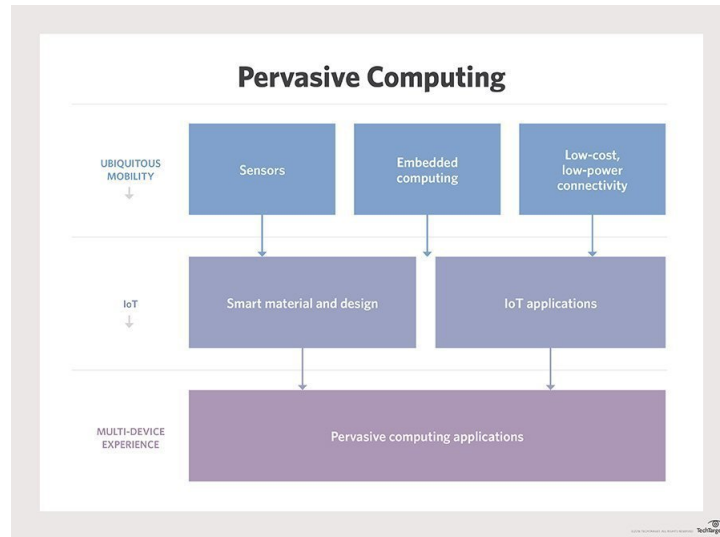


Figure 2.3: A sketch of a ubiquitous computing application

2.2 Ubiquitous Computing

The domain of ubiquitous computing also known as pervasive computing according to Michael Friedewalda and Oliver Raabe is concerned with countless small, wirelessly intercommunicating microprocessors, embedded into objects. Such techniques are applied in similar concepts, such as “the Internet of things”. The main motive in these domains is assisting people and optimizing economic and social processes through the use of microprocessors and sensors

These microprocessors are equipped with sensors enabling them to capture information about their current environment or process information and communicate over a network with other similar devices[?].

Ubiquitous computing systems consist of features such as:[?]

- The system is decentralised
- Computers are embedded in other devices
- Real-time information is readily available for users
- The system is able to adapt basing on current information.

This concept has a number of real world applications in domains such as

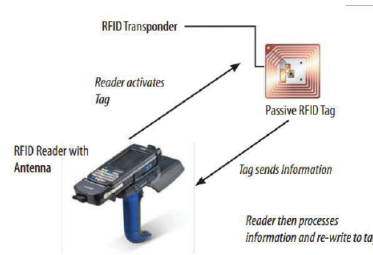


Figure 2.4: Components of an RFID system

retail, industrial production, health care and this is achieved through implementations such as tracking applications, wearable devices like smart-watches.

2.2.1 Use of RFID sensors

In the context of toll payment, ubiquitous computing has been put in use in a number of developed countries, and this has been mostly done through the use of RFID technology.

An RFID system has two main components:

- A transponder: This is the tag that holds information, found on the object to be identified
- A reader/interrogator: This device is able to capture data from the tag. It has a radio frequency module, control unit and coupling element for linking to the transponder. Additionally, an interface is added to pass on data captured from the transponder to a different system

Sabbir Ahmed et al in 2019 also proposed a similar solution. Their proposed system would simplify toll payment through use of RFID tags placed on digitised license plates of all vehicles. Once the tag is scanned, and the motorist has a sufficient balance on their account, the vehicle is granted access[?].

Another study by Etqad Khan et al. in 2018 proposed a system similar to ours that would ease payment of toll fees using RFID tag that would be linked to motorists' personal accounts where would have a mobile e-wallet on which a given amount would be saved. The system also provides a mobile application to view their past payments[?].

2.2.2 Research Gap

These two identified studies are constrained in our project scope's context, because:

- It would first off require digitisation of all vehicle license plate, an endeavour that has not yet been taken on by the government of Uganda.
- Long range RFID tags and scanners are costly to purchase which would be needed in this use case are costly ,and would thus the need for a low-cost solution that's accessible to majority of the motorists.



Figure 2.5: A mobile money kiosk in Kampala. These are a common sight in the city with agents to handle mobile money transactions as bank tellers would in normal banks

2.3 Mobile Commerce

The term E-commerce is used to refer to the buying and selling of goods over the internet. A subset of this is mobile commerce, which is strictly concerned with the same task, but conducted over mobile devices, [?] especially applications on smartphones. This can be attributed to the increased ubiquity of smartphones as well as other handheld devices such as tablets, allowing phone users to do shopping, make bank related transactions. This study is mostly concerned with the process of mobile payments.

Mobile payments refer to using a mobile device, such as a smartphone or tablet, to make financial transactions. This can include making purchases at a store, transferring money to another person, or paying bills.

In Uganda, the commonest implementation of this is through the mobile money systems[?]. In Sub-Saharan Africa, the use of mobile money platforms is promoting financial inclusion, with 548 million registered mobile money accounts in the region. These platforms have seen a 23% growth in transaction value, reaching 490 billion dollars.

In countries like Uganda, mobile money accounts are held by 43% of the population, compared to just 11% who have bank accounts. This demonstrates the significant impact that mobile money platforms are having on financial inclusion in the region[?].

One of the main advantages of mobile payments is convenience. With mobile

payments, there is no need to carry around a physical wallets. Transactions can be completed quickly and easily with just a few taps on your mobile device. This is especially useful in situations where carrying cash is inconvenient or unsafe, such as when traveling or when making a purchase online.

Another advantage of mobile payments is speed. Since mobile payments do not require the physical exchange of cash or the processing of a credit card, transactions can be completed quickly and efficiently. This can save time and effort for both the consumer and the merchant. In addition, mobile payments can enable real-time tracking of transactions, allowing both parties to have immediate access to information about the transaction, such as the amount, the date and time, and the location.

Enhanced security compared to cash payments. Mobile payment systems often use advanced security measures, such as encryption and authentication, to protect against fraud and unauthorized access. This can give consumers peace of mind when making financial transactions, knowing that their personal and financial information is protected.

Payments for these mobile transactions can be completed in a number of ways such as credit cards, debit cards and mobile money platforms such as MTN mobile money, Flutterwave. Our project will rely on the mobile money systems which are ubiquitous in Uganda[?]. It would therefore be advantageous to leverage these platforms

2.3.1 Uganda National Roads Authority

With regards to toll-fee payment, in Uganda, the Entebbe express highway is currently the only existing toll road. Mobile money platforms are leveraged here, but only for loading money onto the UPESI card,[?] that is then used by motorists to pay their fee. This process is quite long, as motorists have to first purchase the card, and repetitively load money onto it. A more simplified approach would be to automatically pay directly from the mobile phone

Project Gaps

One major shortcoming on the use of mobile commerce with regards to this project, is the payments are only used to add money to the card, which is then later scanned and not directly for access to the road.

2.3.2 Use of NFC technology

Near field communication, or NFC, is a technology that allows two devices to communicate wirelessly when they are close together. This technology is based on radio frequency signals, and it operates over a very short range, typically within a few centimeters of the devices. To use NFC technology, a device must be equipped with an NFC chip, which contains the necessary hardware and software to transmit and receive NFC signals[?]. When two NFC-enabled devices are placed near each other, they can exchange information and perform various actions, such as making a payment or transferring data. NFC technology is commonly used in mobile phones, payment cards, and other devices, and it offers a convenient and secure way to conduct transactions and share information.

Rugnesh Rameshram Kanojia and Professor Sujata Pathak in 2018 also proposed a mobile application that would be used for payment of these fees that leverages NFC technology[?]. An NFC device such as an NFC tag is tapped at the tollgate's NFC tag reader, thereafter user data is verified and the toll charge is deducted

Research Gap

NFC payments are very useful as they offer convenience, speed, and security for consumers, and they are becoming increasingly popular as a way to make purchases. Many major banks and retailers now support NFC mobile payments, and the technology is expected to continue to grow in popularity in the coming years, however, as of this writing, they are not yet supported by many of the local payment merchants in Uganda.

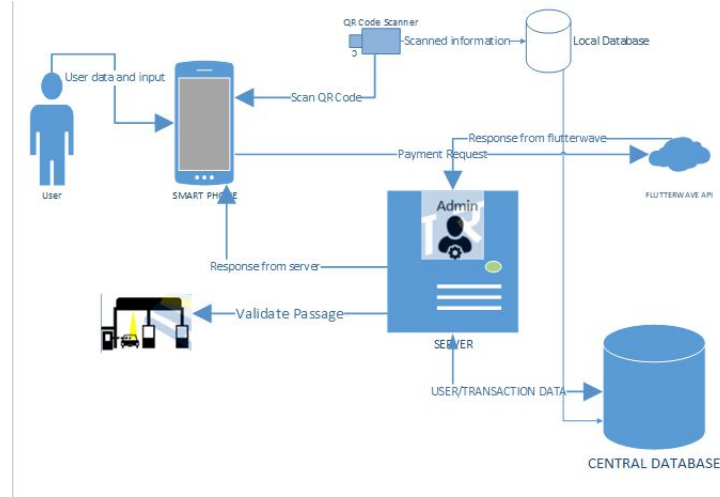


Figure 2.6: System Architecture Diagram for the proposed solution

2.4 Our Contribution

A lot of work has been done by other researchers to address the issue of tollgate queues. Many of these solutions leverage RFID technology as an alternative to the physical cash payments. This would however require purchasing costly scanners and tags, thus the need for a similar but cheaper solution. The biggest benefits to our proposed system:

- Use of the local preferred payment platforms such as MTN mobile money, increasing the system's accessibility to individuals in Uganda.
- Use of embedded QR code readers as an alternative to RFID tags and scanners which are costly. The QR codes that motorists will use to access the gates will be generated on their mobile phones, thus no need for tickets or such that would be wasteful
- Prepaid payments that would eliminate the delays and queues: Our proposed system would eliminate the queues that commonly arise as motorists make their payments.

Chapter 3

Methodology

3.1 Introduction

This chapter discusses the techniques that are to be used to achieve the objective of the proposal. It covers the approaches as well as techniques that will be used data collection, design, final implementation, and system testing.

3.2 Data Gathering and Elicitation

The team intends to collect relevant and appropriate data to determine the requirements of the proposed system. This will be done through questionnaires, interviews and physical observation[?].

3.2.1 Questionnaires

Questionnaires contain open or closed ended questions given to a selection respondents to solicit information on a selected research topic[?]. Google forms will be used to create online questionnaires that will be shared through social media and emails to targeted stakeholders. Advantages of online questionnaires are that they are relatively easy and quick to distribute. It is also quicker to receive responses and the data can be collected directly into the database for analysis.

3.2.2 Interviews

An interview is a one on one planned conversation with a person with an aim of attaining information. Researchers will have interactions with owners of the system currently in place as well as a selection of the motorists in order to get firsthand information on issues faced. This will help in better defining the system requirements of the project. The interviews will also enable the researchers to establish relationship with potential respondents and therefore gain their corporation, yielding highest response rates in the survey research.

3.2.3 Observation

Observation involve spending time with stakeholders and keenly monitoring their activities. This will provide unbiased information that will benefit the study. Researchers will take a physically closer look at what takes place during the daily activities of motorists trying to access the university and the challenges they face and will entail systematic noting and monitoring of events, behaviors of the motorists as they go on with their activities

3.3 Data Analysis

This will be done to remove inconsistencies in the data collected, as well as sieve out useful data that will be used to improve the system requirements.

3.4 System Design

For the system design, context diagrams will be created and used to define the scope of the project and its environment as well as the entities who will interact with it. Additionally, there will be detailed processes and data modelling[?].

3.4.1 Process Modelling

Here, data flow diagrams will be used to demonstrate the processes and entities that interact with the system.

3.4.2 Data Modelling

Entity relationship modelling will also be carried out to identify the entities as well as their relationship how they interact with each other This will be

achieved by use modelling entity relationships. The researchers will use this top down approach to identify the entities interacting with the system and relationship between the data that must be represented in the model.

3.5 System Implementation

At this stage the team will of the E-Tolls application. A number of tools and technologies will be used and these are defined below:

3.5.1 Software tools

- Android Studio.
- Xcode
- Flutter mobile framework: This will be used to write the cross-platform code for the application
- Google Firebase: This will be used for adding, accessing and processing of data.

3.5.2 Hardware tools

- Microcontroller
- Camera to be used to scan QR codes
- Wi-Fi GSM module to enable internet connection of the microcontroller

3.6 System Testing and Validation

Here, the system is tested with the intention of evaluating its functionality. [?]

Prototype builds for user testing and validation will be created. These will be shared using Firebase App Distribution[?]. This will be done to verify certain aspects of the application such as exception handling, security as the application involves connecting to users' mobile money accounts.

Chapter 4

System Analysis and Design

Chapter 5

Presentation of Results

The project intends to achieve the following outcomes:

- Informative results on testing and evaluating the current payment system used at toll gates in comparison to the new proposed system
- A well developed and operational cross-platform mobile application to enable payment of toll fees as well as verification of the payments. This application will be available for both iOS and Android mobile platforms
- A functional embedded QR Code scanner that's able to capture QR code values and verify payments that have been made.

5.1 Project Gaps and Future Works

Currently, implementation of the project will be limited to the university scope and only accounts for users with smartphones with iOS and Android Operating Systems.

This project can easily be scaled to various places such as malls and hospitals, and extended to account for non-smartphone users.



Figure 5.1: The proposed system's payment will be limited to smartphones. In future, the project could be improved to support other phones

Appendices

Interview Questions: Motorist

- What are some of the challenges you have faced using Makerere's toll gates?
- Describe the process of payment for toll fee at the ticket stations.
- How many times do you use the toll gate in a day?
- How much do you typically spend on toll gates?
- Do you often find queues at the toll gates?
- If you do, how often does this happen and at what times of the day?

Interview Questions: Toll Operator

- How many vehicles use this gate?
- What challenges do you normally face when using these gates?
- Do you believe cashless payments would ease your organisation's work?

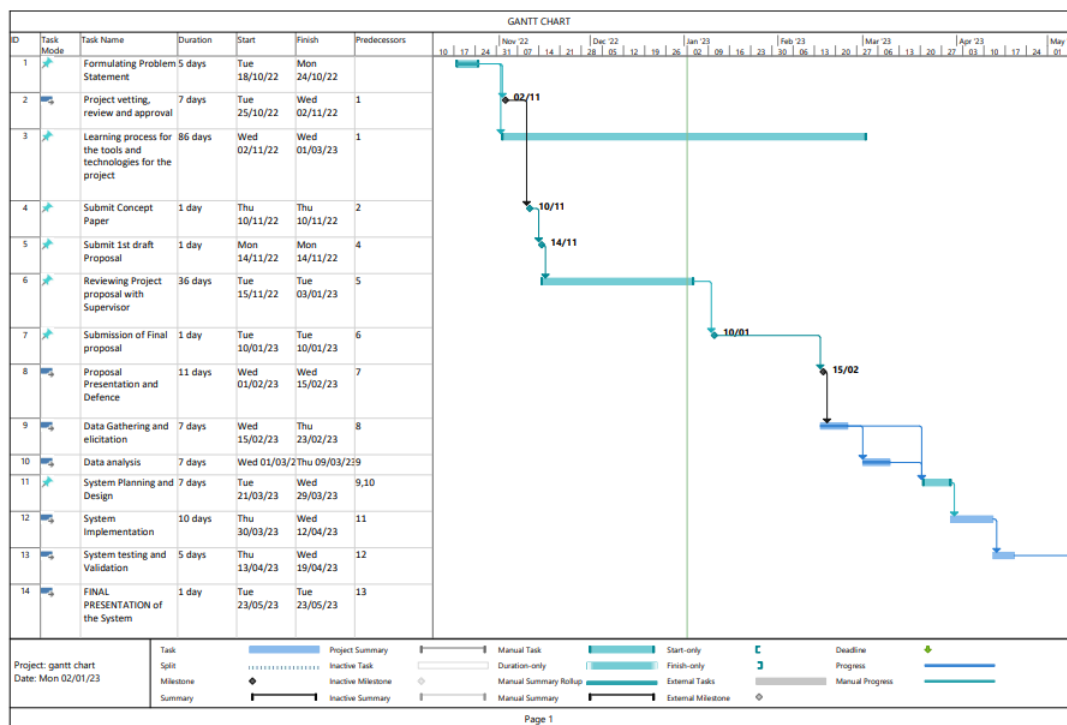


Figure 2: Gantt chart for execution of the project