INTERNET OF THINGS-BASED FRAMEWORK FOR PUBLIC TRANSPORTATION FLEET MANAGEMENT IN THE FREE STATE

by

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Declaration

I certify that the work in this dissertation, submitted at the Central University of Technology, Free State, is my own original work and that it has not been submitted at any other institution.

All the sources in this dissertation are acknowledged through citations and a list of references.

A. Shoman

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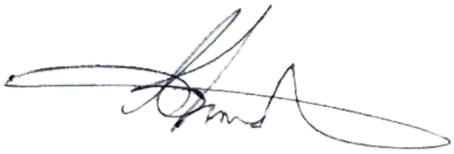
A. Shoman



Abstract

The poor service delivery by the Free State public transportation system inspired us to design a framework solution to improve the current system. This qualitative study focuses on improving the management of the public transportation fleet. One of the most recently developed technologies in Information and Communication Technology (ICT), namely the Internet of Things (IoT), was utilised to develop this framework.

Existing problems were identified through research observations, analyses of the current system, analyses of the current problem areas, as well as participants' questionnaire answers and recommendations, the participants being the passengers, drivers and vehicle owners.

The framework was developed in two phases, namely a hardware phase that makes use of ICT sensors (e.g. RFID, GPS, GPRS, IR, Zigbee, WiFi), and a software phase that uses an internet connection to communicate with the different ICT devices. The software utilised a Graphic User Interface (GUI) to ensure that the software is user-friendly and addresses possible problems and barriers such as multiple language interfaces and different ICT skills levels. The newly designed framework offers different services and solutions to meet the participants' needs, such as real-time tracking for public transport vehicles to help passengers manage their departure and arrival times, as well as for vehicle owners to monitor their own vehicles. In turn, vehicle arrival notifications will encourage passengers to be on time so that vehicles will not be delayed unnecessarily. Another feature is counting devices that can be installed inside the vehicles, which will inform vehicle owners how many passengers are being transported by a vehicle. The passenger pre-booking system will support the drivers when planning their trips/routes.

Finally, the framework was designed to fulfil all the participants' needs that were indicated in the questionnaires in order to achieve the goal of the research study.

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Acronyms and Abbreviations

3G	Third Generation (mobile communication system)
AI	Artificial Intelligence
API	Application Program Interface (API)
BPT	Business Process Testing
CCTV	Closed-Circuit Television
DoT	Department of Transport
DSL	Digital Subscriber Line
EDGE	Enhanced Data for Global Evolution
GIS	Geographic Information Systems
GNSS	Global Navigation Satellite System
GPRS	General Packet Radio Service
GPS	Global Positioning System
GSM	Global System for Mobile
ICT	Information and Communications Technology or Technologies
IoT	Internet of Things
IPv6	Internet Protocol Version 6 (IPv6)
ITS	Intelligent Transport Systems
LLN	Low Power and Lossy Networks
M2M	Machine to Machine
NFC	Near Field Communication
QTP	Quick Test Professional
RFID	Radio Frequency Identification
RPL	Routing Protocol on Low Power
SANRAL	South African National Road Agency Limited

SCADA	Supervisory Control Protocol and Data Acquisition
SCM	Supply Chain Management
SMS	Short Message Service
SOS	The System Of Systems
TCP/IP	Transmission Control Protocol/Internet Protocol)
USSD	Unstructured Supplementary Services Data
WSNs	Wireless Sensor Networks

Publication Originating from This Research

Masinde, M., Shoman A. and Mostafa M., 2018. Internet of Things-based Framework for Public Transportation Fleet Management in Non-Smart City. The 2nd EAI International Conference on Emerging Technologies for Developing Countries (AfricaTek 2018) Proceedings, held in Cotonou, Benin, May 29-30, 2018

Shoman A, Hassan, Masinde, M. and M.M., 2016, October. Internet of Things Based Framework for Public Transportation Fleet Management in Free State, South Africa. In e-Infrastructure and e-Services: 7th International Conference, AFRICOM 2015, Cotonou, Benin, December 15-16, 2015, Revised Selected Papers (Vol. 171, p. 220). Springer.

CHAPTER 1

1. Introduction

1.1 Background

Public transportation is an important area that the government must constantly pay attention to because of the large number of people in South Africa using it on a daily basis. The South African government established a Department of Transport to deal with all transport-related matters, including the public transportation environment. This Department, over a period of 10 years, carried out many surveys as part of the initiative to improve the service level of public transportation in the Country.

Research indicates that about 19% of the members of the public are willing to make use of public transportation if their service requirements are met (Ryneveld, 2008). Development in this field is ongoing in order to improve the service and to meet the requirements of the public (Ryneveld, 2008).

IoT technology is already being used to improve the quality of service in the field of public transportation in a number of cities. Cape Town uses the Transport for Cape Town (TCT) application (app) (Berg, 2014), and Johannesburg uses i-Traffic (Sanral, 2017). Uber is used as a public-transport app globally as well as in some South African cities such as Johannesburg, Pretoria, Cape Town, Durban and Port Elizabeth (Uber, 2017). All these apps use ICT sensors and apply IoT technology.

The public transportation system in the Free State Province of South Africa has many challenges that need to be addressed in order to improve the quality of the services offered (National Household, 2014). A government survey revealed that many people do not make use of public transportation because of the poor service, the number of safety concerns and the time factor (Ryneveld, 2008).

Since the Department of Transport has been putting several measures in place over the past ten years, in an effort to improve the service level of public transportation, and has already applied IoT successfully in some cities, it is clear that this may be the solution to the problems in the Free State (Avenri, 2004).

1.2 Problem statement

The public transportation system in the Free State has limited information technology (IT) resources. No services such as bookings, timetables, notifications, etc. are offered to passengers, drivers, vehicle owners or operators of other modes of public transportation (e.g. buses). Passengers have to arrive as early as possible to get transport and most of the time they still have to wait for this transport for an uncertain time frame. Currently, there are no timetables for public transportation vehicles for passengers to follow. Delays or trip cancellations due to accidents or road constructions are not conveyed to the passengers timeously to enable them to find alternative solutions. Furthermore, drivers of public transportation vehicles also experience problems, as they do not know in advance where all the stops on the routes they follow will be. They also have no way of knowing how many passengers, if any, are still waiting for transport at the station.

The owners of public transportation vehicles also experience problems, not only in terms of tracking their vehicles but also in keeping track of the number of passengers served. The drivers of public transportation vehicles still use very basic management systems, since they register the arrival of their vehicles manually in logbooks. This registered information is not readily available to the owners of the vehicles. The public transport infrastructure is very poor since services such as the internet, closed-circuit television (CCTV) cameras, arrival/departure monitors, vehicle tracking are not being utilised; neither can vehicle passenger pre-book any public transport services.

1.3 Research questions

In addressing the overall objective of this research, the following research questions were answered:

- How can the adoption of IoT lead to an affordable, efficient and effective public transportation management system in a resource-challenged environment such as the Free State?
- To what extent will the implementation of the proposed framework ensure the creation of a generic, intelligent, robust, resilient, reliable and scalable public transportation management system?

1.4 Objectives

The aim of this study was to develop a framework that will integrate the technologies within the IoT paradigm in order to provide efficient and effective management of the public transportation system in a resource-challenged environment such as the Free State Province in South Africa.

The specific objectives were to:

- Investigate the technological challenges facing the public transportation sector in the Free State and identify applicable IoT technologies;
- Develop an IoT integration framework, consisting of at least five components, to enhance the current infrastructure of the public transportation sector in the Free State; and
- Evaluate the success of the framework.

1.5 Research justification

After general observations of the Free State public transportation system, the researcher realised that a solution had to be found to improve the current public transportation management system. This research study, therefore, focused on designing a suitable and improved public transportation management framework that will integrate ICT devices and incorporate IoT technology in an effort to achieve its goal of improving the public transportation management system of the Free State. The researcher envisaged that this newly designed framework should deal sufficiently with the existing problems in order to satisfy the needs of the commuters.

The thesis then was that IoT-technology will provide all the different role players (passengers, drivers and owners) with multiple services. These services will be enhanced by the ubiquity of the system, in other words, being available anywhere, any time and through multiple devices such as mobile phones, computers and tablets.

Further, the framework will supply the necessary information in the language of choice and in a format that is applicable to the specific device that the user may be using (Android, Apple, USSD), as well as at a user-friendly technical level.

1.8 Dissertation outline

The remaining section of this dissertation is structured as follows:

Chapter 2: Literature review

This chapter reviews related literature in the realm of application of ICTs in public transportation. The review includes discussions on the different types of technology that were used, various frameworks that were designed, as well as various public transportation systems. Some of the other applications used in the public transportation field are also compared.

Chapter 3: Research methodology

This chapter focuses on the methods used in this study, namely observation, interviews and questionnaires. The general findings are also discussed here.

Chapter 4: Data Analysis and Framework design

In this chapter, the architecture of the proposed framework, which is aimed at addressing the needs of the public transportation environment in the Free State, is presented and discussed in detail.

Chapter 5: Framework Implementation and Evaluation

The focus of this chapter is the various applications that could be used in the Free State public transportation environment in order to apply the designed framework successfully. It also presents the evaluation of the framework is discussed in an effort to determine the success thereof.

Chapter 6: Framework evaluation, findings and conclusion

This chapter presents a summary of the results and the findings of the current study, and make recommendations for future implementation. The chapter ends with a conclusion on the completed research study.

CHAPTER 2

2. Literature review

2.1 Introduction

This chapter considers existing studies on public transportation systems and the management of these systems. The similarities and differences between various studies in the same field are presented.

The review of the literature includes discussions on ICT in general, the concept of ubiquitous computing, IoT, IoT sensors, and the application of IoT in the transportation sector. The review also considers geographic information systems, cloud computing and the concept of big data and framework design.

Finally, the review discusses the concept of public transport, including an analysis of some of the advantages and disadvantages of public transportation. Further, the concept of intelligent transport systems is presented and concludes with a brief exposition of the use of IoT in public transport in the Free State.

2.2 Information and communication technology

There are many challenges in our daily lives. ICT is one of the common technologies that offer a successful solution for most of these challenges and is the underlining technology used to design smart cities that involve the public transportation system in its totality (Kumar, Reddy & Singh, 2003). Any system that uses ICT within a transportation environment should aim to cover the gaps between the users' needs and the services that are provided. This can be achieved by offering some of the required services, such as trip information that includes trip time (estimated duration of the trip), real-time information to support decision-making, and more (Kumar *et al*., 2003).

Intelligent transport system (ITS) technology (discussed in Section 2.12) is used in the field of transport and offers services to satisfy many of the transport needs, such as smart parking, which shows the driver the available parking; navigation to the destination. This will, in turn, reduce passage time and hence cut costs. It will furthermore provide schedule planning to indicate the expected time of arrival and the availability of transport (Deakin, Frick & Scabardonis, 2009).

2.3 ICTs for public Transportations

This section discusses various types of ICTs applicable to public transportations.

2.3.1 Wireless sensor networks

A wireless sensor network (WSN) enables communication between multiple sensors, nodes, servers and an internet connection, either through a host or without a host (Alcaraz *et al.*, 2010).

A WSN comprises two parts, namely the cluster head, named the gateway, and the group of nodes. The gateway is the server that usually gets the data from the node sensors and transmits it to the internet. The node is the part that does the actual sensing. It consists of a battery that serves as the power supply, a radio antenna that receives the signal, a microcontroller that manages all parts, an analogue circuit that converts the reading measurement to digital readings, and a sensor that measures physical changes in the environment (see Figures 2-1 and 2-2) (NIC, 2015) (changes such as temperature and humidity). It can even detect forest fires (Badia-Melis *et al.*, 2015).

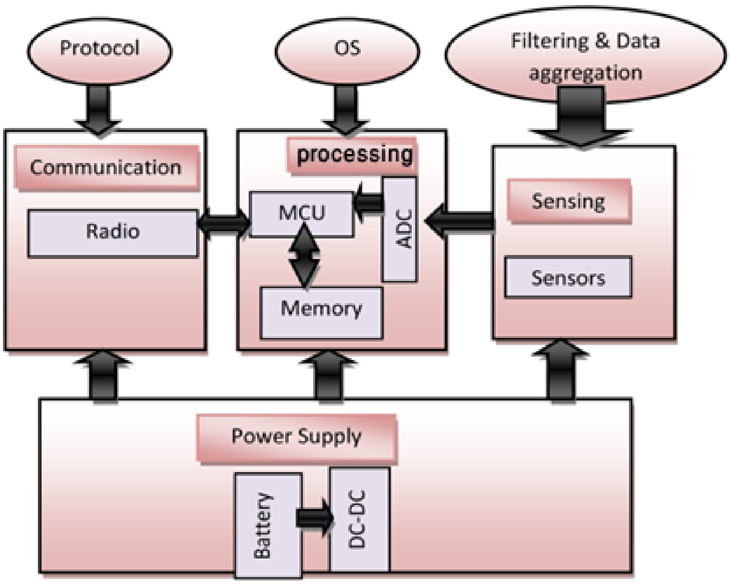

Figure 2-1 Generic node architecture (Maraiya, Kant & Gupta, 2011)

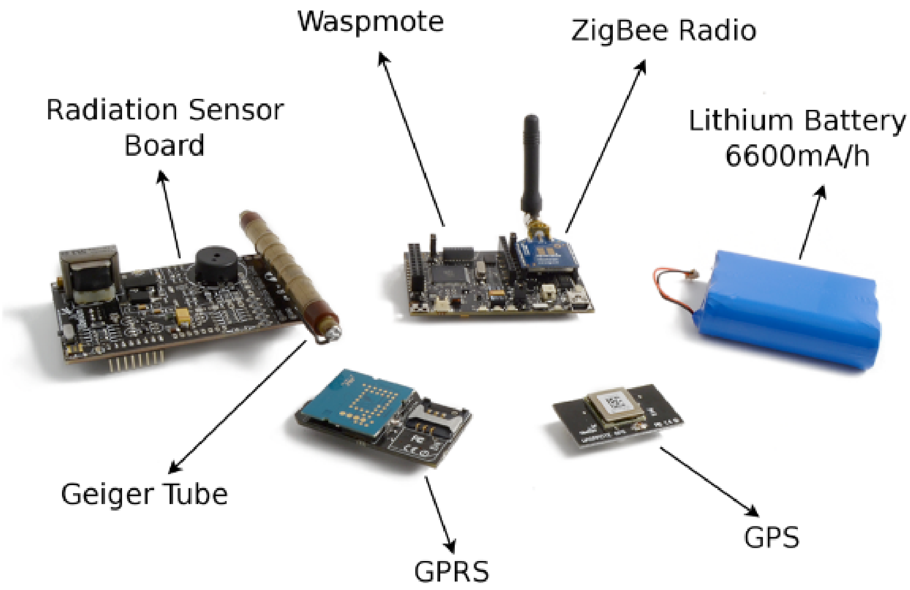

Figure 2-2: Examples of wireless sensors (Gascón & Yarza, 2011)

In WSN configurations, the network structure between the nodes and the gateway can be designed in three different topologies. The first topology is the star, which has all nodes connected to the gateway. The second topology is the tree, where all nodes are connected to the gateway through other higher-rank nodes. The final topology is the mesh, where each node can be connected to multiple nodes leading to the gateway (see Figures 2-3 and 2-4) (NIC, 2015).

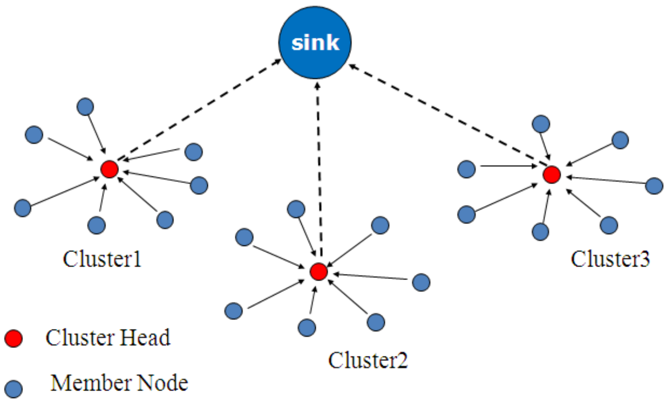

Figure 2-3: Sensors in a network (NIC, 2015)

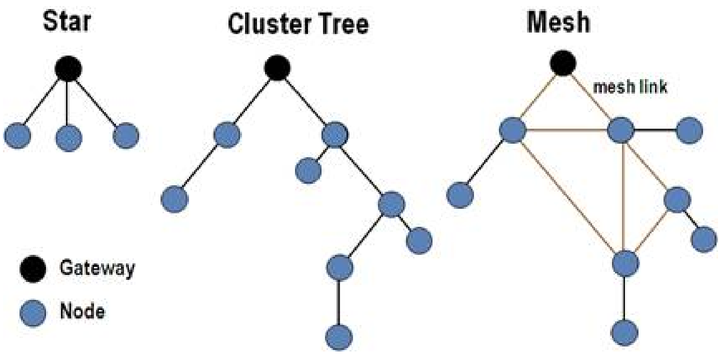

Figure 2-4: Node shapes (NIC, 2015)

2.3.2 Radio-frequency identification

Radio-frequency identification (RFID) works as either a transmitter sensor or a receiver sensor to communicate via radio frequency.

RFID is mainly used to identify objects without physical contact or visible sight. The RFID reader supplies power to the reader antenna, which sends the radio signals. These radio signals power up any RFID inlays within their reach (Behr, 2014). An RFID transmitter sends a signal to the receiver to retrieve information. The RFID receiver stores information that can be used for identification and tracking (Angell & Kietzmann, 2006) (see Figure 2-5).

There are three types of RFIDs in the market: passive, semi-passive and active. The passive RFID does not have any type of power source attached to it but pulls power from the reader and can be used to identify the attached device. The semi-passive RFID has a battery as the power source and it is mostly used to run processes on electronic chips, such as storing data. However, it still uses the power of the reader to obtain the data. The active RFID is used as an interrogator or reader and has an internal power source (battery) attached to the antenna that transmits the data to the reader (Gigli & Koo, 2011). In addition, there is a middleware layer consisting of software installed on a computer host that manages the reader and translates the data between the reader and the passive RFID (Kopetz, 2011; Mukhopadhyay, 2014; RFID Journal, 2015).

RFID is used in the field of public transportation to identify different vehicles. During rush hours, it can be used to notify passengers every time that a vehicle arrives at the station, which gives passengers an opportunity to use it as an alternative vehicle (Narayan, Assaf & Prasad, 2015).

Figure 2-5: Example of an RFID reader on the left, and an RFID tag on the right (LAZADA, 2018)

Recently, a study was conducted in India to show the use of RFID in public transportation. The RFID sensor tagged each bus stop with a unique number. At each bus stop, the RFID reader was used to read the identification number on the bus when it passes through. This information is then sent to the receiver via a Zigbee transmitter. The Zigbee receiver then sends the data through a GPRS signal to the database presented on an accessible web page (Dhende *et al.*, 2017) (see Figure 2-6).

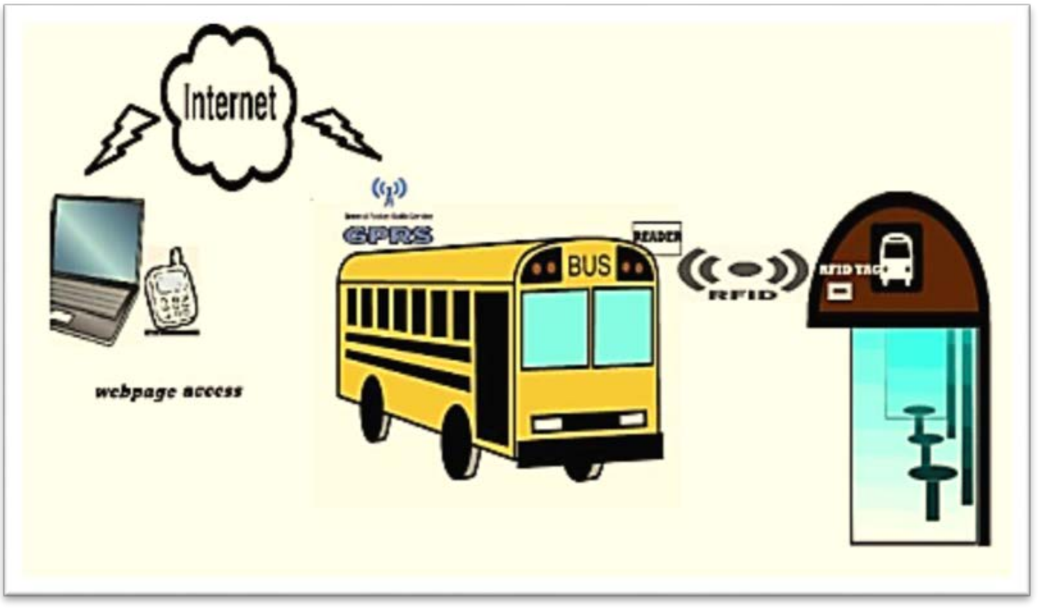

Figure 2-6: Example of RFID-sensors uses in public transportation (Dhende et al., 2017)

2.3.3 Infrared sensors

An infrared (IR) sensor is one of the sensors (besides ultrasound) used to measure distance and obstacles. IR sensors have two parts, namely a passive IR and an IR intruder. The IR intruder is the side that generates the IR signal, while the passive IR receives the IR signal. Active IR can operate by emitting light diode energy, known as LED for non-imaging active IR detector, or a laser diode for imaging IR detector. Both active IR detectors provide a count, presence, speed and occupancy data, both at night and during the daytime, while the laser diode can be used additionally for vehicle classification. Passive IR can detect presence, occupancy and count without emitting any energy to detect objects (Kon, 1998).

The IR sensor is widely used for obstacle detection, as it can detect any obstacle that moves through the distance between the two IR parts, namely the IR intruder and the passive IR (Noguchi & Seo, 2005). IR sensors can also make use of obstacle reflection, which takes place when the IR sensors use the active pole to emit the signal beam to the obstacle surface, from where it bounces back to be received by the passive pole of the IR (Rajani & Viegas, 2017) (see Figure 2-7).

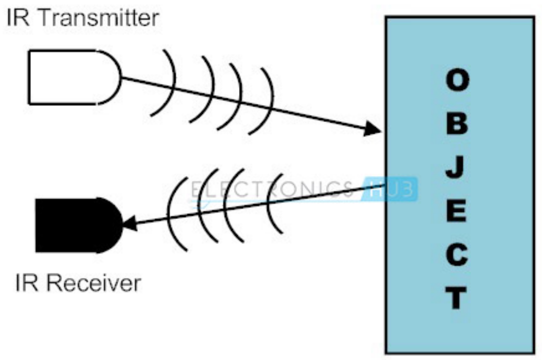

Figure 2-7: Active IR and Passive IR (Rajani & Viegas, 2017)

Infrared (IR) has been widely used in different fields for many years; IR was implemented in different functions in vehicles, for instance, in reversing sensors and night vision. IR imaging sensors could be used to notify the driver to the presence of a pedestrian in a blind spot by detecting the infrared radiation emitted from the person’s body or any object when the person/object is within the IR signal range. This method is also widely used in vehicles for a reverse function.

IR is used in thermography imaging that is used for surveillance and monitoring roads and other transports sectors as one of the best solutions on outdoor, day/night, and long-term monitoring, as it supports night vision monitoring (Dumoulin & Crini`erea, 2017) (see Figure 2-8).

Figure 2-8: Infrared Video Security Camera (CCTV Cameras Pro, 2018)

Further study shows that the output voltage reading for an ultrasonic sensor (US) provides a linear result, while the IR sensor provides a non-linear result. The study proves that results obtained by IR sensors are more accurate than results obtained by US (Chandekar *et al*., 2017).

2.3.4 Mobile phones

Our daily lives are increasingly integrated with mobile phones, as these phones offer more services than were ever available with the global system for mobile communications (GSM). Mobile phones have multiple types of signals for establishing communication, such as cellular radio signals, WiFi, near-field communication (NFC), Bluetooth and GPS. These different radio signals allow mobile phones to communicate with other devices (not necessarily limited to phones), machines (known as machine-to-machine or M2M), and low/non-power devices, such as NFC tags. Having all these communication options in one device (such as a mobile phone) enables the device to act as a hub that connects multiple things (sensors). In addition, the availability of communication with the internet makes it a perfect channel for implementing IoT (Perez, 2011).

Mobile phones are used globally and there have been significant changes regarding the applications they can be used for. This makes mobile phones the perfect mode for supporting ubiquity. For example, mobile phones can be used in a public transportation environment to obtain e-tickets by using mobile ticketing (M-Ticket) (Dekkers & Rietveld, 2007).

As an example of mobile phone uses, M-PESA was one of the developed phone apps that deal with finance in Kenya. This app was designed to work even with non-smart phones to help unbanked people or people in a rural area and far from any banking services to use services similar to the one that the bank can offer, such as loans and the transfer of funds. This service was launched by Vodafone associate in Kenya in the mid-2000s (Joseph, 2017).

2.3.5 Global Positioning System

The Global Positioning System (GPS) is considered one of the most used technologies in the public transportation environment. GPS sensors can be used in an IoT application to keep track of vehicles and people by monitoring GPS coordinates over an internet page. The real-time tracking system using GPS sensors system that Hatem created in 2010 is an example of one of the systems developed in this field (Hatem & Habib, 2010). Hatem combined it with an identification facility using RFID sensors and closed-circuit television (CCTV) technology to cover the existing limitation of the GPS sensors in the bus management system (Raut & Comput, 2013).

A GPS makes use of other sensors, such as GPRS, 3G and SMS to transfer the GPS readings for real-time monitoring. The collected data from the vehicle are typically transferred to a server in a control building. The server usually contains the Smart On-Board Unit (SBU) as its main component (Tarapiah & Atalla, 2015). The kinds of data to be collected in a public transportation system depend on the system, but are usually one of the following:

- The first is the visual vehicle, which indicates the current position of the vehicle on a map. This information gives the coordinate of the vehicle to point it on the map.
- Secondly, vehicle speed reports on the speed of the vehicle during the tracking trip by calculating the current speed of the vehicle and present it in real-time.
- Thirdly, alerting notifies the control centre if the driver exceeds the speed limit in an area, based on the zone speed-limit allowance.
- Finally, geo-fencing determines some of the geo shapes on the digital map that the driver must avoid and geo-casting notifies the control centre of an emergency, such as an accident, road congestion, or construction work.

All of the previous examples mention data collected for any public transportation system that use GPS sensors for management and control purposes should consist of the vehicle identification, longitude, latitude, speed, direction and timestamp to keep every record for the same vehicle unique and usable (Tarapiah & Atalla, 2015).

2.3.6 General Packet Radio Service

A General Packet Radio Service (GPRS) uses radio signals that work with the GSM (Global System Mobile). Its range of cellular communication is worldwide (Regis, 2002). Because of the slow speed of radio communication in general, GPRS developed the Enhanced Data for Global Environment (EDGE) service that provides a higher speed for radio media transmission (Regis, 2002).

It is important to note that GSM technology developed in two communication fields at the same time, namely sound and data. The development in sound was limited, compared to the development of data technology. The Adaptive Multi-Rate (AMR) service, which improves speech service over the phone, is one example of the development in the field of sound. The development in the transmission of data was improved by upgrading it from 2.5G to GPRS technology, which provides a packet-data air interface and an IP-based core network. After the development of EDGE, the speed became three times faster than GPRS. This technology was further improved by introducing Wideband Code Division Multiple Access (WCDMA), which provided multi-radio networks continuous with 3G speed using the Universal Mobile Telecommunication System (UMTS). The GSM EDGE Radio Access Network (GERAN) was developed to enhance network architecture access by using GSM/EDGE that provided a signal that is in full harmony with UMTS (see Figure 2-9).

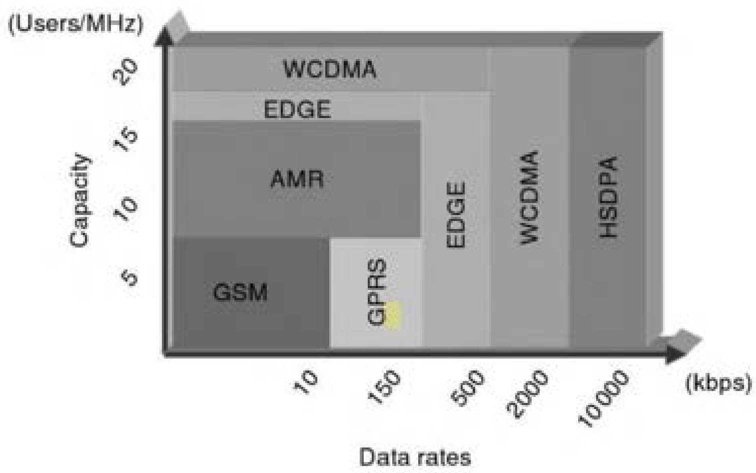

Figure 2-9: GSM evolution (Halonen, Romero & Melero, 2004)

2.3.7 Other communication tools

Communication tools such as WiFi, Bluetooth and Zigbee all use radio signal technology without any physical media connection. WiFi is like a wired network and uses the same IP protocol, but without a wired connection to the hub, switch or router. Bluetooth is another wireless connection that works perfectly between two points, peer to peer, without a hub. Bluetooth is one of the easiest ways to communicate and is a very popular technology implemented in cell phones. A study by Friesen and McLeod (2014) used Bluetooth sensors to communicate with participants' Bluetooth-enabled devices to store/read information related to the traffic situation (flow and congestion during different times), which could later be used as decision support (Friesen & McLeod, 2014). Zigbee is a similar type of wireless connection that allows data transfer, much the same as the two previous types, but at a slower speed and longer range. Some of the benefits of Zigbee include low power consumption, a very robust network, a large number of nodes that exceeds 65 000, and nodes that are easy to add to or remove from the network (see Figures 2-10 and 2-11) (Kanda, 2012).

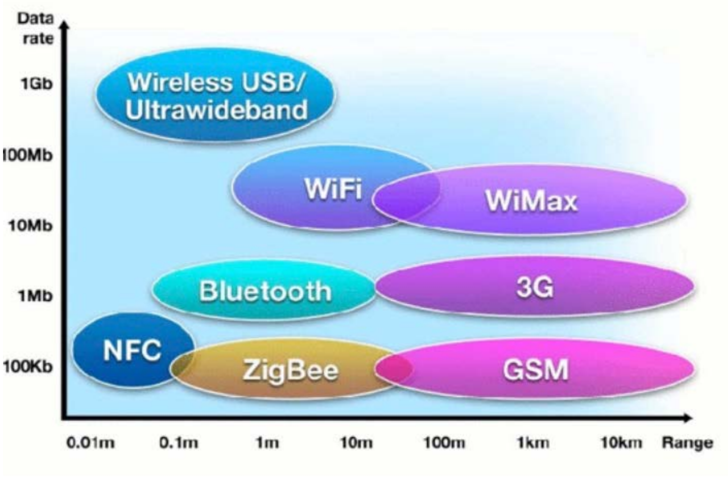

Figure 2-10: Comparisons among the different wireless devices (Arduino, 2017)

Figure 2-11: Zigbee electronic device (Lee, Su & Chen, 2007)

2.5 Ubiquitous computing

Ubiquitous computing, also called UbiComp, is the continuous interaction of processed data and communication between people, the environment and servers. This results in improved services, information and communication (Kuniavsky, 2010).

Ubiquitous computing is a modern term that was coined in the third period of computer development. In the first period, the focus was on the development of servers. During the second period, the development of personal computers was at the forefront. Recently, in the third period, the biggest development was in terms of small portable devices such as phones and tablets (Krumm, 2016).

Atzory, Iera and Morabito (2016) maintain that IoT refers to an established communication between identified things, through the internet, by means of phones, sensors, tags or applications (Atzori *et al*., 2016). As already mentioned, the ubiquitous features of IoT allow the use of technology anytime, anywhere and from any smart device (Borgia, 2014) (see Figure 2-12).

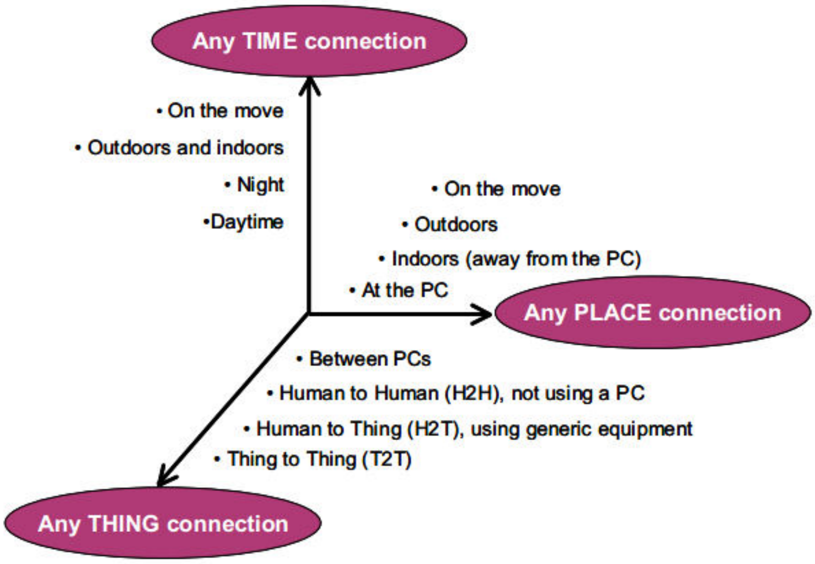

Figure 2-12: Features of the Internet of Things (IoT) (Jamoussi, 2010)

2.6 Internet of Things

Since the birth of the Internet of Things (IoT) concept at MIT in 1999 (Gama, Touseaui & Donsez, 2012), tens of other definitions have emerged – mostly depending on the application context. Conceptualization of IoT in terms of the 4As vision (anytime, any place, anyone and anything) by ITU in 2005 expanded this definition and closely tied it with ubiquitous computing (ITU, 2005). In the definition used in the Cluster of European Research projects on the Internet of Things (CERP-IoT), the ITU's 4As vision has been extended to 6As by including any path/network and any service representing any type of location or network and any available service, respectively. The IoT definition in CERP-IoT is adopted as follows (Jain *et al*., 2009):

> *"a dynamic global network infrastructure with self-capabilities based on standard and interoperable communication protocols where physical and virtual "things" have identities, physical attributes, virtual personalities and use intelligent interfaces, and are seamlessly integrated into the information network."*

Communication between the connected things usually takes place through sensors that either access the recorded data or control the data through the internet. IoT uses different types of sensors depending on the environment and needs. These include wireless sensor networks (WSN), radio-frequency identification (RFID), cameras, barcode scanners or a global positioning system (GPS) (Kopetz, 2011a). These sensors are discussed in detail in Section 2.3. Things can be connected using either wired or wireless methods. For the past few decades, a physical wired connection using copper or fibre optic cables for communication has been used. A wireless connection, on the other hand, is an established connection between objects without physical media, such as Wi-Fi, radio frequency or GPS. The communicating objects of IoT can be servers, tags or sensors.

The basic concept behind the Internet of Things (IoT) is the interlinking of physical, social and cyber worlds. The technology has had huge impacts on society and humans as well as social networks. This is due to the technology's ability to turn traditional systems into smart systems, for example, smart mobility services that provide citizens with tools to plan their journeys accurately with public transportation (Borgia, 2014).

Over the last five years, the number of IoT applications has grown exponentially. According to Cisco, IoT will reach around 25 billion connected things in 2020, which will lead to the creation of a complex system that will be known as the system of systems (SOS) (Mezghani, Exposito & Drira, 2017). IoT brings tangible benefits, primarily to physical industries such as agriculture, manufacturing, energy, transportation and healthcare, military, logistic supply chain management (SCM), disaster/crisis management, agricultural control and structural health monitoring. IoT technology is applied whenever there are sensors to access/monitor, tags to identify or communication to be established between different objects. IoT supports real-time accumulated collected data, which leads to big data and cloud computing that require massive and flexible storage space. IoT combined with big data is a powerful feature in terms of supporting any decision-making system (Bi, 2016).

Besides the benefits of IoT in connecting things, it also enables the transmission and communication of data with each other and with the server of real-time data capturing. This leads to a wide range of possible uses of IoT in the world.

Key generic requirements for IoT application include the ability to manage heterogeneity, support for dynamism, scalable, support for interoperable communication protocols, cost-effective, self-configuration (including self-organisation, self-adaptation, self-reaction to events and stimuli, self-discovering of entities and services and self-processing of big data), flexibility in dynamic management/reprogramming of devices or group of devices, quality of service (QoS), context awareness, intelligent decision-making capability, and adherence to secure environments (Borgia, 2014; Ray, 2016).

Fig. 2-13 shows the main domain areas under which these applications fall.

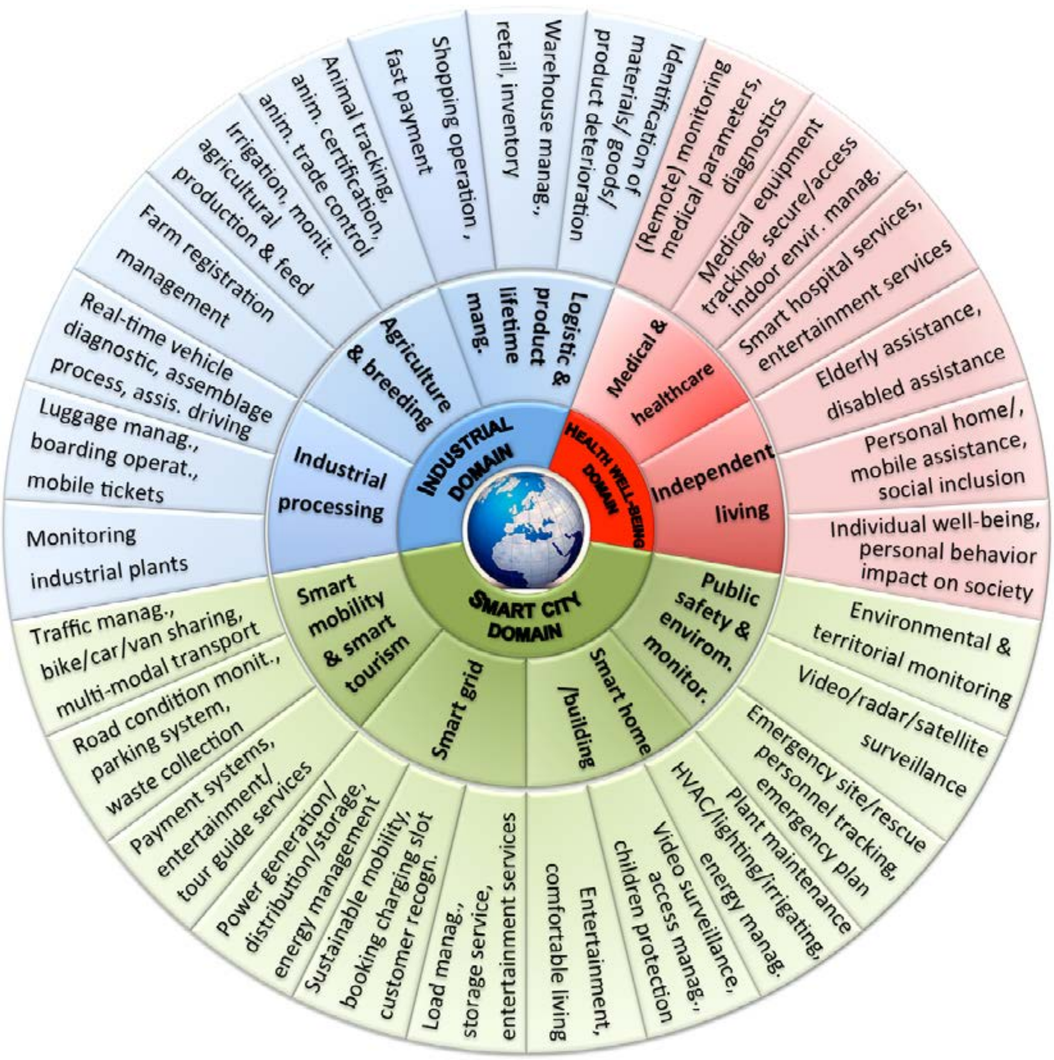

Figure 2-13: IoT application domains and related applications (Borgia, 2014)

Close to half of the application scenarios shown in the figure fall under the smart-city domain. The core challenges of this domain are urban sensing and data acquisition, computing with heterogeneous data and hybrid systems blending the physical and virtual worlds (Behrendt, 2016).

Of interest to this dissertation is the transport and mobility aspect of a smart city. Examples of applications in this realm include a system that automatically records public vehicle positioning data (Padrón *et al*., 2014), and On-Route – an information service for passengers (discussed later in Section 2.9.4) (García *et al*., 2012a). Others examples are cooperative intelligence transport systems (C-ITS) (Neisse *et al.*, 2016) and the Internet of Vehicles (IoV) (Kaiwartya *et al.*, 2016). Datta *et al.* (2016) look at the five challenges around connected vehicles, while Rakotonirainy, Orfila & Gruyer (2016) tackle a more complex solution of managing drivers' behaviour by incorporating quantified self and artificial intelligence. (Kaiwartya *et al*., 2016; Rakotonirainy *et al*., 2016)

2.6.1 Some uses of IoT sensors in real-life situations

The concept of IoT is based on using the shared information between the various engaged IoT sensors, for example, parking sensors, cameras, speed sensors and traffic robots (Silva & Malo, 2014). IoT sensors are increasingly used in real-life situations. Pollution sensors are used to measure the level of pollution in water or air and send the readings to a monitoring centre. Light sensors are now used to control streetlights. These sensors measure the level of darkness to switch lights on or off. Sensors can also be used to monitor one's home (a smart house), by allowing one to control light switches from a mobile phone, receive notifications if anything happened while one was not at home (e.g. fire or water pipe burst) or even switch on the heater, air conditioner or geyser to be ready by the time one arrives home. Sensors are generally used in the implementation of safety measures. If the owner is not at home, he or she can make sure that the electrical equipment in the house, such as the stove or oven, is switched off by checking their current state online (Meola, 2016).

A study by Darwish (2016) discusses a method where software processes are applied on ICT sensor devices, for example, image processing is applied on CCTV images to identify real-time traffic situations such as road congestion, traffic flow management, road planning and logistics (Darwish, 2016).

2.6.2 IoT applications in the transportation sector

A South African developer has designed a public transportation application to help users choose the best route between a current location and any other destination in the country. The application works on a mobile phone operating system (Android, iOS, Blackberry) and provides the user with various options, including the estimated travel time for each of the suggested routes (Okpamen, 2013).

A – The 'ubiquitous tourist'

Ubiquitous tourist information in public transportation networks is one of the IoT applications in the public transportation field (García *et al*., 2012). This application offers several services to the passenger, for example, the passenger can receive tourism information in a graphical and audio format on a mobile phone. This application uses GPS services that send information on each area that the vehicle will pass by, such as the tourism centre and the next bus stop. Passengers can also receive notifications on when they will reach their destination. These notifications can be in an audio or visual format, or even a vibration on a mobile phone, which makes it user-friendly for passengers with disabilities (e.g. deaf or blind persons). Passenger phones can be connected via Bluetooth or Wi-Fi to a small, local computing service on the bus, which eliminates the need for long-distance signals such as the internet. Moreover, the application can notify the bus driver if the door of the bus is open when the bus arrives at the next destination, and when a payment has been received (García *et al*., 2012).

B – 'On-Route'

On-Route is another example of an IoT application in public transportation that offers a variety of services. For example, the service can inform the passenger about departure and arrival times and provides information regarding the next bus stop. It can also inform passengers about the available methods for payment of the bus fare. The service could also provide the transport company with access to information on the trip, such as the number of travellers on the bus and any activity that takes place during the trip. This application mainly uses the passenger's cellular phones; however, it does not support an iOS system (García *et al*., 2012).

C – Android

Android applications are considered the best widely used systems in the public transportation field because of their portability feature and popularity. The Transit App: Metro, Bus, Bike, and Off-Journey Planner are examples of international Android applications that provides many services, such as tracking a vehicle, reporting on a delay or cancellation and scheduling (Lenk, 2015).

Transport applications are becoming widely used on smartphones. Moovit is one of the free transit-navigation phone applications that support iOS, Android and Windows in 45 countries, including South Africa (Cape Town and Gauteng), Mauritius, Lesotho and Swaziland. This application helps users to find their destination by making use of GPS to deliver real-time information about traffic using the Cloud feature, and providing information about the nearest transit, taxi and bus stop (Lenk, 2015).

D – Transport for Cape Town

The City of Cape Town launched a mobile transportation application that helps visitors to explore the city. The Transport for Cape Town (TCT) application maps out all the public transportation services, such as buses, taxis, and trains in the city and gives an estimated *en route* time to reach a specific destination in the city. The application can also provide notifications about accidents and roadworks and suggests alternative routes (Van der Berg, 2014).

E – I-Traffic

I-Traffic is a South African public transportation management system that (especially in Johannesburg) offers many services, including, incident alerts, road construction alerts, live camera feed and notifications on traffic conditions. IoT technology can be applied to I-Traffic, as it uses many of the connected sensors to the internet, such as cameras, e-tag readers, speed sensors and incident alerts. I-Traffic is currently involved in a major project in the Gauteng area. The project addresses some of the ITS services, such as congestion and incident information and traffic management. Congestion management is used to reduce the driving time to reach the destination. Incident management provides notifications regarding accidents and emergencies that may have an influence on the safety of the passengers. Traffic management is done in real-time by using closed-circuit television (CCTV) camera network and e-tag scanners. It is used in the e-toll system (Sanral, 2017).

F – Intelligent Bus System using RFID, Zigbee and GPRS

The Intelligent Bus System (IBS) offers an IoT solution to one of the most common public transportation issues in India, namely waiting time. Passengers have to wait for a long period at bus stops for a vehicle to arrive, or for vacant seats to be free. One possible solution is to make use of IoT technology, using ICT devices such as Zigbee, RFID sensors and GPRS to share information through a web page with the passengers. The webpage is accessible from any device, such as a smartphone or a computer, and provides information such as the number of passengers, expected arrival time, and when the bus passed the final stop on the route. Passengers can register their information and their specific trip through a device with a keypad and LCD available at each bus stop, and will then receive notifications via SMS or e-mail on the arrival of the bus (Dhende *et al*., 2017).

RFID tracks the bus when it stops at the various stops along the route, transmits this information to the receiver through Zigbee and then transmits it to a receiver that uses GPRS to the shared database.

Figure 2-14 shows the interaction between the ICT devices, which could also be a solution to the problems of public transportation in the Free State. The figure starts with reading RFID-tag that is embedded in each bus. The FRID-reader that is attached to each bus stop will read the RFID-Tag and then transmit it to a smart device via Zigbee. The smart device will use a GPRS network to send the data to the online server for remote access (see Figure 2-14).

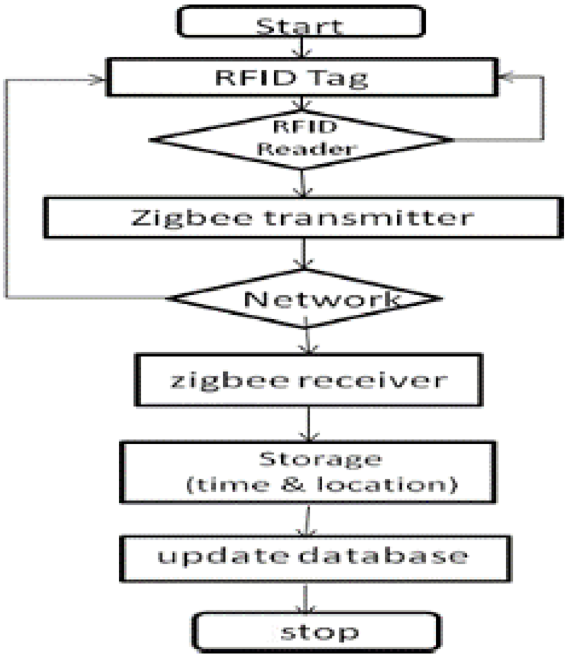

Figure 2-14: RFID Bus tracking flowchart (Dhende et al., 2017)

2.7 Geographic information systems

Bruce Elsworth Davis defines the geographic information system (GIS) as computer-based technology and methodology that collect, manage, analyse, model and present geographical data that support infrastructure (Davis, 2001). The ‘G’ (geographic) represents the real world and the landmarks on earth. The ‘I’ (information) refers to information gained from collected data that represent the actual landmarks. The ‘S’ (system) refers to the system technology behind it, including hardware (such as a computer), and software, which includes the software application.

GIS usually works on points that represent landmarks and it is assigned by two coordinates of the intersection between the horizontal (longitude) and the vertical lines (latitude) or the address system. GIS includes different types of represented data, including maps, a GPS that provides accurate data of locations, images (such as air photos), reports and tabular data, which include a list of numbers that describe economic data (El-Rabbany, 2002).

There are a few requirements to ensure effective GIS infrastructures. The most important is the organisation of the people who will use the system. Thereafter, in the following order of importance (highest to lowest):

- Firstly, the application that will be used;
- Secondly, the methodology based on the question that needs to be asked about it;
- Thirdly, the data, which sometimes include times;
- Fourthly, the computer software to be used with the GIS application; and
- Finally, the hardware, which includes all the necessary devices, such as computers, sensors and plotters (Davis, 2001).

2.8 Cloud computing and big data

Cloud data is a massive amount of data or stored information (big data) that are kept on the server and can be accessed remotely through the internet. The benefits of big data are that it assists businesses in better decision-making, and enhances the accuracy of results (Vincent, 2014). Cloud computing offers many benefits to users who want to manage a huge amount of data that require more than simply high-performance computing (HPC). It needs a number of requirements that must be addressed, such as the limitations of the accessibility, security and communication speed, before these advantages can be exploited to the full (Catlett *et al.*, 2013).

A multiple cloud system is a less-explored field of study. It has a number of challenges and shortcomings because of a lack in application processing interface (API) and accessing resources for multiple cloud services, limited engineering techniques and tools, and the incompatibility of the existing cloud system with multiple cloud systems (Catlett *et al.*, 2013).

2.9 IoT Frameworks design

Framework design refers to a systems design consisting of guidelines that should lead to achieving the desired development (Pillai, 2015). Framework design is used in many fields, especially in information technology (IT).

Researchers have proposed various object (the 'things') federation architectures to ensure that the myriad components that are part of the IoT can operate in harmony. Borgia (2014) presents this in form of three phases: data collection phase, transmission phase and process, management and utilization phase (see Figure 2-15). Similar architecture for the implementation of low-power applications is presented by Yelmarthi, Abdelgawad and Khattab (2016), while a middleware designed around an *inlining* approach is described in Mhlaba and Masinde (2015) as it will be discussed later in this chapter. A semantic-based framework that integrates machine learning is found in Zhang *et al.* (2016). Here five layers are included: physical entities, abstract entities, data stream, fusion and utility layer.

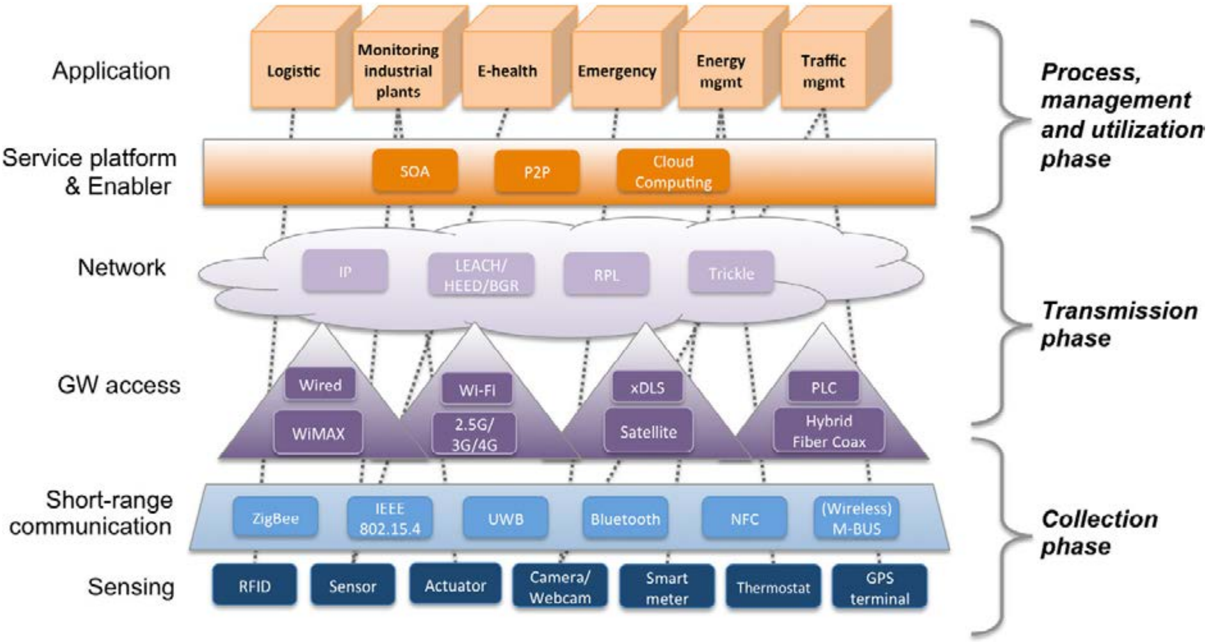

Figure 2-15: A non-exhaustive list of technologies and protocols is shown (Borgia, 2014)

In the context of this research, for example, passengers have different levels of education, speak different languages and differences in age and skill, making it challenging to design a framework that is applicable to all users. A good framework is one that passengers with different levels of skill find easy to use (Dziekan, 2008).

Before designing any transportation system framework that supports IoT technology, the following aspects must be considered:

- First, how will the passengers cope with a large number of information sources available?
- Secondly, how will the passengers respond to ubiquity?
- Thirdly, how can the interaction between the passengers, vehicles and other infrastructure be improved?
- Fourthly, do the existing systems support input data from other fields (Stockt, 2008)?
- Finally, we need to assess how to evaluate the improvement after applying the designed framework (Antoniou, Polydoropoulou & Khattak, 2015).

From a commercial perspective, the framework design must be based on system activities consisting of groups of activities and sub-activities. The sub-activities generate the output based on the user input. The activities execute the sub-activities in a unique way. The method of providing activities must be based on:

- Starting by creating a sub-activity that contains and executes business logic.
- Then, defining the activities that include graphical user interfaces, for example, a web basis that is used to execute sub-activities.
- Next, select one of the activities from the input received from the user; and
- Finally, designing an interface to receive the user input and to show the executed sub-activity output (Aaron & Underwood, 2004).

2.9.1 Ubiquitous Sensor Network

Ubiquitous Sensor Network (USN) is an application and service used in the Next Generation Network (NGN). USN is built over physical networks, which allows it to use wired sensor networks besides the WSN. This gives the USN the ability to offer service of information to anyone, any time, and anywhere.

The USN structure consists of three main layers described as follows:

- First, USN middleware, which is a software that runs on the server. This software run as a mediator between the physical part and the users' part.
- Secondly, a physical part named as a sensor network. Sensor networks layer usually consist of a group of nodes. The sensors network should not lose connectivity to other sensors network, despite the connection loss to a single node to ensure the accuracy. In order to ensure the lifetime connectivity and management, a configuration and reconfiguration have to be done regularly.
- Thirdly, the user part as known as USN application and services. USN application and service layer hides all the complications of the process and displays a user-friendly application program interface (API) in different fields like agriculture, medical care, military fields and disaster management.

- API allows monitoring and controlling access data (e.g. sensor position, battery level, network structure) through the network (Butenko *et al*., 2014) (see Figure 2-16).

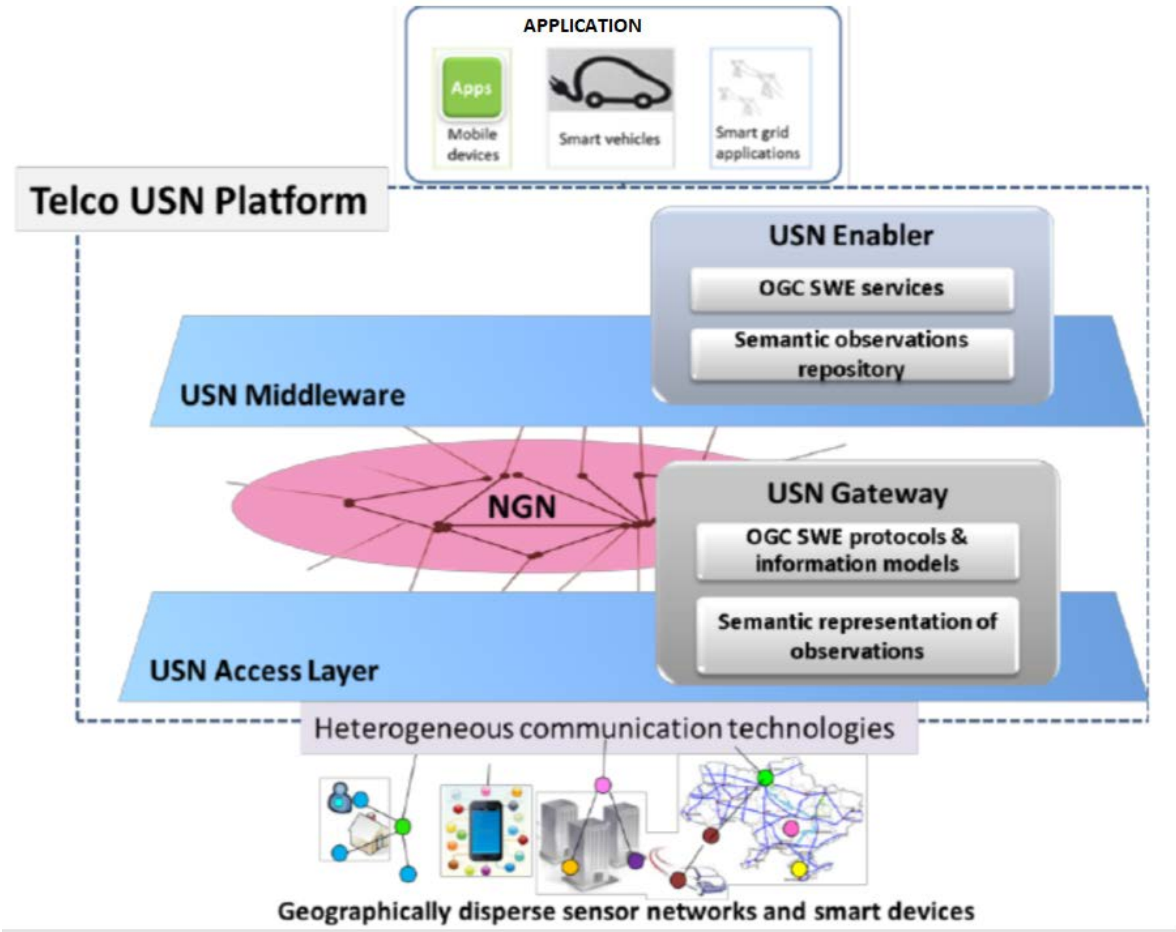

Figure 2-16 Architecture of a Ubiquitous Sensor Network (USN) that connects applications (e.g., smart devices) with sensor and networks. (Vera, et al., 2014)

2.9.2 Multiple-stream

This study deals with different factors (history, behaviours, vehicle, driver) and allows the interaction between them to achieve the study goal by predicting the accident opportunity. The multiple factors and the interaction between the different factors will be a helpful example to use in the designed framework in this study, but in this case, dealing with different factors (vehicle, driver, passenger, station, owner, route) (Jafari, 2017).

A study by Jafari focused on “traffic safety measures using multiple-stream real-time data”. This study archived a driver’s profile by measuring the behaviour of the driver 10 to 15 seconds before the action (e.g. a crash) and 10 seconds after it (Jafari, 2017).

A multiple-stream study focuses more on the methodology design using a framework than on the development of the application. A multiple-stream framework starts with the main event and then flows to different attributes. Each object in the real world is represented as an attribute in the framework. The collected data from different ICT sensors that use sharing and communication implement IoT technology. The first attribute is a snapshot of the start/end time of the action (crash), the driver’s behaviour during the event, the weather and flight status, and road information. The second attribute is time series data that register time and date. The third attribute is the driver, whose habits (e.g. sleeping), behaviours and driving history are recorded. The vehicle is the fourth attribute, and all vehicle conditions and history are registered (Jafari, 2017) (see Figures 2-17 A, B and C for the expanded diagrams).

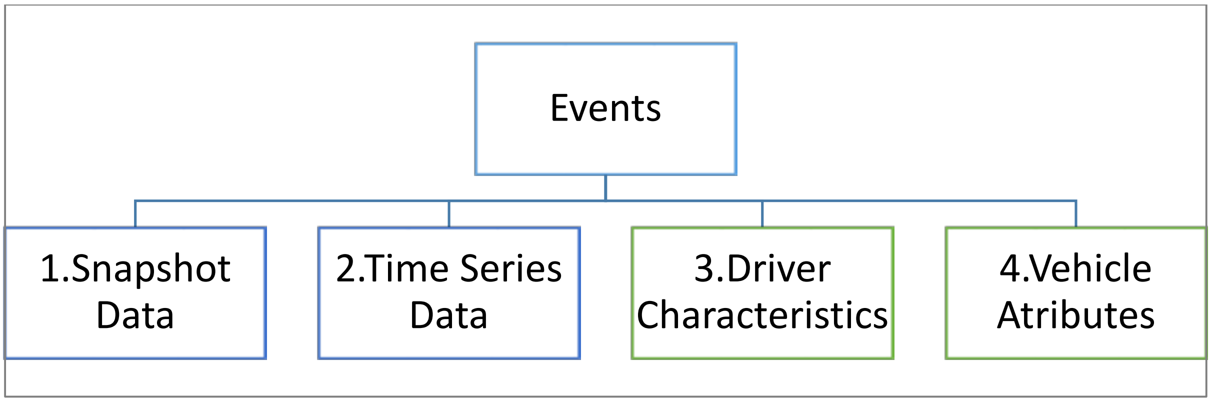

Figure 2-16: General Data Collection Summary Model (Jafari, 2017).

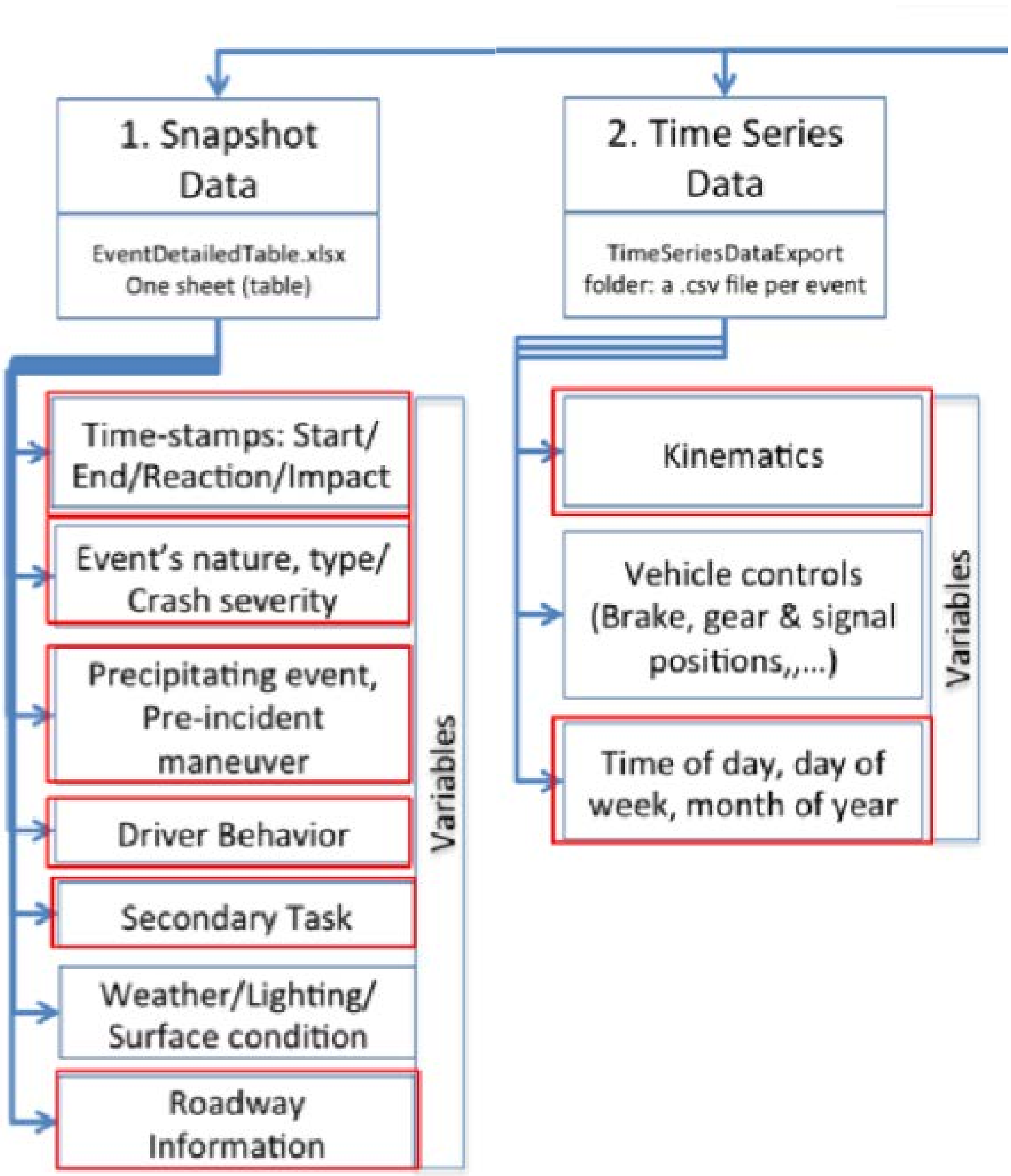

*Figure 2-17B: Expanded model **

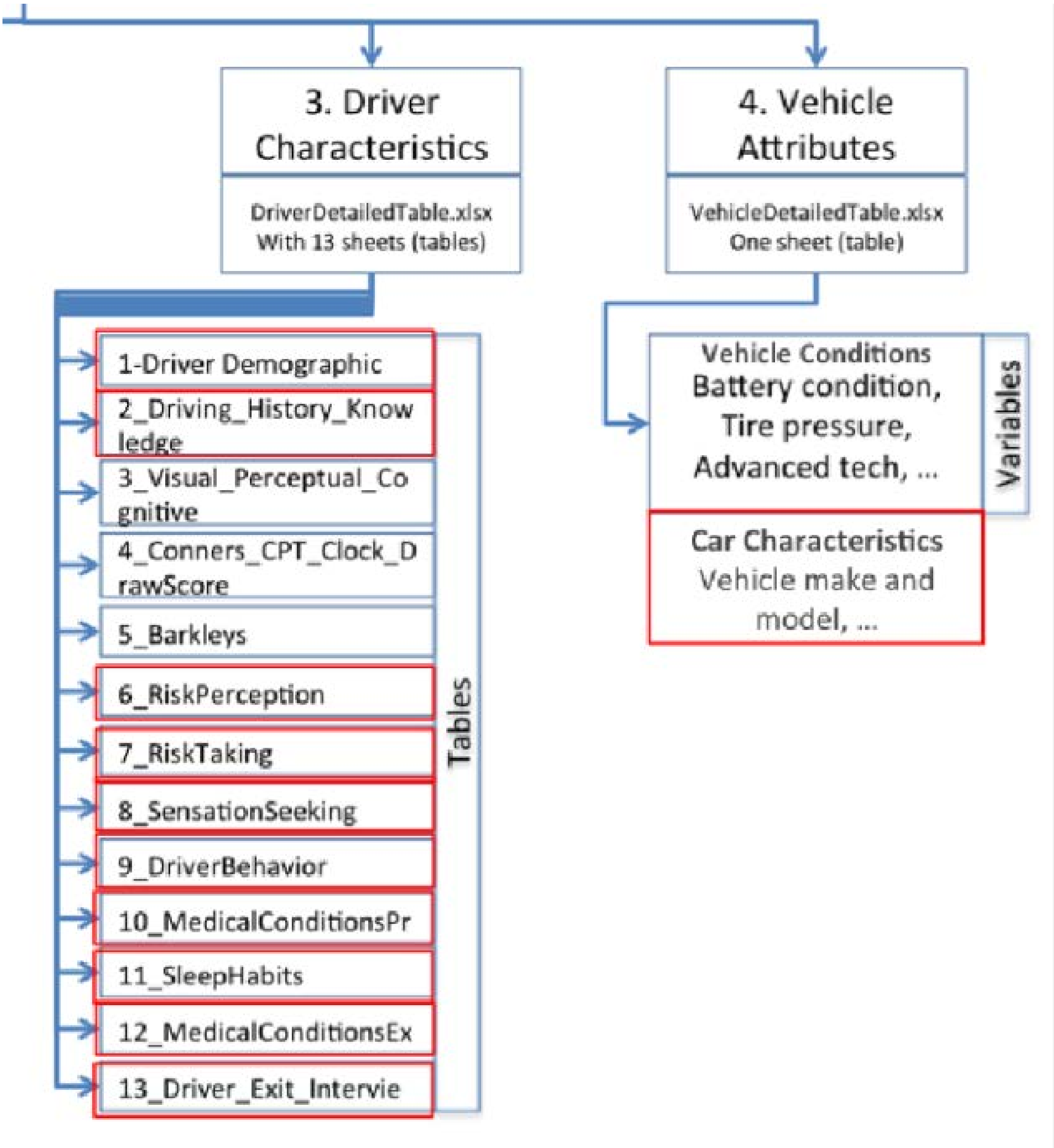

*Figure 2-17C: Fully Expanded model **

*General data collection model – red boxes are primary candidates. The first graph is the full diagram, while the following shows the individual pictures (Jafari, 2017).

2.9.3 Multilayer framework

This type of multilayer framework study helps the machine learning by collecting data from users and the cloud computing technique. A multilayer framework has several benefits, such as low-cost data collection, efficient data transfer, flexible data management and data analysis mechanisms. The interaction between the different layers (application, data storage and analysis, data process and sending, data collection) addresses these benefits (Zheng & Ordieres, 2016).

The application layer is the layer where services such as monitoring, power optimisation and activity are offered through various applications. Data on the different machines are stored on the data storage layer to provide machine learning (prediction, e.g. by making use of the stored history to predict certain user behaviour), and cloud computing. The data processing and sending layer is the layer where all the data from smart objects such as computers, phones and tablets are collected and managed through the internet. The final layer is the data collection layer. This is where smart-devices (smart-watch, smart-band, smart-glass) read the data from the user and send it via Bluetooth or RFID to the smart-objects (e.g. computers and phones) in the previous layer (Zheng & Ordieres, 2016) (see Figures 2.18 and 2.19).

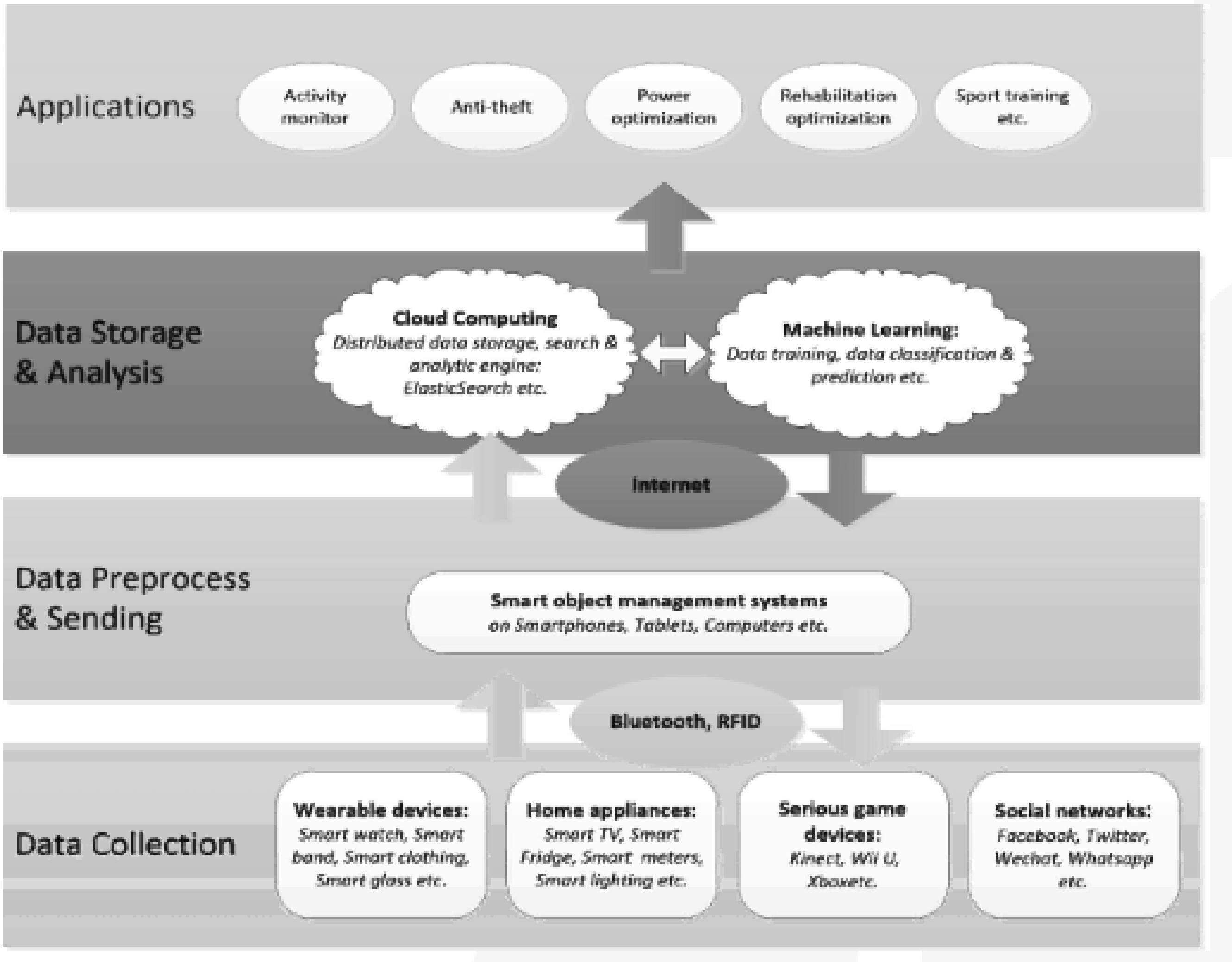

Figure 2-17: Overall framework of social applications based on the Internet of Things (Zheng & Ordieres, 2016)

An example of Multilayer Framework can be applied by firstly, using one the ICT-devices such as a smart-watch, smart-band, or smart-glasses that are wearable by users. Secondly, these ICT-devices will be used to measure and collect data from the user and send it to a smart-object like a computer or a smartphone via Bluetooth or Zigbee. Thirdly, the smart-object will receive the collected data and pre-process it, including other data like coordinate, date and time. Finally, the smart object will transmit the collected data to cloud database servers like Apache, where this data is ready for processing, query and analysis (see Figure 2-18) and (see Figure 2-19).

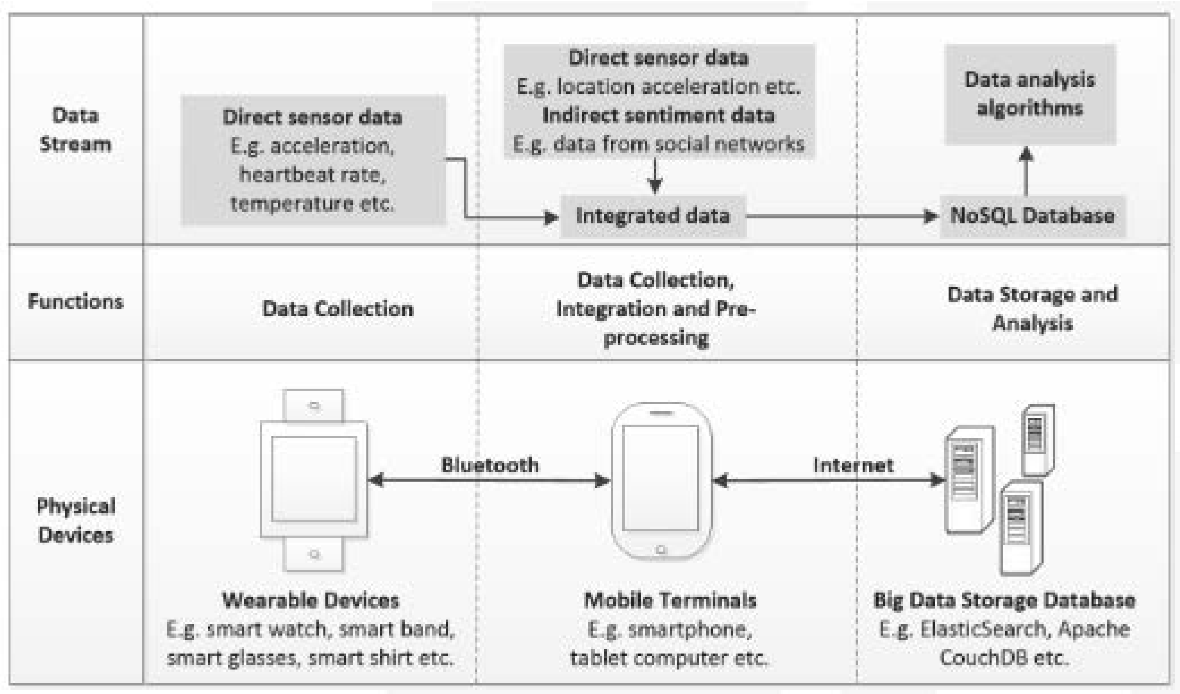

Figure 2-18: An example of the data collection and management system (Zheng & Ordieres, 2016)

2.9.4 Another framework in IoT

Several studies used cellular phones as one of the objects in the framework to apply IoT for game design (Kim, 2017). This framework has three phases, namely:

- Firstly, the initialising phase, where all sensors such as phones confirm operations and communications status to the server.
- Secondly, the data exchange phase, which occurs when a server communicates and exchanges data with its sensors successfully.
- Finally, the error handling phase, this is necessary, should any interruptions or lost communication happen in one of the previous two phases, in order to reset the connection. The interaction between those phases will be monitored and managed by a web server that collects data from the sensors on the SQL-server (see Figure 2-20) (Kim, 2017).

Figure 2-19: Game framework environment (Kim, 2017)

2.9.5 An integrated framework using traffic flow data

This study designed a framework using IoT real-time input data to the server to predict a timetable for a bus. The server analyses the different flow data factors (accident, traffic, weather, etc.) and processes it to produce a timetable for the bus (Mazloumi *et al*., 2014). This framework simulates different factors and, based on the history calculate and predict the timetable for the buses as the following: the framework stands on two main input factors. Those lead to the result of the output factor. The first main input factor is the capacity or the availability of the buses. This factor is controlled by many of the sub-factors like weather, accidents, driver behaviours and management policies. The second input factor is demand. The demand factor is also controlled by sum sub-factors like passenger demands, represented by the number of waiting passengers. The second sub-factor, the traffic flow, represents the period taken per trip (see Figure 2-21).

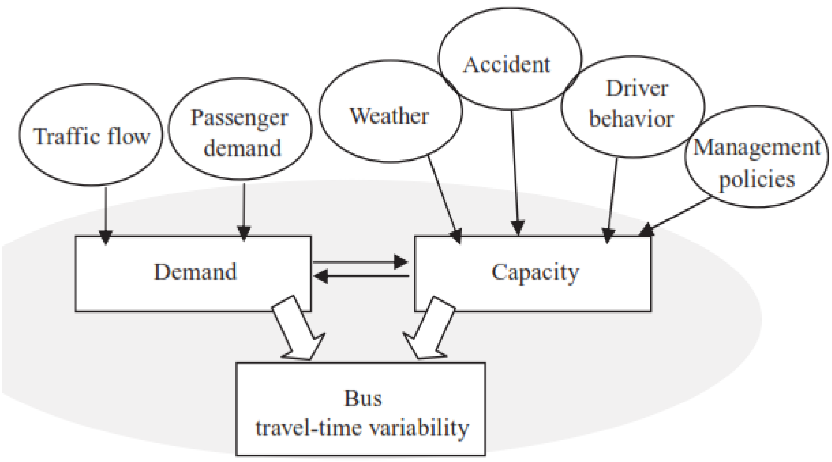

Figure 2-20: Various factors that may determine bus travel time (Mazloumi et al., 2014)

2.9.6 Implementation of Middleware for the Internet of Thing in asset Tracking application

The Implementation introduces an early warning system for missing or stolen assets. The system works by tracking them and notify the owner on their missing assets.

The implantation consists of three main layers; application layer, Middleware layer, and hardware layer. The application layer is where several services like; monitoring; and data collection, communication and recovery are proposed. Middleware; is the layer that handles both hardware interface with the database interface with all events handlers such as SMS and location services. Hardware Layer is the layer that operates all physical devices like 3G modem, Biometric scanner, RFID, and wireless sensors (A Mhlaba, 2015) (see Figure 2-22).

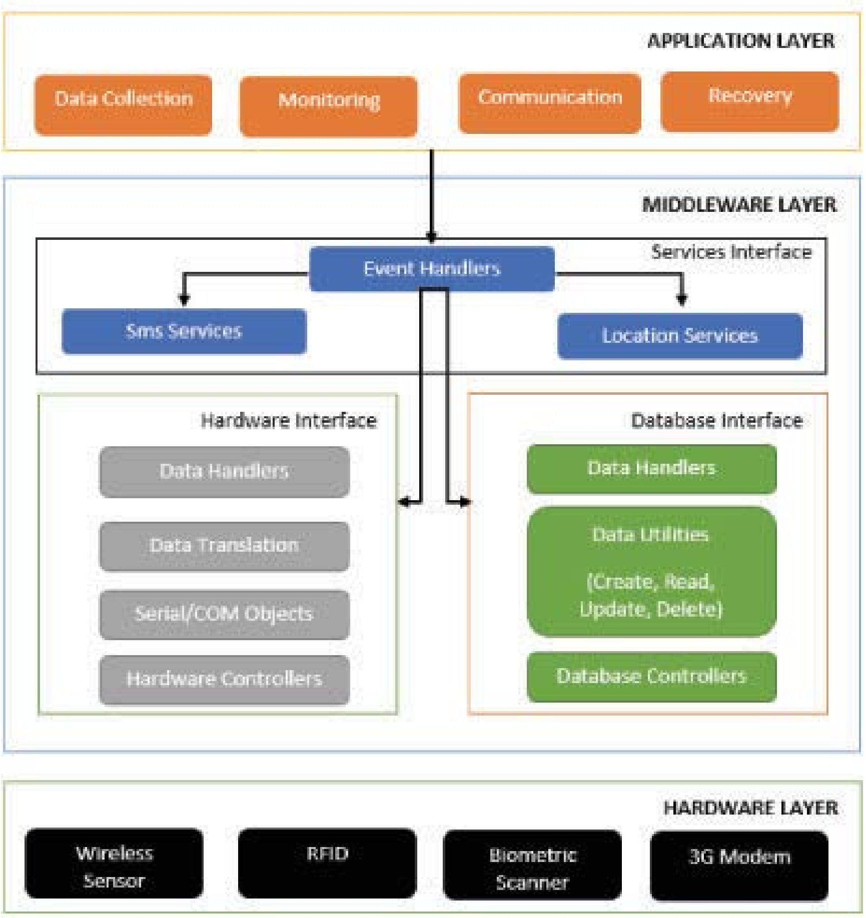

Figure 2-21: Proposed Middleware framework (A Mhlaba, 2015)

2.10 Public transportation

This section considers three public transport concepts, namely tracking, timetables, and reports and notifications.

Public transportation is one of the most affordable methods of transport to travel between places. Public transportation intersects with other fields, such as opening roads and transport infrastructure, promoting tourism and creating employment opportunities (Walker, 2012). The busier the traffic, the higher the economic power of a specific area; therefore, in addition to being an economic method of transport, transportation can be seen as an economic investment (Wortman, 2005).

Public transportation is useful for saving resources. Reduced fuel usage due to a reduced number of vehicles on the roads helps to reduce air pollution. Moreover, public transportation offers an ideal solution to reduce traffic congestion and accidents, which are serious problems. Public transportation also provides an ideal service to poor, old or disabled persons. It is also easier to manage and control public transportation vehicles than privately owned vehicles (Lester & George, 2011).

2.10.1 Tracking

It is important that a public transportation management system can determine the location of a vehicle (real-time monitoring), in other words, the physical coordinates of that vehicle at any given moment. As mentioned earlier, GPS or mobile signals are examples of ICT tools that can be used to track the current position of a vehicle, for instance, by communicating with either multiple towers or satellites (Chung, 2012).

It is also necessary to register public transportation vehicles to create a history of the vehicles' movement. Two things are required to register the movement of a specific vehicle, namely vehicle identification and vehicle location. The vehicles can be identified by RFID sensors. GPS technology can be used to record the coordinates of the vehicle at a specific moment in time. In addition to vehicle information, passenger information must also be registered and stored (Chung, 2012).

2.10.2 Timetables

Public transport usually provides different information to the passenger about the trip, such as destination, timetables, fees, availability, payment methods and notifications regarding delays or cancellations of trips, which can be very important to the passengers. Other passenger information, such as the number of passengers on the trip, and peak and off-peak times is aimed at helping a traveller to make better decisions (García *et al*., 2012).

One of the challenges of any designed framework is to be ubiquitous, which is seen as one of the features that render a framework successful. In order to apply ubiquity in such a framework, the technology needed to run the application must be well-known technology, for example, mobile phones (García *et al*., 2012).

2.10.3 Reports and notifications

Fleet management concentrates on technology that can improve vehicle and fleet planning, scheduling efficiency and the safety of the vehicles and the operation. The GIS, which includes hardware and software, is one of the most suitable methods of fleet management. It has procedures to capture, manage, manipulate, analyse and display referenced data, which all help to improve the management system. This technology includes communication mechanisms, real-time vehicle location and transit operation software (FHWA, 2012).

The Transit Management System is a computer-aided system that can do restoration and service monitoring and is an example of one of the software packages that applies GIS. Reporting can include current vehicle positions, passenger data, traffic and weather conditions, vehicle and driver performances, alarms and calls. According to the US Federal Highway Administration (FHWA) agency, the monitored information is analysed and then used to determine adherence to the schedule and route, status of vehicle components, estimated time of arrival, service requests, statistical information and emergencies. In the case of an emergency, the system will determine the best alternative solution to restore the interrupted service (FHWA, 2012).

2.10.4 Passengers of Public Transportation

When one considers the disadvantages and limitations of public transportation, it is clear that not having an accurate timetable is one of the most challenging aspects. Research proved that merely having schedules and timetables is not enough to manage or reduce delays in terms of the duration of the waiting period; however, they are valuable to operators and passengers in managing time and improving performance (Mazloumi, Rose & Currie, 2011). Timetable and real-time navigation complement each other in transportation management systems. Real-time navigation is more useful for private transportation in terms of re-routing in case of traffic congestion or an accident. Timetables and published information are more relevant to users of public transportation as they will also receive suggestions with regard to alternatives in the event of delays and cancellations (Holland, 2007).

However, there are ICT tools available to assist with time management, reduce the waiting period and assist the passenger in making better decisions on how to manage the waiting time (Avenri, 2004). Some of these tools include GPS trackers and Wi-Fi localisation, which can provide the real-time location of a specific vehicle and indicate any delays or route changes caused by traffic congestion, accidents or road construction. These kinds of devices can thus not only indicate the expected arrival time but also provide passengers with an updated timetable of the actual arrival time, allowing passengers to change plans in case of delays or cancellations (Ferris, 2011). Ubiquitous information, accessible online and by phone, can be very useful to passengers in terms of planning their trip in advance. The availability of information supports passengers' decision-making and trip planning in terms of choosing the best type of public transportation for their needs. These technological tools can form part of a framework to enhance its usefulness (Fonzone, Schmöcker & Viti, 2016).

Furthermore, a good framework is one that passengers with different levels of skill find easy to use (Dziekan, 2008). Passengers have different levels of education, speak different languages, and differ in age and skill, making it challenging to design a framework that is applicable to all users. Although a successful system has its own characteristics in order to reach its goal, there are three factors that any properly designed system must contain, namely usability, self-explanatory systems and customer satisfaction. These factors must reach a level of ease-of-use in order to render the system efficient and reaching their goal (Dziekan, 2008). Recent studies focused on data collection of performance monitoring, route and network design, frequency determination, and vehicle and crew scheduling in order to improve the service (MIT, 2015). Another study indicated that the best public transportation system is one that achieves a combination of reliability, safety, good coverage of routes, and cleanliness (Voyer, 2015). Other studies focused on the policy for an efficient public transportation system as it affects reliability and quality of service to the passengers. Cost efficiency is another factor that is necessary for the system to be used continuously (eThekwini Transport Authority, 2005).

The eThekwini Transport Authority has published a book that describes the two goals of an effective public transportation system as the following:

Public transportation must be promoted over private transport by increasing the quality of service, mobility and accessibility. The needs of the poor have to be addressed by means of a user subsidy (eThekwini Transport Authority, 2005). The second goal of efficient public transportation is regulating all public transport modes and reducing unnecessary or duplicated services, optimising the followed roles by workers, and improving the cost efficiency of the system by integrating fares and services (eThekwini Transport Authority, 2005).

2.10.5 Drivers of public transportation vehicles

Drivers of public transportation vehicles are responsible for transporting members of the public between different places. Public transport usually conveys people locally to places such as malls, shops and workplaces and is used to convey people nationally, across states or across borders.

2.10.6 Owners of public transport vehicles

Generally, the government often lays down several requirements that a person must adhere to before being allowed to own or run a public transportation business. These requirements include having the applicable licenses, provincial operating licence boards, and various permits and vehicle requirements. In addition, the Department of Transport (DOT) regulations require that a quality, safe and reliable mode of transportation be provided to transport the passenger from departure to arrival. All public transportation vehicles in South Africa have to comply with South African transportation regulations law, which includes the issuing of a contract operating licence by the provincial licence office, and a copy of the contract, as the licence is valid for one year only (DOT, 2017).

2.10.7 Goals and objectives of an effective public transportation system

According to the ETA, the first goal of efficient public transportation is to consider customer needs, including special-needs people such as disabled and elderly people. Furthermore, public transportation must be promoted over private transport by increasing the quality of service, mobility and accessibility. The needs of the poor must be addressed by means of a user subsidy. The second goal of efficient public transportation is regulating all public transport modes and reducing unnecessary or duplicated services, optimising the followed roles by workers, and improving the cost efficiency of the system by integrating fares and services (ETA, 2005).

As a sign of the weight of this field, the South African government established the Department of Transport (DOT) to deal with all transport-related matters, including the public transportation environment (DOT, 2017).

According to the DOT website, the mission of the DOT is to

> *"lead the development of integrated efficient transport systems by creating a framework of sustainable policies, regulations and implementable models to support government strategies for economic, social and international development."*

The strategic objectives that the department aims to achieve by providing policy framework, regulation and implementation models are competitive transport costs; safety and security improvements; a reduction in infrastructure backlogs; improvement in access; and reduction of time in transit (DOT, 2017).

Over the last ten years, the DOT has carried out many surveys as part of the initiative to improve the service level of public transportation in South Africa. Some of the results of these surveys indicate that about 19% of the public is willing to make use of public transportation if their service requirements are met. There is ongoing development in this field to improve the service and to meet the requirements of the public (Ryneveld, 2008).

2.10.8 Advantages of public transportation

According to the US Bureau of Labour Statistics (BLS), vehicles like buses can usually seat between 15 and 60 passengers if loaded to full capacity, and the number can exceed 100 if the vehicle has two connected sections (BLS, 2014). Obviously, if people make use of public transport, there will be fewer cars on the roads. This will help to ease the traffic congestion problem, especially apparent in cities.

These are some other advantages of using public transport:

- The fuel consumption of rail transport is up to 80 times less than that of private motor vehicles.
- A UK statistics study indicates that travelling by rail is up to nine times safer than travelling individually by car (Vexen, 2007).
- Time and money can be saved, as the service and repair of a private motor vehicle are minimised (Queensland Government, 2017).
- One does not need to look for parking if one makes use of public transportation (Vexen, 2007).

Timetables and published information are more relevant to users of public transportation as they also provide suggestions regarding alternatives in the event of delays and cancellations (Holland, 2007).

2.10.9 Disadvantages of public transportation

These are some of the disadvantages and limitations of using public transport:

- Passengers are limited to and restricted by the schedule of the public transportation system (Vexen, 2007).
- Passengers may have to wait for long periods for vehicles to arrive. Sometimes there is no information available on how long the waiting time may be, and passengers could be unsure as to how to spend their time (Avenri, 2004).
- Luggage space is usually limited to public transport. Sometimes, it is easier to move luggage in a private vehicle. At times, one may even have to arrange a courier to transport luggage items (Vexen, 2007).
- Public transportation follows fixed routes that are not necessarily close to the passengers' destinations.
- There is less privacy and security when using public transportation than when using a private vehicle.

- Seat availability on public transportation is unpredictable.
- There could be limited availability of public transport vehicles, especially during the night.
- At times, public transport vehicles are not clean.

When one considers the disadvantages and limitations of public transportation, not having an accurate timetable is one of the most challenging aspects. Research has proven that merely having schedules and timetables is not enough to manage or reduce delays in terms of the waiting periods; however, they are valuable to operators and passengers in managing time and improving performance (Mazloumi *et al*., 2011). Real-time navigation is more useful for private transportation in terms of re-routing in case of traffic congestion or an accident.

2.10.10 Advantages of ICT in public transport

There are ICT tools available to assist with time management. These tools can help to reduce the waiting times and passengers will then be able to make better use of their 'dead time' at transport stations (Avenri, 2004). Some of these tools include GPS trackers and Wi-Fi localisation, which can provide the real-time location of a specific vehicle and indicate any delays or route changes caused by traffic congestion, accidents or road construction. These kinds of devices not only indicate the expected arrival time but also provide passengers with an updated timetable of the actual arrival time. This allows passengers to change their plans in case of delays or cancellations (Ferris, 2011). Ubiquitous information, accessible online and by phone, can be very useful to passengers in planning their trip in advance. The availability of information supports passengers' decision-making and trip planning in terms of choosing the best type of public transportation for their needs. These technological tools can form part of a framework to enhance its usefulness (Fonzone *et al*., 2016).

2.11 Factors necessary for an effective system

Although any successful system has its own characteristics to reach its goal, there are three factors that any properly designed system must contain, namely usability, self-explanatory systems and customer satisfaction. These factors must reach a level of ease-of-use in order to render the system efficient and reaching their goal (Dziekan, 2008).

Studies at the Massachusetts Institute of Technology (MIT) focused on data collection of performance monitoring, route and network design, frequency determination, and vehicle and crew scheduling to improve the service (MIT, 2015). Another study indicates that the best public transportation system is one that achieves a combination of reliability, safety, good coverage of routes, and cleanliness (Voyer, 2015). Other studies focused on the policy for an efficient public transportation system as it affects the reliability and quality of service to the passengers. Cost efficiency is another factor that is necessary for the system to be used continuously (ETA, 2005).

2.12 Intelligent transport systems

Intelligent transport systems rely on the development and deployment of public transportation based on the continuous development of ICT. This technology was first applied in Germany and Italy (Kumar *et al.*, 2003). At first, ITSs used applications based on NAVSTAR GPS (Navigation Satellite Timing and Ranging Global Positioning System) to manage the public transportation system. Later, it switched to Galileo, which the European Union (EU) is currently creating the global navigation satellite system (GNSS).

An intelligent transport system (ITS) is a technology, application or platform that improves the quality of transportation. These systems refer to any transport system that uses ICT technology, represented by sensors and widely used devices such as computers and mobile phones, to improve the road traffic services (Koide, Toishi & Ikeuchi, 2017). Applicable architectures and paradigms of ICT include ubiquitous computing, IoT, wireless sensor networks, RFID, GPS, GPRS, GIS, artificial intelligence (AI) and mobile phones.

ITS combines telecommunication and electronic technologies with information to the transport system. This technology allows communication and sharing of information between different ITS stations and assists decision-makers to improve the safety and comfort of the passengers and the sustainability and efficiency of the system.

The more this technology is used, the more efficient it will become. ITS is widely used in European countries, allowing these countries to share information that, in turn, helps to enhance the quality and the purpose of this technology (Horton *et al.*, 2016).

A recent study (Rakkesh, Weerasinghe & Ranasinghe, 2016) clearly highlights the relation between ICT and intelligent transport. The study focuses on decentralised vehicles that mainly use different ICTs that allow wireless communication via vehicular ad-hoc networks (VANETs) and mobile ad-hoc networks (MANETs). It has two types of intelligent interfaces, namely vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I), with wireless communication requirements. ITS interacts with different fields in transport such as industrial fields, commercial, public, and private on all interruptions like delays and cancellations, and alternative options (Thomopoulos, Givoni & Rietveld, 2015).

Smart-Way, introduced in 2010, was one of the earlier applications in Europe to adopt ICT in public transportation (Thomopoulos *et al*., 2015). It was unique in that it not only offered real-time support but also was accessible on a smartphone. The application offered many services to the user, namely vehicle tracking in real-time, booking a trip, receiving a timetable for all the trips with full details of time of departure, time of arrival, and the final destination, as well as receiving notifications.

2.13 Public transportation in Free State

The Free State uses different resources for public transportation. These resources are divided between government and private enterprises. On the one hand, the government's public transport is represented by train railways, taxi ranks and airports. On the other hand, non-government public transport vehicles are represented by shared taxis, interstate buses and long-distance buses between the different provinces. Shared taxis, also known as minibuses, are located at a place called taxi ranks where they pay certain fees for using the place. These places are mainly owned by individuals. Interstate was founded in 1975, and they have a big fleet that contains more than 600 buses. Long-distance buses are owned by different companies like Intercape, Greyhound or Translux (Mangaung Metro, 218; Lonely Planet, 2018; Interstate, 2018).

2.14 QoS and QoE of the framework

QoS measures the quality level of the offered service. The framework offered some services to achieve this goal like notifying the driver of the next stop, as well as the number of passengers leaving the vehicle, and other notifications can be used like detour, accidents, or congestion, which can also be made available for the passengers to be notified about the delay (Singh & Singh, 2017).

QoE was represented by the satisfying level of the participants, and in this study, that was mainly the passengers. Passenger dissatisfaction could be caused by waiting for a long time without having a chance to use this time or waiting for a trip that was cancelled or delayed without their knowledge. The designed framework was designed to avoid such things in order to improve the QOE by using real-time monitoring and notifying services (Hoßfeld *et al*., 2011).

CHAPTER 3

3. Methodology

3.1 Introduction

This chapter discusses the tools and methods used to identify the limitations in the public transportation system in the Free State. Recommendations are also made on how to improve the quality of service and management at the station(s) of public transportation in the Free State. Figure 3-1 below illustrates the steps that were followed in developing the framework that that was the goal of this study (using IoT to satisfy the participants' needs). A brief discussion on each of the steps in the methodology is presented later in the chapter.

The current study used a combination of observations, interviews and questionnaires as methods of data collection. The data that was collected can be presented in different formats, namely text, pictures, audio and video, which all should lead to the same goal (Pawar, 2004).

There are two types of research studies, namely quantitative and qualitative studies. Quantitative studies are more concerned with numbers and statistics and are similar to reports. Qualitative studies deal with the population or a sample of the population. The sample of the population is a sub-group of the population who participates in the study survey. Another method of data collection, namely focus groups that deal with numbers of people who are included in the study because of their knowledge about the phenomena that are being studied, can also be used. Focus groups usually refer to qualitative studies (Nagle & Williams, 2016).

The study was both qualitative and quantitative by nature and consists of three kinds of data collection; observation, interview and survey. The observation was based on visiting the public transportation station by the author and making recommendations. Interviews were conducted with taxis committee members considered as a focus group of this study. The survey was formed as a questionnaire of sample groups, namely drivers, vehicle owners, and passenger. The first phase in the study was to identify the existing problem. Once the data was collected, it was analysed in an effort to find solutions to the problems and achieve the goal of the research study (Pawar, 2004). The study employed multiple methods that focused on a specific topic to achieve its goal. This included sources of combined tools, such as case studies, related materials, first-hand experience, interviews and observations, which define a regular problematic phenomenon (Neergaard & Ulhøi, 2007).

As mentioned above, the surveys consisted of questionnaires that were distributed to drivers, passengers and vehicle owners. The questionnaires were based on two factors, namely observation and face-to-face interviews with vehicle owners and station administrators. The questionnaires were distributed randomly among the participants at two venues, namely at the bus station where the drivers and passengers were, and at the vehicle registration office, where the owners of the vehicles were.

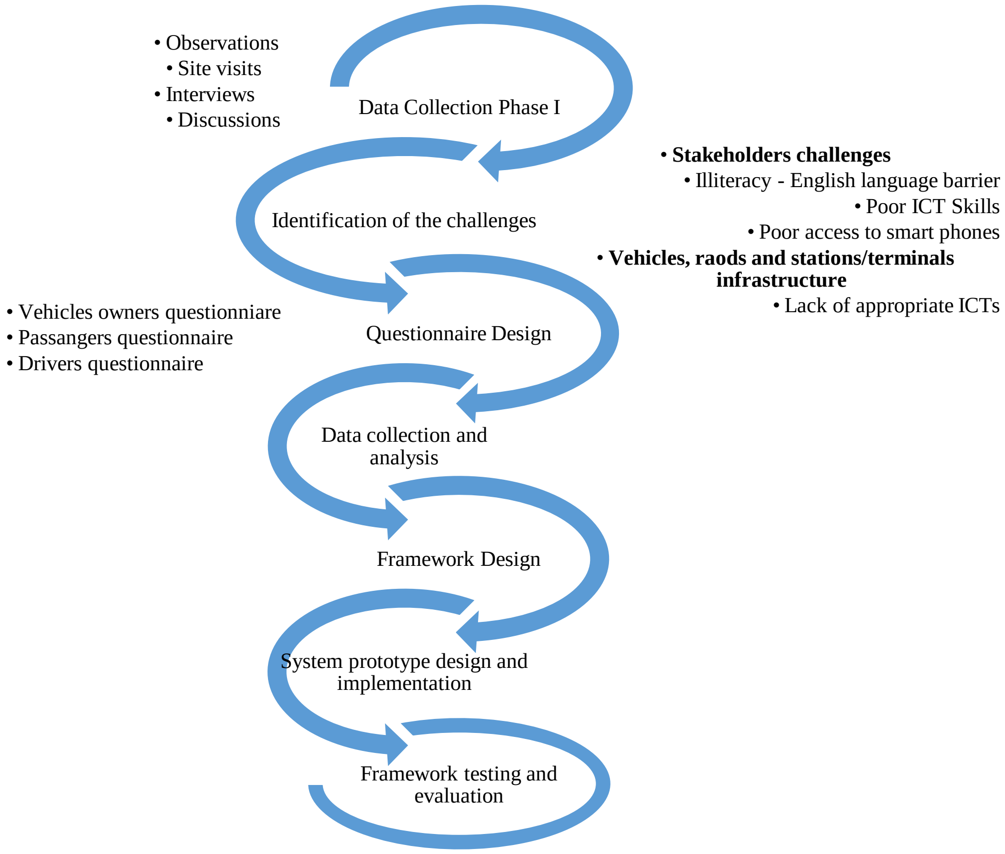

Figure 3-1: Methodology Steps

3.2 Methodology Steps

Based on the previous flowchart (Figure 3-2), a brief discussion follows.

The study was divided into the following five phases in an effort to achieve the research goal, namely observations and interviews, identifying the problems, questionnaires, analysis and the designed framework. These phases will now be discussed in detail, and analyses will be presented.

3.2.1 Phase 1 (Observation, Interviews)

During this phase, the data for the research study were collected by means of observations and interviews. The researcher aimed to gather as much information as possible about the case study in the Free State public transportation management system as a starting point for the remainder of the phases.

3.2.2 Observation

The researcher, during this phase of the research study, visited the research sites to observe and to conduct interviews. These sites included public transport stations in the Free State, namely Bloemfontein and Thaba Nchu. The researcher also commuted between these two stations by means of public transportation to experience first-hand what the public has to go through on a daily basis.

3.2.3 Interviews

The researcher interviewed members of a number of public transportation committees and noted their opinions, complaints and suggestions.

Some of the taxi owners as well as members of taxi communities were also interviewed in an effort to discover the challenges that they were facing.

3.2. 4 The outcome of observations and interviews

The following information was obtained from the researcher's observations and the interviews conducted with the participants, as mentioned earlier:

The Public Transportation System in the Free State

There are two main public transportation systems in the Free State, namely Interstate Bus Lines (IBL) and taxis (minibuses). The IBL buses travel according to a timetable (e.g. every 15 min) and the drivers are paid a fixed salary, without commission on the number of passengers. The passengers use a renewable ticket that they buy at the bus station. The ticket is valid for a fixed number of trips before it expires.

The taxis are privately owned vehicles and travel according to the number of passengers. For example, the vehicle does not follow a timetable but departs only when it has reached capacity, in other words, when the taxi is full. Taxis accommodate a small number of people, compared to IBL buses and do cash transactions only. Both systems work on fixed standard fees for all passengers, regardless of the location where the passenger boards the vehicle. In other words, passengers who travel from the starting point of the route and passengers who only travel from the halfway point pay the same price (Government of South Africa, 2017).

Drivers of public transportation vehicles in the Free State

Drivers are either vehicle owners or hired drivers. Hired drivers usually receive a commission from the fares that they make on a daily basis. The drivers who drive long distances outside the city are more controlled since they do not collect cash from passengers. Long-distance passengers have to buy tickets from the station prior to departure and only need to present the ticket to the driver. Passengers who travel short distances pay the driver in cash at the end of the journey, making it very difficult to control, as the employer has to rely on the driver's honesty and integrity (Public-Transport-Comittee, 2015). However, drivers of IBL buses receive a fixed salary without commission.

Owner of public transportation vehicles in the Free State

Most of the owners of private transportation vehicles in the Free State do not drive their own taxis, because they own multiple taxis, are busy with other work, or do not have the time and the need to do so. Therefore, the taxi owners hire drivers to fulfil the task and they share the profit. The owners have a common problem, namely managing their vehicles, as the owners do not trust the drivers with the amount of money they claim to make daily. These owners currently do not have access to tools informing them of the number of passengers that are transported, specifically the number of passengers who use the vehicle outside the station, between the starting and the destination point (Public-Transport-Comittee, 2015). However, this is not applicable to other types of vehicles, such as IBL buses, that are not privately owned. This type of transport works according to a timetable and passengers have to buy tickets beforehand in order to make use of this type of transport.

Local Authority/Government:

During the interviews with taxi owners, the researcher discovered that the public transportation authority assigns a certain number of vehicles to every route, depending on the activities that take place on the specific route. More vehicles are assigned to busier routes and vice versa. The taxi owners have to pay a fee to the government for using the route. The taxi cannot drive on different routes without special permission from the proper authority. With regard to long-distance transportation outside the city or the town, one of the permanent employees at the station registers passengers' details in case of an accident. However, records are only kept of passengers on long-distance routes, and not for shorter routes in town.

3.3. Phase 2 (Identifying problems)

When taking the above into consideration, it became clear that there are problems that need to be addressed. These problems are divided between the limitation in the Free State station infrastructure and the participants' needs. The infrastructures need many types of ICT technology to support the current management system at Free State Public transportation stations. The participants' (passenger, driver, owner) needs differ, based on the position of each. The passengers have their own needs, like the arrival time and the notification for their vehicle, by taking the difference of skills (language, education, age) into consideration. The drivers also have their own needs regarding ensuring the quality of delivered service to the passenger like being aware of the next stop to disembark in advance. The vehicle owners will have needs such as managing and monitoring their vehicles.

3.4 Phase 3 (Questionnaire)

Next, it became necessary to collect participants' opinions on various relevant aspects. This was done by means of surveys. The surveys were done in the form of questionnaires that were distributed to passengers, drivers and owners, the results of which will be discussed in more detail later in this chapter. The questionnaires focused on three topics, namely current infrastructure/ICT/ services/management, improving the service, and improving the efficiency of the system by means of suggested IoT solutions using ICT devices (see Appendices-Questionnaires).

The information obtained from the questionnaires were analysed and a statistics report was compiled in Excel (see Appendices-Statistics Report). A conclusion was compiled that addresses the existing problems and aims to achieve the goal of the research study.

The questionnaires were divided into three different categories, based on the position of the participants. The first questionnaire targeted the main sample, namely the passengers who make use of public transportation. The second questionnaire targeted the drivers of public transportation vehicles, and the third questionnaire was distributed to the owners of public transportation vehicles.

3.5 Phase 4 (Analyses)

This is the main contribution of the study, as the design of the framework was generated here. In this phase, the analysis highlighted the problems in the Free State public transportation system, leading to the design of a framework, based on IoT to solve the problems best and thus achieving the goal of the study.

3.6 Phase 5 (Designed Framework)

The framework was designed using a combination of methods from the frameworks in the literature review. In order to enable IoT technology, it was required to improve the Free State stations' infrastructure with ICT devices. Ubiquity also had to be included in the framework design in an effort to achieve the goal of the research study.

3.7 Feedback

Feedback was necessary in order to evaluate the designed framework and to compare the framework output with the goals of the research. There is always feedback from the output of any designed framework to allow updates on the designed framework, should all goals not be met. This step can be repeated until all goals are achieved.

CHAPTER 4

4. Data Analysis and Framework design

4.1 Introduction

Based on the researcher’s observations and the data gathered from the questionnaires in this study, the following diagram (Figure 4-1) presents one of the scenarios for the public transportation system in the Free State. Vehicle-to-vehicle communication (V2V) is one of the smart communication methods that connect to another (vehicle) GPS without using the server, which can be considered in further studies. A GPS sensor is one of the most widely used sensors in transportation systems, and it is commonly used in intelligent parking cloud service. IoT allows GPS sensors to communicate with other GPS sensors and servers to share data (Ashokkumar, 2015). Vehicle-to-environment (V2E) communication, by making use of IoT sensors such as RFID (Moruzzi, 2014), is one of the methods used in the current study to improve fleet management and will be explained further in the present chapter.

Figure 4-1 shows possible uses of IoT between the different interacting objects (passengers, drivers, vehicles, stations), and a possible way of improving fleet management in the public transportation system of the Free State. The methodology of the framework consists of various steps. The first step is to identify all potential difficulties, such as time wasted while waiting, management, trip schedules, security and efficiency. After analysis, the needs from outputs that are obtained from observation, questionnaire and interviews, the next step will be building a framework that offers a solution to those needs. The framework will be to incorporate IoT technology using applicable ICT devices, communication, and software (SW). Two results could be obtained from the analysis; an initial framework design that can satisfy the participant's needs, or feedback to improve the output of solving the problem (see Figure 4-1).

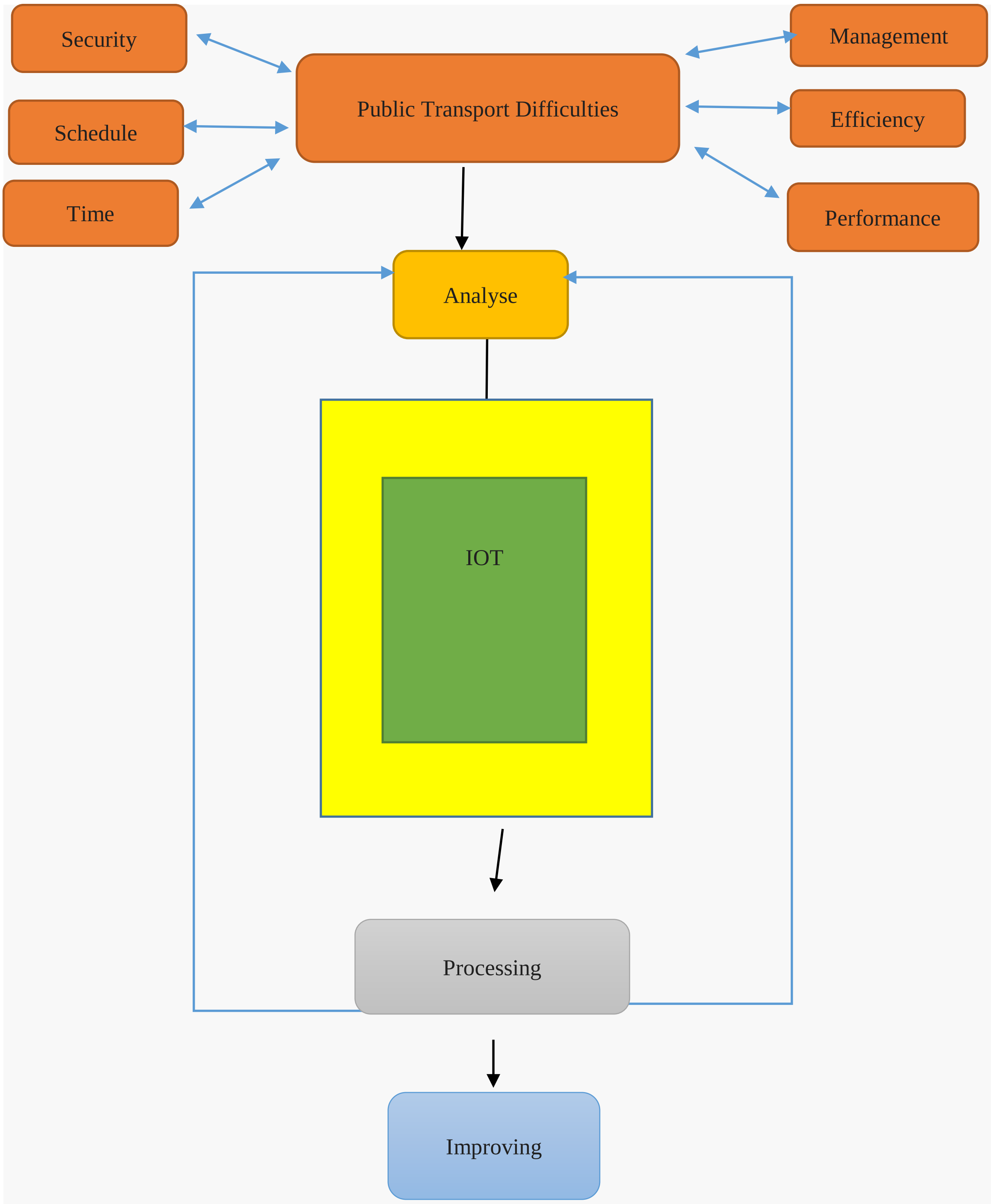

Figure 4-1: Methodology phases

4.2 Results from Data Analysis

The questionnaire was split into three different categories, namely passengers, drivers and vehicle owners. The questionnaires of each group are analysed and discussed separately. Examples of the complete questionnaires are presented in the Appendix. The results of the questionnaire analyses are discussed in the following sections.

4.2.1 The Passenger Questionnaire

The participants who completed the passenger questionnaire comprised 45% males and 55% females. The age of the participants ranged from 18–35 years. The majority of school learners younger than 18 years of age make use of taxis (minibuses) rather than other public transportation vehicles such as buses. The passengers rated the average waiting time for a vehicle as 7 out of 10, where 1 is not having to wait at all, and 10 having to wait for a long time. Approximately 55% of passengers prefer to do shopping while they wait at the public transport station, which results in 40% of them missing their awaited transport. More than a third of the passengers complained that they never disembarked where they were supposed to as most of the time the driver dropped them further down the route. This is due to the method used to notify the driver of a disembarking passenger, which is either by shouting, asking someone to notify the driver, knocking on the window or, in some cases, using a buzz button. However, most of the vehicles are not equipped with buzz buttons, and if they are, the driver is notified too late, not allowing him enough time to prepare to stop the vehicle. The remainder of the passengers, who do not experience these problems, are passengers on long-distance routes outside the city, or passengers who drive from one station to another that allows them to avoid stopping between the two main points. The study shows that more than 70% of passengers possess smartphones. One seldom finds a passenger without any kind of mobile phone. Some of the suggested technologies were discussed with the passengers and they were requested to rate the technologies on a scale between 1 and 10, where 1 is not necessary, and 10 is very important. The results were as follows (see Table 4-1):

Table 4-1: Summary of the results of the passenger questionnaire

Questions	Average Answers
Tracking and monitoring	8
Notify when the vehicle arrives	8
Register passenger	8
Replace money and ticket with biometrics	6
Indicate destination on each vehicle	7

4.2.2 The Driver Questionnaire

The majority of the drivers were between the ages of 18 and 35. The drivers are mostly hired (71%) by the vehicle owners and they work on a fixed salary basis. Because they are not the owners of the vehicle, the drivers did not want to agree to any kind of system that can monitor the number of passengers boarding the vehicle daily. The results further indicated that about a third of the drivers go home when it is late, without checking if there are any passengers waiting at the station. About half of the drivers would quickly return to the station if they knew that there was a high number of passengers waiting for a vehicle. However, the majority agreed that, except for calling someone at the station, they did not have any way of knowing if passengers are waiting. Almost half of the drivers stop and ask each passenger for his destination. The other half do not need to do this because they drive long distances towards a predetermined destination. The majority of the drivers (71%) supported the idea of having tools to notify them when they should stop next to drop passengers, comparing to almost 29% who replied that they did not really care.

Some of the suggested technologies were discussed with the drivers and they were requested to rate the technologies on a scale between 1 and 10, where 1 is not necessary and 10 is very important. The results were as follows (see Table 4-2):

Table 4-2: Summary of the results of the driver questionnaire

Questions	Average Answers
Tracking and monitoring	6
Notify passenger when the vehicle arrives	9
Register passenger	7*
Replace money and ticket with biometrics	5
Notify driver of disembarking passenger	7
Indicate destination on each vehicle	7

* Registering the passengers on each trip may cause some confusion:

Some passengers get on board the vehicle between the station stops, and others board the vehicle just before it starts moving. Both these scenarios leave no time for the registration of passengers. Some passengers, however, are not interested in registering their information.

4.2.3 The Vehicle Owners' Questionnaire

The majority of the owners were aged 45 or older, attended secondary school and possessed smartphones, which could be useful to design a tool to help them manage their vehicles. As mentioned earlier, a common problem among owners is managing their vehicles. They suspect that the drivers steal money, but they do not have any way of proving their suspicions. The main issue is to determine the number of passengers using their vehicles on a daily basis. This might explain the high rating that these participants gave to the suggested services. Some of the suggested technologies were discussed with the vehicle owners and they were requested to rate the technologies on a scale between 1 and 10, where 1 is not necessary and 10 is very important. The results were as follows (see Table 4-3):

Table 4-3 Summary of the results of the vehicle owner questionnaire

Question	Average Answers
Tracking and monitoring vehicle	9
Counting Passengers	10

4.2.4 Findings

Based on the questionnaire result, the study shows that almost all participants are familiar with English, and only a small percentage of participants, less than 10%, cannot speak English.

In general, all three categories of questionnaire participants supported the idea of using a system to do the mentioned services. However, although the owners approved the idea, they raised concerns regarding the cost involved and whether it would become compulsory (see Figure 4-2).

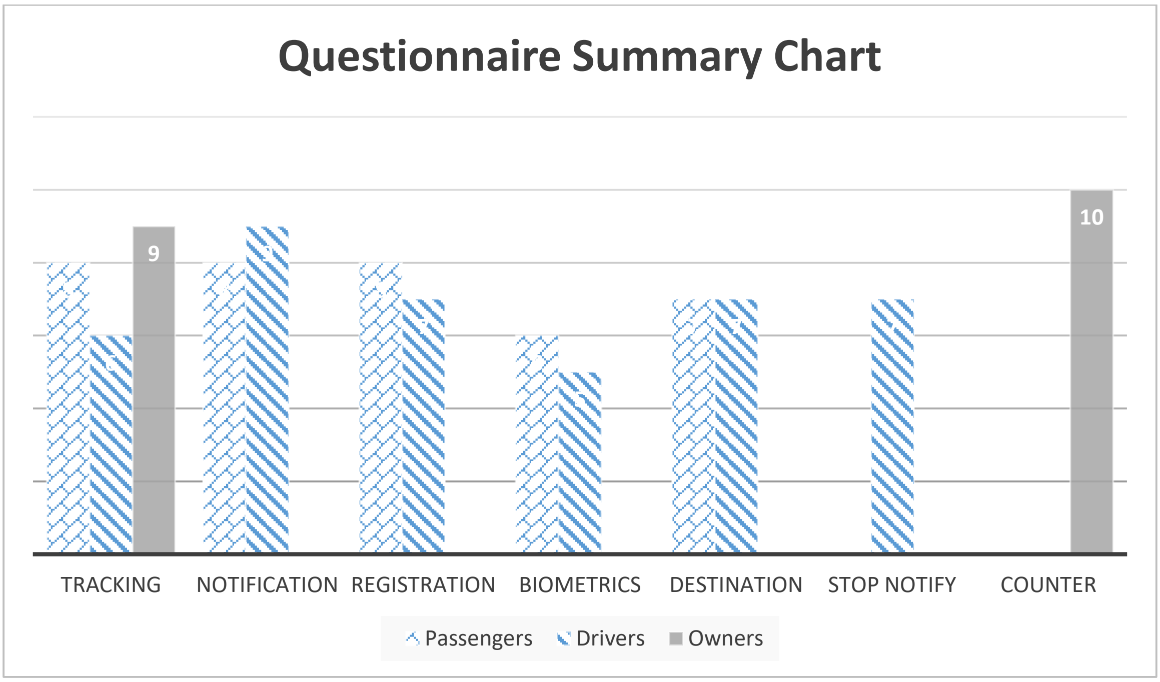

Figure 4-2: Summary of all the participants' answers

In this chapter, the used methods were discussed in detail, and the participants' questionnaire feedback was also discussed to determine their needs. Hereafter, based on these outcomes, Chapter 4 will discuss the framework design that will address participants' needs.

4.3 Framework layers

The framework developed consists of five main layers, namely the application, sensors/devices, communication, services and infrastructure layers. The layers interact with one another through different channels. In order to explain the framework, it is necessary to separate the various layers of the framework, which are presented in Figure 4-3.

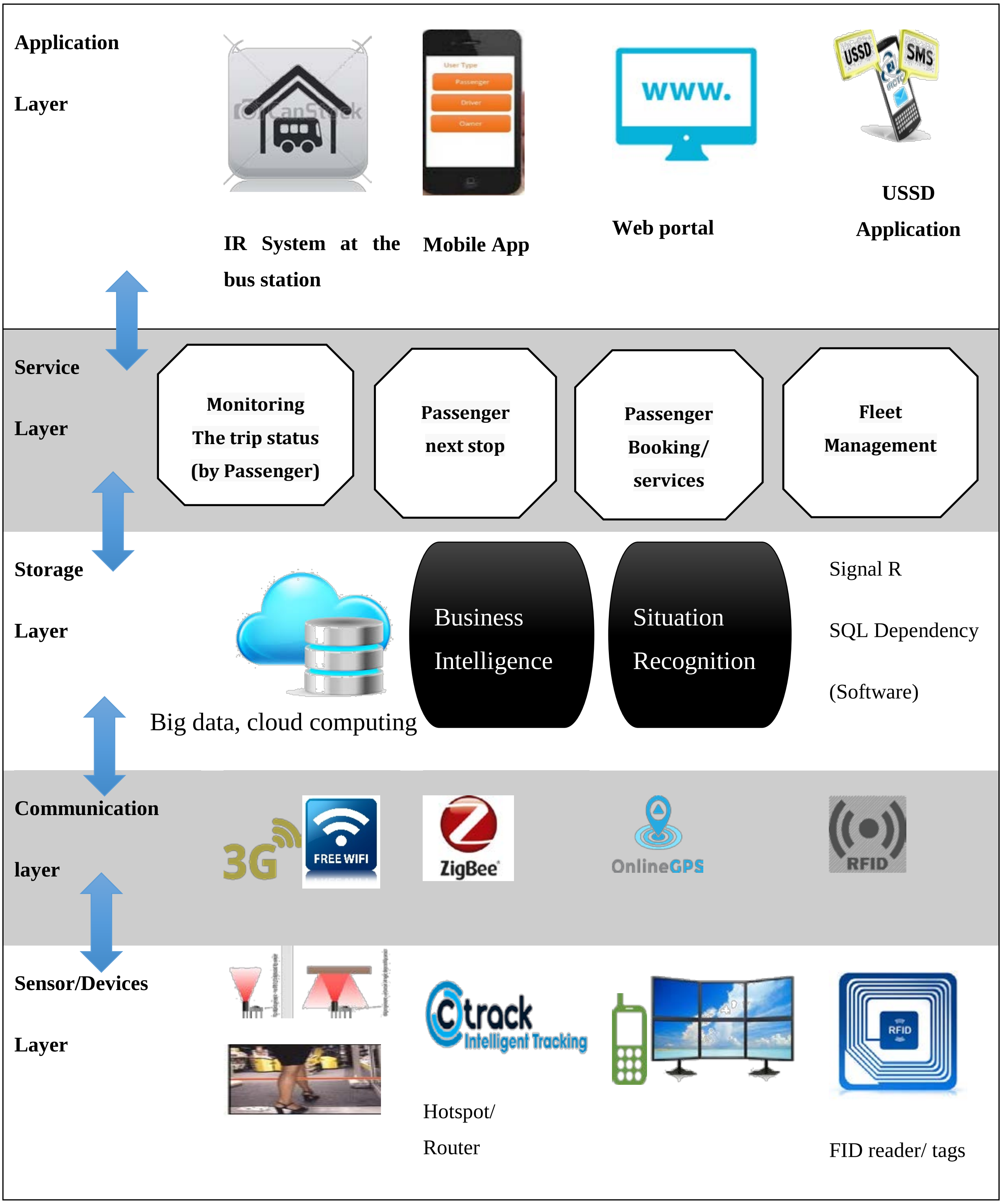

Figure 4-3: Framework layers

4.3.1 Application Layer

The top layer is the application layer; different users interact with the system through this layer. In order to achieve this, the layer supports different user interfaces that offer different services to the different users such as monitoring, visualising, analysing, reporting, notifications, guiding and managing information. It is through this layer that ubiquity (access by anyone, at any time, from anywhere and using any of the supported devices) of the framework is implemented. As currently implemented, the framework is designed to offer an Unstructured Supplementary Service Data (USSD) application for non-smartphone users and an Android mobile phone application for smartphone users. The web portal ensures the availability of the system online for all users who have access to the internet.

4.3.2 Device/Sensor Layer

The device layer is where all the IoT devices are located. This layer is responsible for generating data from the sensors and sending it to the server for processing. This layer is currently implemented to support four sensing devices: RFID, GPS, IR and GPRS.

RFID tags are supposed to be attached to each vehicle to identify the vehicle, while the RFID reader is installed at the station/terminal entrance to notify the users of the arrival of vehicles. RFID sensors are linked to a server (Gateway) that transmits its data to the online database.

Each vehicle participating in the system is fitted with a GPS sensor to enable real-time tracking. Together with the GPRS, the GPS transmits the GPS coordinates of the location of the vehicle to the online database.

An IR sensor is used for counting the number of passengers boarding or leaving the vehicle. Each vehicle uses two IR sensors; one of these is located at the gate (the point where the passenger leaves/enters the vehicle) to determine the direction of the passenger. If the outside IR is activated first, then the inside IR will indicate that the passenger is getting into the vehicle. Conversely, if it is the other way around, it will mean that the passenger is disembarking. The IR sensor is linked to a smart chip that is programmed to count the number of passengers (according to this method), and this information transmits it via GPRS to the online database.

4.3.3 Communication Layer

The next layer is the communication layer, which establishes different types of communication technology (3G, GPS, RFID, Bluetooth, Zigbee and IR-Light-Emitting Diode) between the devices, sensors, servers and users. As currently implemented, this layer uses three different types of communication signals. The RFID reader at the gate of the bus station uses a computer that is connected to the internet via Local Area Network (LAN), Wi-Fi or a 3G modem. Both GPS and IR sensors on the vehicles will use GPRS communication. Users at the station access the station's Wi-Fi. Users outside the station use the 3G connection on their smartphones or the general cellular connection for the USSD application in the case of non-smart phones.

4.3.4 Service Layer

The other layer is the service layer. Here, several communication services are offered to first layer objects (passengers, owners, drivers, vehicles, stations). Station administration/ vehicle owners are provided with fleet management service, and vehicles are equipped with real-time tracking equipment so that the station can be notified when a vehicle arrives or leaves. Vehicle owners will be able to receive a real-time location for their vehicles and keep records of a number of passengers used their vehicle. The passenger can make a booking for the next trip and he/she will be notified of the arrival of the vehicle.

The driver application offers services such as an update on the current number of passengers who have registered for a specific trip and advance notification of the next location where passengers will be disembarking.

4.3.5 Storage Layer

The storage layer is the layer where database engines, such as the Oracle engine or Microsoft SQL, manage and control the database. The database engine is responsible for the following: storing, querying, managing and clouding big data. This layer will be discussed further in the next section. Future extension to the framework will include the ability to support big data, cloud computing, situation recognition and business intelligence (BI) analytics.

4.3.6 Infrastructure Layer

The infrastructure layer is where database engines, such as the Oracle engine or Microsoft SQL manage and control the database. The database engine is responsible for the following: storing, querying, managing and clouding big data. This layer will be discussed further in the next section

4.4 Framework Design

4.4.1 ERD-Diagram

The ERD-diagram will show all the related fields and tables in the infrastructure layer. Some of those relations are one-to-many and others are many-to-many, such as the following:

The relationship between the vehicles and the drivers is many-to-many, as a vehicle can be allocated to more than one driver, and a driver can be allocated to more than one vehicle. However, there is a one-to-one relationship in the case of Interstate bus drivers and their buses. The relationship between the different stops and the passengers are many-to-many, as one passenger can book different destination stops in several time frames. The same stop can, however, also be booked by many passengers.

The relationship between owners and their vehicles are one-to-many, as an owner can own many vehicles. Although a person can own more than one vehicle, owners do not share vehicles. In other words, a vehicle can have only one owner. The relation between the routes that contain multiple stops is a one-to-many relation (see Figure 4-4).

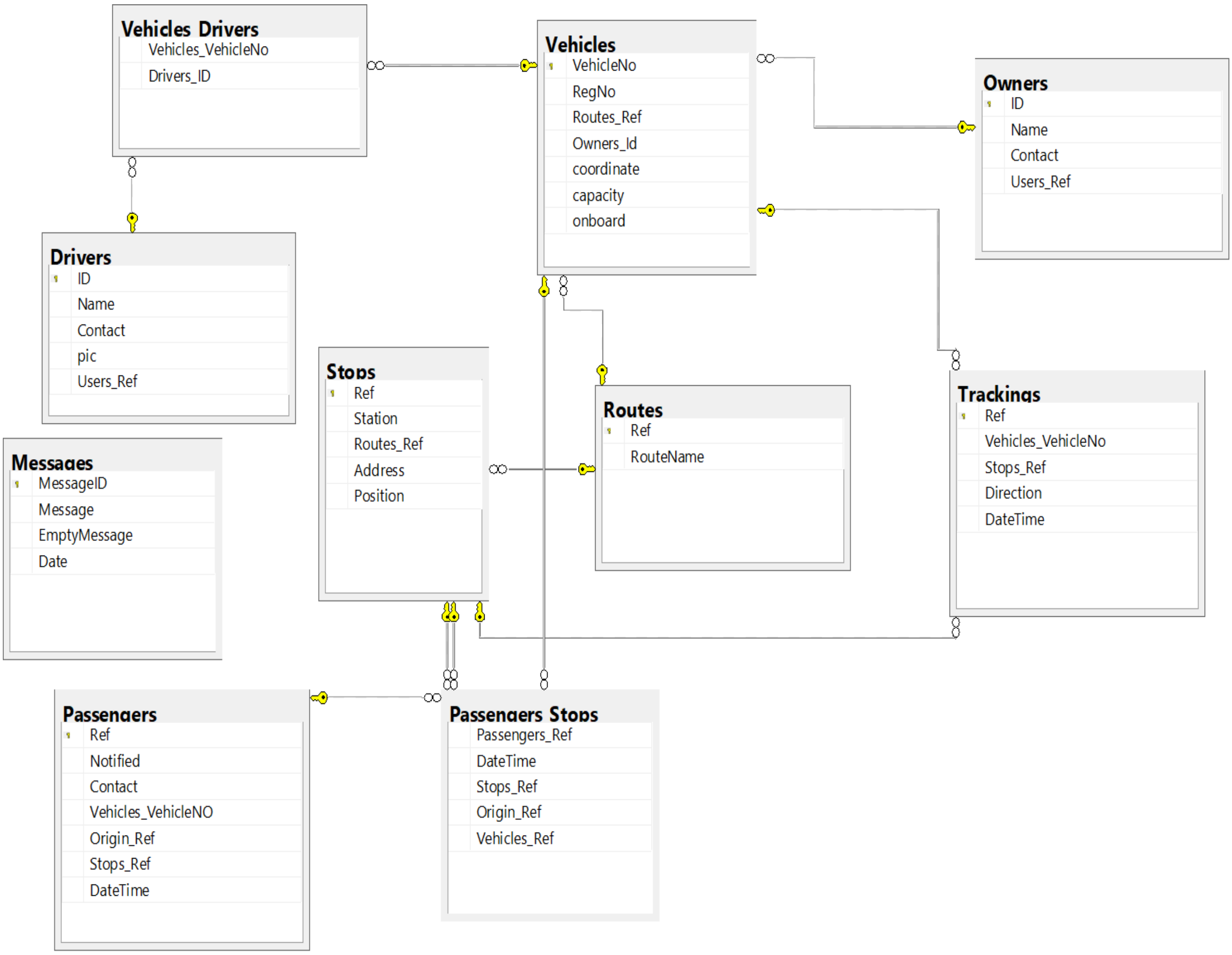

Figure 4-4: Framework's ERD-diagram

The tables in Figure 4-4 and in Appendix (D: Database) – Tables 1 to 12 – are explained as follows:

- **The Driver Table** presents all information on the driver, such as his ID number, name, contact number and a picture of the driver. This table is also used to store and manage the driver's details. The field "Users_Ref" is used as foreign_key, to join this table with the user table in order to allow the users to log in as drivers.
- **The Owners Table** is used to store and manage all the information that belongs to the owner. This table has the field "Users_Ref" that is used as foreign_key, to join this table with the user table in order to allow the user to access a certain page on login as the vehicle owner.

* **The Passenger Table** is where the passenger's information is stored and managed. In this table, certain fields are used to set up the trip, the bus station (origin) "Origin_Ref" and the stop "Stops_Ref", using a foreign key that connects this table to the trip and stops tables. This table does not have the foreign_key "Users_Ref", because passengers are not going to log in as existing users, but as anonymous.
* **The Route Table** stores the trips of each vehicle; the route names for each vehicle are indicated as well.
* **The Stops Table** is used to store all the possible stops on each route by grouping all the stops with their routes in the route table using the foreign_key "Routes_Ref".
* **The Tracking Table** stores the data from the GPS sensors in every vehicle. It will allow a different user to see real-time coordinates for each vehicle. Each coordinate will be linked to the vehicle's table via foreign_key "Vehicles_Vehicle No", and coordinates will be distinguished by vehicle number and the date and time.
* **The Users Table** is where all the credentials of the users are stored. It allows a different user to access certain pages, depending on its policy type, by linking each user type to the role (Driver, Owner, Admin) in the role table via the foreign_key "Role_Ref".
* **The Role Table** is where all different types of user roles are stored (Driver, Owner, Admin). The role will decide which page the user can access.
* **The Vehicle Table** is where all the information of the vehicles are stored or managed, such as the registration number or the owner using foreign_key "Owner's_ID" that links it to the owner table, and routes that are linked to the route table via foreign_key "Routes_Ref". This table will show the maximum load of passengers using "capacity", and it shows the current number of passenger on board using the field "on board".
* **The Passengers_Stops Table** shows many-to-many tables between the passenger table, Station "origin_ref", attended vehicle "vehicle_ref", and stops via "stops_ref".
* **Intermediate Tables** are tables generated to support many-to-many relationships between tables. The table's name will describe the relation between the tables by combining both tables names separated with "_" as a new name for the generated table. Those tables are "Vehicles_Drivers" between vehicles and drivers' tables; and "Vehicles_Stations", between vehicles and station tables.

4.4.2 Sequence Diagram

The factors, namely the vehicles, drivers, owners and stations will interact with one another through the database. This interaction is presented in Figure 4-4.

The passenger will interact with the database by making a booking for a specific destination. The database will interact with the different vehicles serving the specific route and destination. When the vehicle arrives at or leaves the station, it will interact with the database, which in turn will notify the station and the passengers. While the vehicle is following its route, the database will interact with the driver by notifying him of the location of the next stop and of how many passengers are leaving the vehicle at the specific stop (see Figure 4-5).

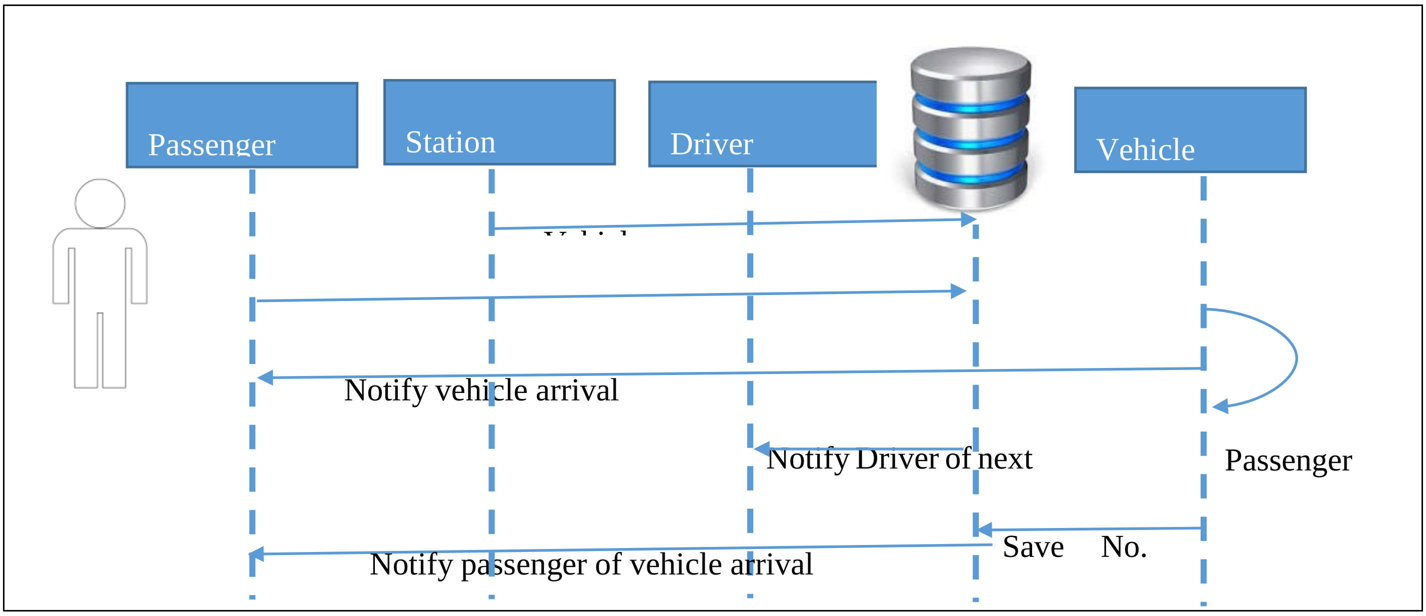

Figure 4-5: Sequence diagram

4.4.3 Use Cases

The use cases show the different types of users that can use the framework. The users can be passengers, which are the main users in the framework, who can make a booking and receive a notification on the time of arrival of the vehicle. The driver will be notified of the location of the next stop, as well as the number of passengers who are leaving the vehicle at that specific stop. Vehicle owners can manage their vehicles, as they will receive reports of the number of trips each vehicle has completed, as well as the number of passengers who have used the service. Administration users will have more access in terms of managing all of the vehicles, routes, owners, and drivers by adding/editing/deleting different categories. Finally, the stakeholder will have the ability to generate different reports and statistics that can help decision-makers to support their decisions. A detailed explanation is presented in Figure 4-6.

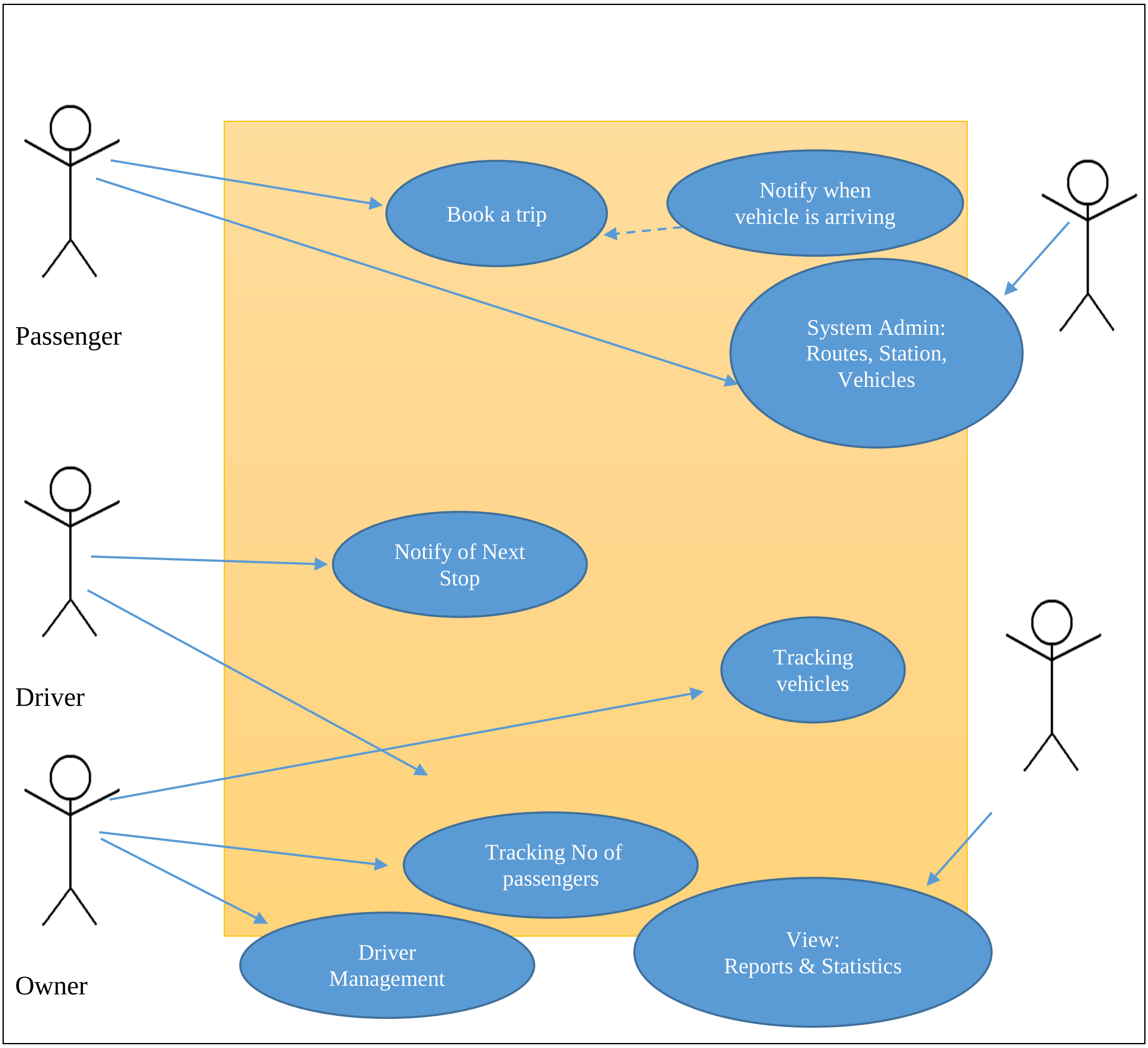

Figure 4-6 Use cases diagram

4.4.3.1 Example of a Framework Scenario

The following is a possible scenario to indicate how the framework is applied. A potential passenger reaches one of the stations of public transportation in the Free State. The passenger will be able to see the real-time location of the different public transportation vehicles on a public screen. The vehicle position will be synchronised with a GPS sensor and transmitted through a GPRS signal to the published database. The first thing that the passenger should do is to register for a certain trip, which can be done in any one of three ways. Firstly, users with a smartphone can download the Android app whereafter they must scan the QR-code and select the destination from the drop-down list. Secondly, users with non-smart phones can register by using the Unstructured Supplementary Services Data (USSD) service (Rouse, 2017b), whereafter they will have to choose the trip they want to go on as well as the place of disembarkation. Thirdly, passengers without mobile phones can register for a trip by making use of the reception computer or by asking the receptionist for assistance (especially for non-literate passengers).

When the passenger has registered successfully for a trip by using one of the above-mentioned registration methods, the drivers of the specific route will be notified through the smart application on their mobile devices. When a vehicle arrives at the station, the RFID tag on the vehicle will be detected by the RFID reader at the station. RFID class 1 can be used for the tag in the vehicle, and RFID class 3 empowers the sensor, while class 4 empowers the RFID communication and it can be used by the station gate (Atzori, 2017). RFID next will transmit the information to Zigbee receiver via a Zigbee transmitter. The Zigbee receiver will send the data to the server through Wi-Fi. The passengers registered for the same vehicle trip will receive notifications on their cell phones, either through the application for smartphones or through Short Message Service (SMS) (Rouse, 2017a). An announcement will also be made at the station for passengers without mobile phones. Every passenger boarding the vehicle will be counted by the two IR sensors at the vehicle gate. The IR will transmit the data through a GPRS signal to the server. This information will be reported to the vehicle owner’s phone. When the passengers board the vehicle, the driver can allocate them to his vehicle by scanning their QR-generated ticket on their phones, typing the generated number from non-smart-phone users, or from a printed ticket from reception. By allocating the passenger to this vehicle, the driver enables the system to notify him of the next passenger’s stop (see Figure 4-7).

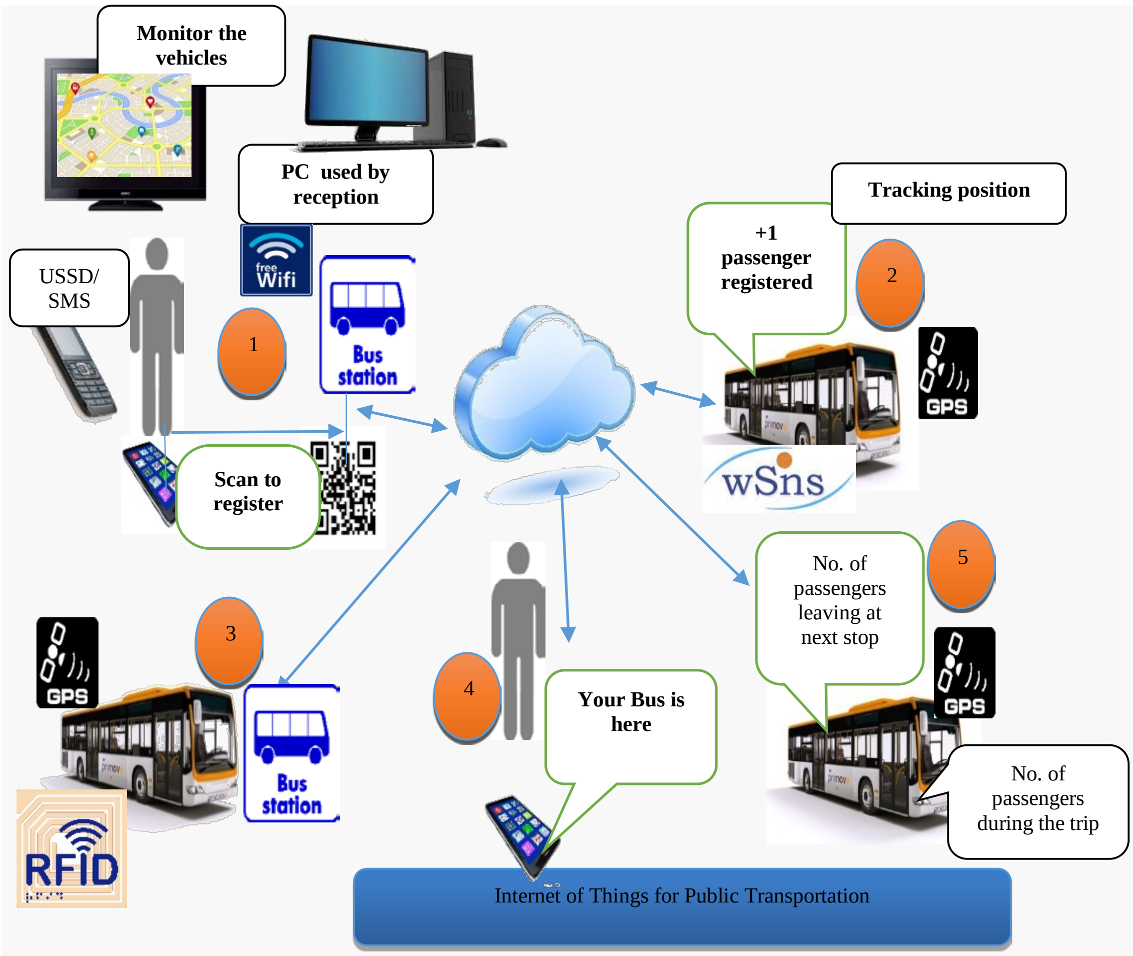

Figure 4-7: Scenario of public transportation with IoT (Designed by author)

4.5 Summary of the designed Framework in Relation to Other Research Studies

The framework design in this research study was based on previous studies as discussed in the literature review (see Chapter 2) as the following:

As discussed previously in "an integrated framework using traffic flow data", that framework study shows methods of using different input factors in the real world to get a certain output. This study used a similar procedure by using different factors from the real world (language, knowledge, phone-smart level, ICT existence) and discussed them in the questionnaire for seeking a recommendation (Mazloumi *et al*., 2014).

The "Framework for Game in IoT" study used three operating phases to deal with ICT-devices (Initial phase, Exchange data Phase, Error handling). In this study, two of the three phases were used, namely the data-exchange phase and the error-handling phase. The data-exchange phase was done by allowing all ICT devices to exchange data through the Internet by sharing it to the database. The error-handling phase was covered by the corresponding between the real-time GPS reading, and RFID sensor reading on each stations-stop, in other words, the real-time GPS reading and the reading of the RFID sensor must correspond (Kim, 2017).

In the study by Jafari, "the multiple stream method" was used. In the current study, it was also used by linking different attributes together (Driver, Vehicle, Passenger, Trip, Station, Owner), The framework of the study by Jafari was used to differentiate between the different layers in the framework of the current study, namely the application, devices/sensors, communication, service and infrastructure layers (Jafari, 2017).

The framework of the study by Dhende "was used to enable real-time communication with the database, for example, with both the RFID sensor and the GPS sensor" (Dhende *et al*., 2017).

Finally, this chapter discussed the designed framework with this study, as well as the common concepts that were shared with other viewed studies in Chapter 2. The following chapter will show the implemented applications that adopt the framework of this study.

CHAPTER 5

5. Framework Testing and Evaluation

5.1 Introduction

This chapter explains the system prototype that was developed based on the designed framework with a view to improving public transportation in the Free State.

The system prototype was implemented in line with the needs of the different types of users, namely users with smartphones, users with non-smartphones, and users without cell phones. For non-smartphone users, the Unstructured Supplementary Service Data (USSD) method was incorporated. Users with smartphones (or other smart devices) are catered through an Android/IOS (for Apple phones) application. The category of users without mobile phones have access to the system through a human operator (situated at the bus stations). The latter is, not necessarily illiterate; the system operator is able to register them on the desired route. Given the different needs presented earlier, five sub-systems were developed. Further, three different user interfaces for each of the different types of users were developed. Each of these interfaces serves a specific kind of user by communicating with all the ICT devices on the one side and with the database engine through an internet connection on the other side, resulting in the application of the IoT technology.

5.2 Mobile Application

This application (app) prototype serves three different user types, namely passengers, vehicle owners and vehicle drivers. Although the main menu of the app is visible to all users, it distinguishes between the different types of users. After determining the user type, the application page navigates to the next applicable page. The user is able to perform user-specific functions once he reached his specific page.

For instance, a vehicle owner or driver has to complete a login page to navigate to the next page. However, the passenger page navigates directly to the next passenger page without having to log in or sign-up. If the driver/owner is not yet registered, he will have to sign up first, and can only continue to use the system once the administrative (admin) user has approved his registration. The admin user will use the web application, which will be explained later in this chapter (see Figure 5-1).

Figure 5-1: Main page

5.2.1 Passengers

The passenger type of user is able to book a trip by typing in the route name, which has an auto-complete function, or by simply scanning a QR-code that is available on the station board. The passenger's route selection populates a drop-down list with all the common stops on this route. The passenger will receive a once-off generated code as well as a corresponding QR-code. The once-off generated code is then used to allocate the passenger to a specific vehicle, which will be further discussed in the section on the driver page. Once the user accepts the booking, the driver will be notified that the passenger has been allocated to him. The following table shows the common tools used by all application types (ICT sensors) and the database; however, the QR-Code can only be used with a smartphone app (see Table 5-1).

Table 5-1: The shared tools between the different applications

	QR-Code	
Web App	**Mobile App**	**USSD**
ICT Sensors		
Database		

5.2.2 Drivers

The driver page requires a user to log in through the login page, after this, the user is then able the driver page. The driver page allows the driver to allocate the passengers to his vehicle by scanning each passenger's QR-code using his smartphone camera or by typing the generated code in its own field. The driver is expected to have supporting tools indicating the number of passengers booked on a specific route, as well as the number of vacancies on that specific trip. The driver is able to receive a notification on his smartphone with the location of the next stop, as well as the number of passengers leaving or entering the vehicle. If a new passenger wants to join the vehicle at one of the sub-stops along the route, the driver will be updated in real-time. This will be made possible by the two infrared sensors placed in the door of the vehicle. The infrared sensor device is one of the ICT smart devices that use an internet connection to update both drivers and vehicle owners with the current number of passengers at each stop, which also implement IoT technology. The two infrared sensors will determine the passenger's direction, for example, if he is leaving or entering the vehicle, by determining which one of the signals was cut.

5.2.3 Vehicle Owner

The owner page also requires the user to log in before further navigation to the owner page will be allowed. The owner page shows all the vehicles that belong to the owner, should he own more than one. The owner will be able to select one of his vehicles to monitor. He can apply filters, such as a specific date, in order to select the information that he wants to access. The owner will also be able to access information such as the number of passengers in the vehicle at that specific time, the total number of the attended passengers during the specified period, the number of trips made during the same period, as well as the final stop of the vehicle on that specific route.

The owner and the driver need to register first before they are able to log in to the system. The admin user authorises (or decline) and activates their registration. The admin user is responsible for allocating the correct vehicles to the owners and the drivers (see Figures 5-1 and 5-2).

Figure 5-2: Mobile application showing the interfaces for three types of users (by Author)

5.3 Web Application

Users can browse the web application online from anywhere and on any smart device, e.g. smartphones, tablets, laptops and computers. Module Viewer Controller (MVC) developed this application by using C#.net. The web application supports all the mobile app tools and additional tools, as will be explained shortly.

5.3.1 Login Page

The login page is visible to all users, namely passengers, drivers, owners and administrative users. It distinguishes between the different user levels to enable navigation to the relevant page for a specific kind of user. From the login page, it is also possible to navigate to the home page or the map page, which are available for anonymous or guest users. The admin user will be created beforehand with the initial credentials of username "admin" and password "admin". From here, the admin user is able to create other users, vehicles and routes (see Figure 5-3).

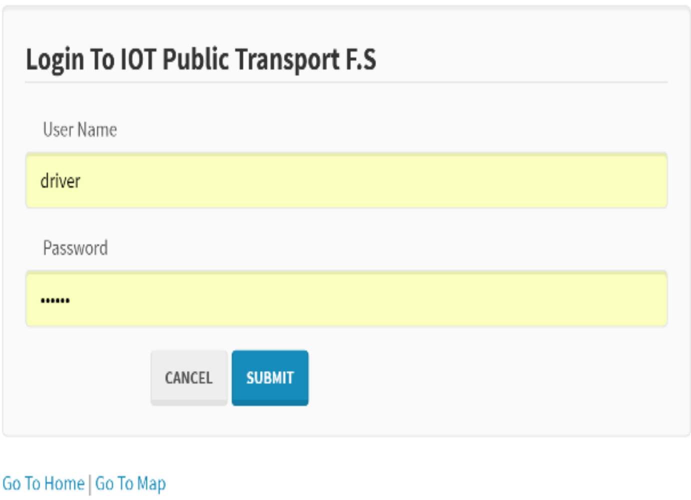

Figure 5-3: Login Page

5.3.2 Home Page

The home page is available to all users as well as guest users (anonymous). This page is displayed on one of the public monitors in the station, listing all available vehicles at the station and showing the arrival time for each vehicle. This page notifies the public, with a visual pop-up and a sound notification, when a vehicle arrives or leaves the station. This page supports query filtering where the user can select to display all the ‘arrived’ vehicles at all the stations in the Free State, all the ‘arrived’ vehicles at one station only using the station reference, or showing all the ‘arrived’ vehicles belonging to a specific trip at the current station. The filtering tool uses the string query method that uses a query string in the Uniform Resource Locator (URL) link in the address bar (see Figure 5-4) (Oracle, 2015).

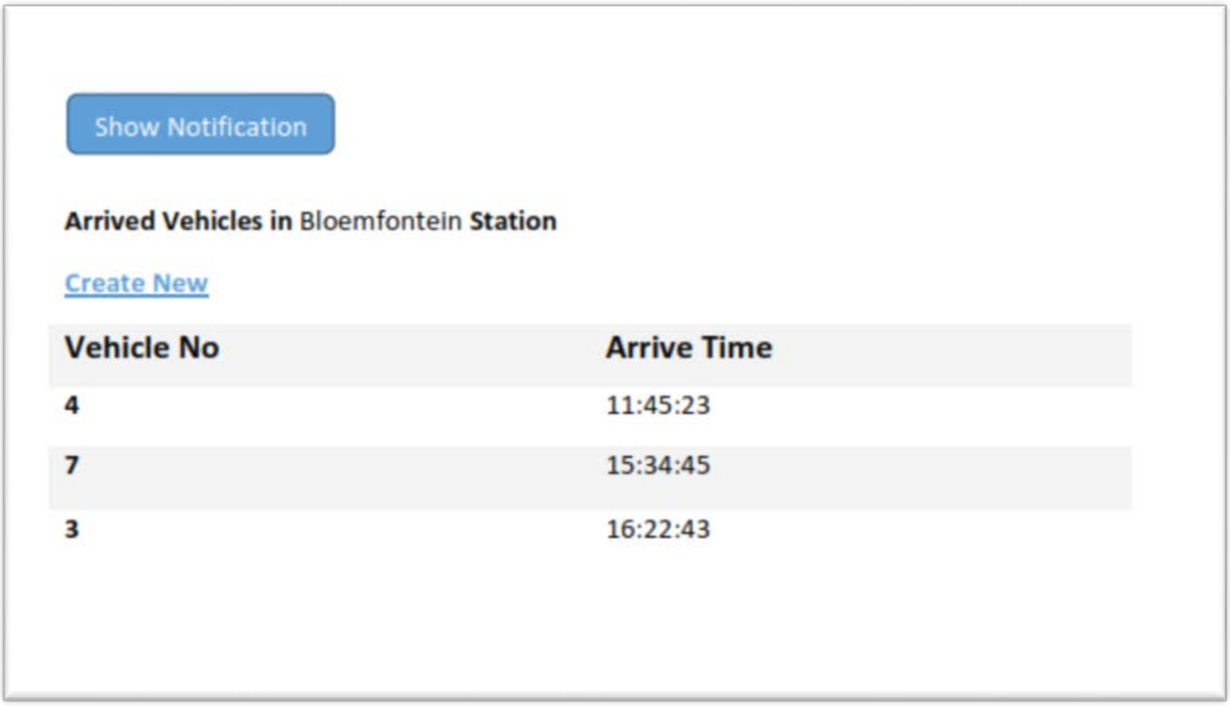

Figure 5-4: Home Page

5.3.3 Administration Page

The administration (admin) page is the page where admin users are able to create the credentials for different users and set their user type, e.g. Admin, Driver or Owner. The admin user registers new vehicles and trips (routes). This page also allows the admin user to assign every vehicle to all of the drivers, the owner and a route. Further to this, the admin page enables the admin user access to view, edit, delete and create all kinds of lists, such as a list of the drivers, a list of the owners of the vehicles, a list of the vehicles and a list of all the routes.

Finally, the admin user also is also able to create other admin users to fulfil the same duties as his. This page is only available to the admin user once he has successfully logged in (see Figure 5-5).

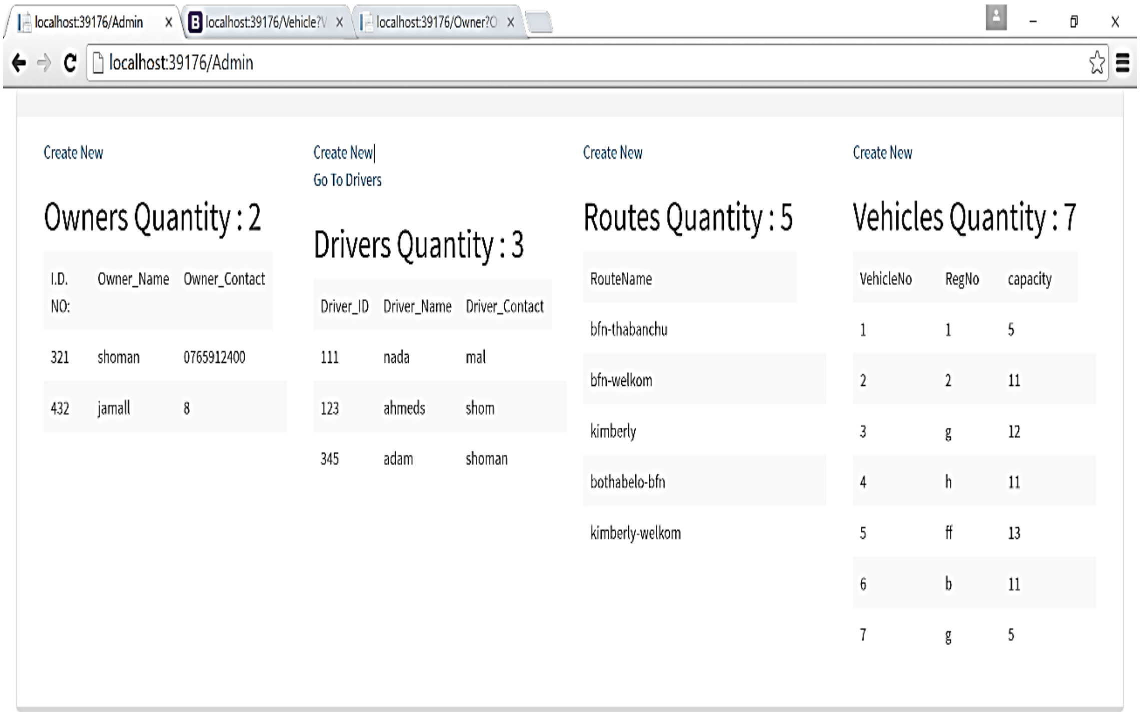

Figure 5-5: Admin Page

5.3.4 Owner Page

The owner page is meant for the owners of vehicles once they have logged in successfully. This page shows a report that has a list of all the vehicles belonging to the owner, as well as the total number of disembarked passengers for each vehicle. This page is read-only, in other words, the owner cannot change any data (see Figure 5-6).

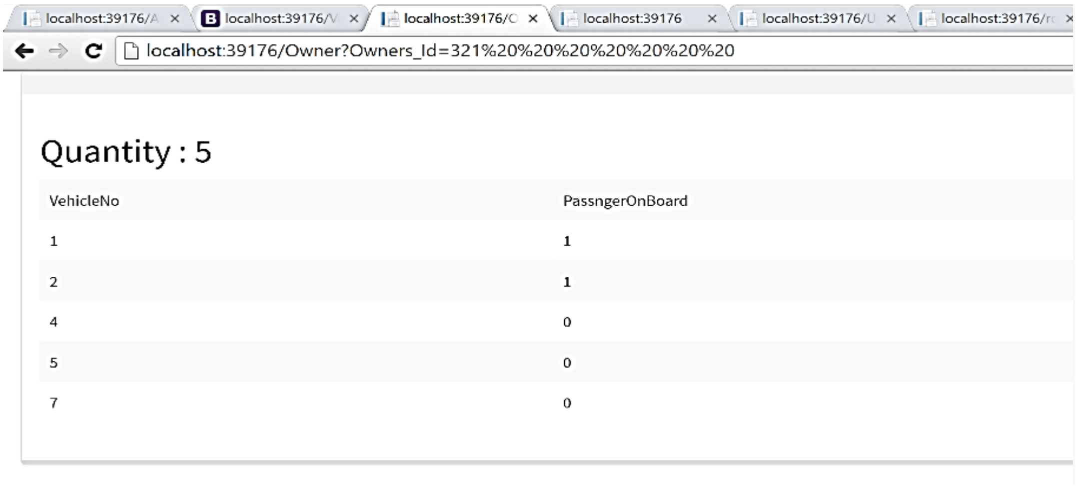

Figure 5-6: Owner Page

5.3.5 Driver Page

The driver page is available to the driver only, and here he can access his ‘vehicle’. The drivers have the ability to assign all the pre-booked passengers to his vehicle. This can be done by feeding each passenger’s once-off generated number into the system by scanning either the QR-code that is generated on the passenger’s smartphone screen or the printed image on the ticket from the receptionist. This page displays the vehicle number, the capacity of the vehicle and the number of passengers on board (see Figure 5-7).

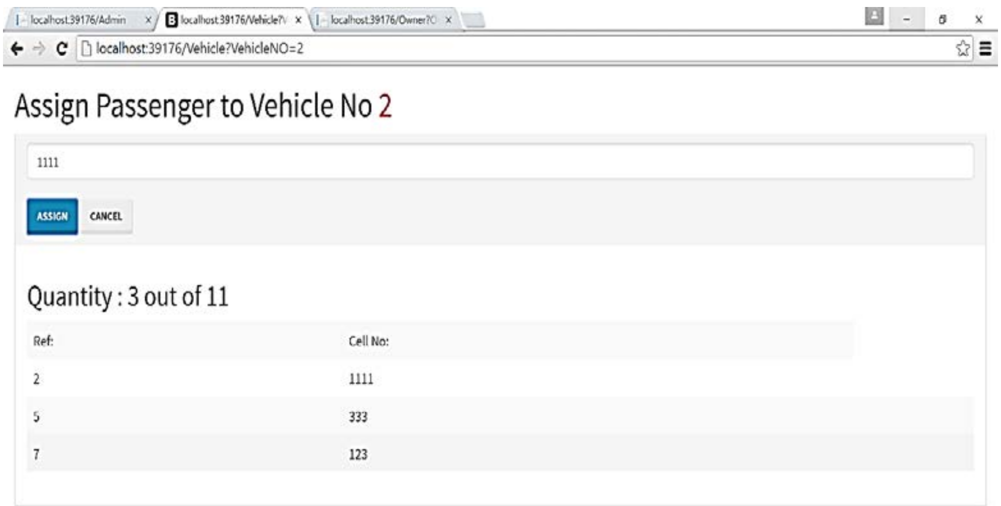

Figure 5-7: Driver Page

5.3.6 Map Page

The map page is available to all users and is displayed on one of the public monitors at the station. It shows real-time tracking for all of the waiting vehicles. The page supports Signal-R and Database-Dependency with SQL-Dependency, which offers a real-time update trigger on the database and pages. Signal-R is a new Asp.net library that adds a real-time web functionality, allowing the server side behind the code to push the changes to the client side (View) in real-time (GitHub, 2016). SQL. A dependency is a tool that works with SQL Command to detect any query, resulting in changes in the database tables. In the system's implementation, the ***on change*** event is executed if the data change and the changed event will be used to indicate if any changes have been made since the data have been retrieved (Microsoft, 2016). This acts as an intermediate tool between the GPS tracking sensor on the vehicle and the software application. In order for the system to work correctly, every vehicle is expected to be equipped with a tracking sensor (IoT sensor) that communicates with the server to update the database coordinate table. Database dependency triggers any change on the database table and it will notify the Signal-R tools. Signal-R tracks the changes and refreshes the page to load the new data. Javascript is then used to avoid full-page reload, and reload only on the necessary fields with the new values (see Figure 5-8).

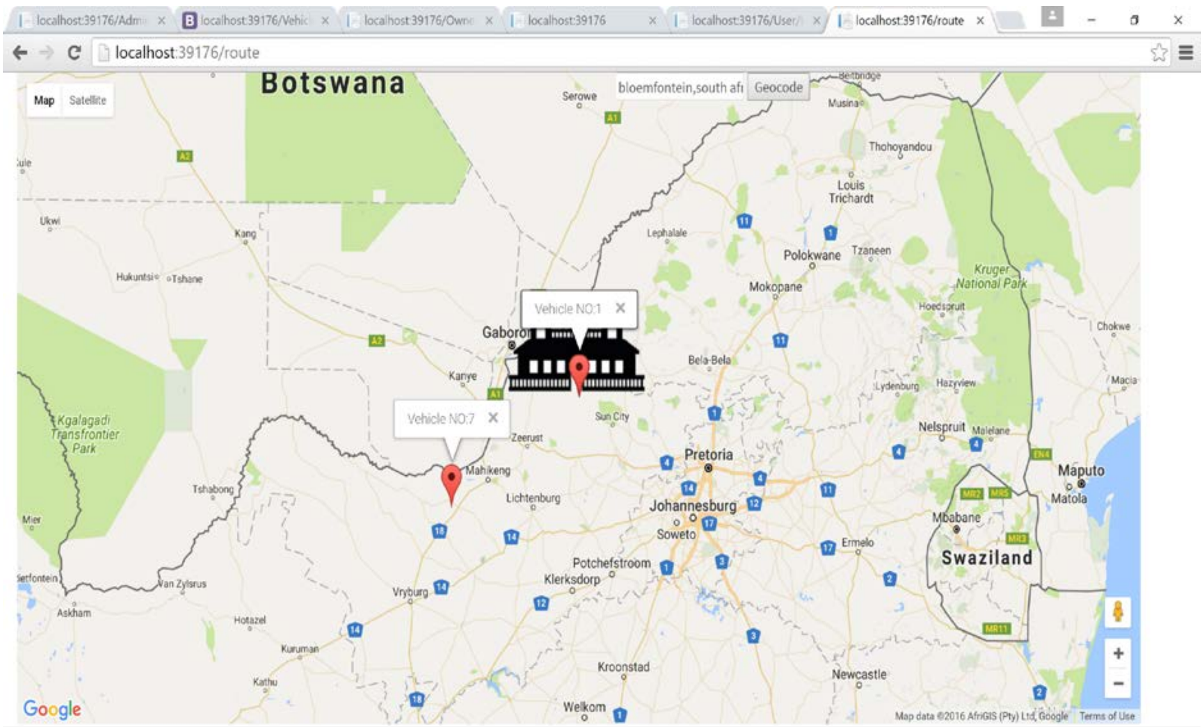

Figure 5-8: Map Page

5.3.7 Passenger Page

The passenger type of user makes use the passenger page to make a booking on a specific route by typing their contact no (optional) then selecting the route from a dropdown list. The selected route in the dropdown list will populate a new list of the stops that need to be selected by the passenger to submit the booking. After the passenger has chosen the route and his/her destination bus stop, the system then generates a one-off code that can be printed. The printed ticket contains the QR-code as proof of booking. The passenger is expected to present the printed ticket when boarding the vehicle. A notification launched to the selected passenger who registered for the same route on the vehicle arriving. The passenger can access the application as a guest without having a user account, unlike the driver, owner or admin (see Figure 5-9).

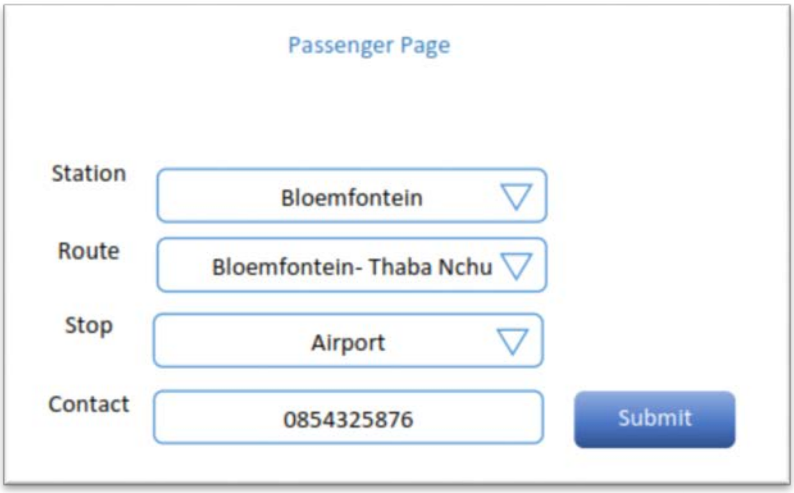

Figure 5-9: Passenger booking page

5.4 IoT Technology Implementation

The implemented system prototype incorporates IoT technology by implementing ICT sensors and smart devices, as follows:

- Firstly, a GPS sensor was used to determine coordinates and publish it through the internet.
- Secondly, an RFID sensor was used to identify vehicles that arriving at and depart from the station.

- Thirdly, Zigbee was used to do the transition from the RFID reader to the Zigbee Transmitter.
- Fourthly, GPRS was used to transmit GPS data to the server.
- Fifthly, Wi-Fi was used to transmit the received data from Zigbee to the server and used in the station to connect the public monitor and other users.
- Sixthly, 3G communication was used on a smartphone to register, monitor and manage data by different users.
- Seventhly, the general cellular signal was used for non-smartphones to send the USSD code and to receive SMS for notifications.
- Finally, the web page was used to register, monitor and manage data. By using all of these devices and making use of the Internet connection, the successful application of IoT will be achieved**.**

5.4.1 Boarding Gate Hardware

The hardware aspects of the system prototype a number of hardware components; the first hardware component is an Arduino board with integrated RFID and Zigbee devices are used at the bus boarding gate. The RFID reads the tags on the vehicle at the gate, whereafter Zigbee will transmit the data to the receiver. The receiver sends the received data through Wi-Fi to the database at the station to be published on the public display sets (see Figure 5-10).

Figure 5-10: RFID Arduino Board (Arduino, 2018)

5.4.2 On-board (Vehicle) Hardware

The second part of the hardware is implemented in the vehicles. This hardware uses a Waspmote board powered with a battery and equipped with an integrated GPS sensor for tracking. GPS data is transmitted through GPRS to the database on the server (see Figure 5-11).

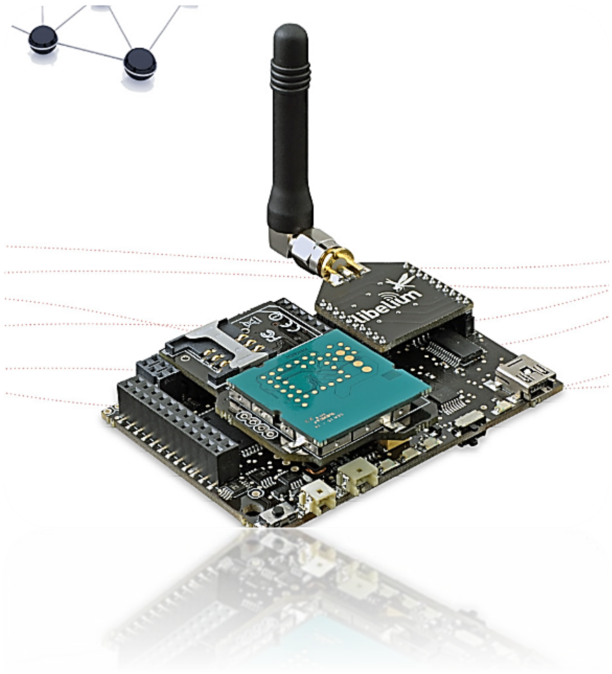

Figure 5-11: Waspmote Board with GPS, GPRS and Wi-Fi (Libelium, 2917)

The software part of the architecture supports real-time updating of the database. The real-time update of the database is implemented using Microsoft SQL Dependency (MSD) technology that supports real-time updates between "code behind" on the server and every time the database is updated by one of the sensors. Signal-R technology is then applied in synchronising changes happening between the "code behind" on the server side and "views" on the client side. Both MSD and Signal-R ensures to show the database changes on the client side presented on the webpage viewed by the user. The software side is implemented in different types, following the web page for computers and an Android application for smartphones. The different applications are available any time and on any smart device (such as a computer or a phone) and available in different ways to prove the ubiquitous concept in the framework.

5.4.3 Integrated System Architecture

The architecture has shown the applied IoT technology on both the hardware and the software sides. The hardware side has applied IoT by implementing multiple ICT devices and sensors. The software side has applied IoT by using supported tools for a real-time update (see Figure 5-12).

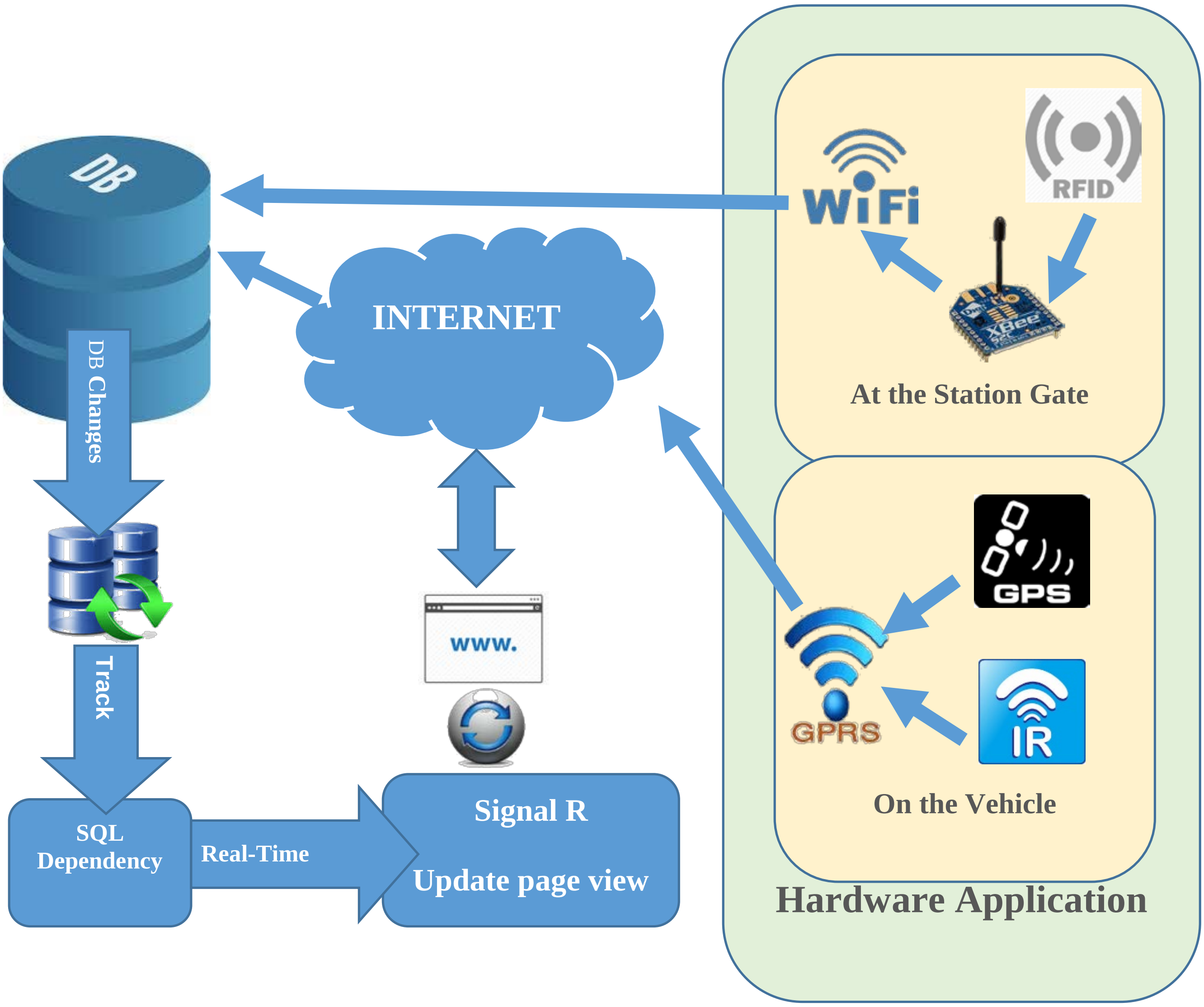

Figure 5-12: Framework Architecture

5.5 Framework Evaluation

5.5.1 Passengers' Evaluation

The first challenge on the passengers' side that will be discussed is the long waiting time for transport, and that they (the passengers) cannot use this waiting time to their advantage since they do not know at what time a vehicle will arrive. This problem can be solved by implementing real-time tracking of vehicles and making this available to passengers. This will allow the passenger to manage his time better, as he/she will then have an estimated arrival time for the vehicle. It was also not yet possible to pre-book a seat on a certain vehicle. Since passengers are afraid of losing their seats if they leave the station to spend this waiting time somewhere else, the waiting time at the station has increased. This problem is solved by the framework design that will allow the passenger to book a seat in advance. It will thus also be possible for a passenger to miss a vehicle if he is busy doing something else, not necessarily at the station. This is solved by implementing various notification facilities such as public announcements, SMSs, or notifications according to the smartphone operating system that the passenger is using. If one takes all of the above into consideration, it seems as if the problems have been solved and the aims of the study achieved in this regard (see Figure 5-13).

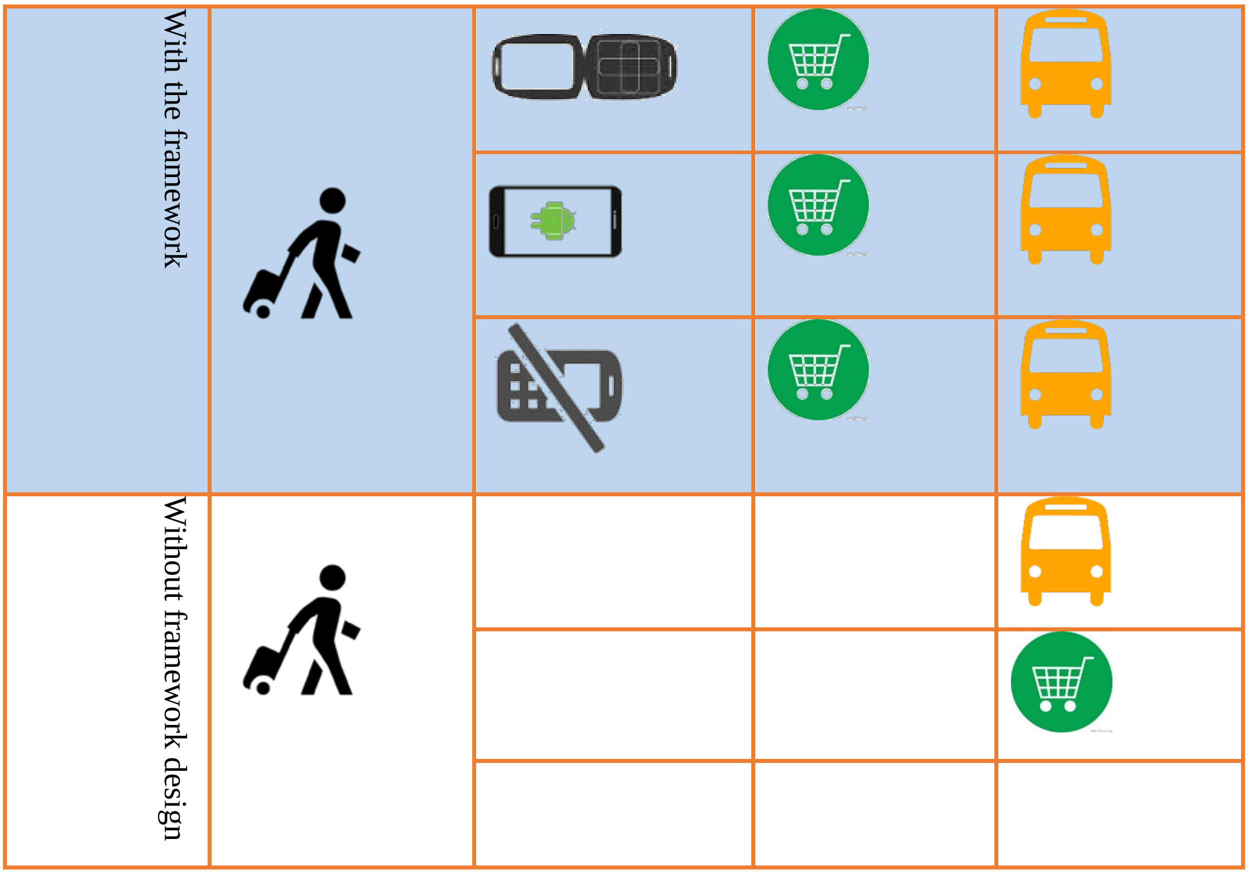

Figure 5.13: Passenger achieved goals

5.5.2 The Drivers' Evaluation

Before the implementation of the framework, the situation was such that the drivers of public transportation vehicles in the Free State did not know how many passengers were waiting at the station at any given time. This led to situations where the driver came to the station only to find that there was either too few passengers to make a trip worthwhile or no passengers at all. This mostly happened on late trips. This problem is solved by notifying the driver every time a new passenger registers for the trip. One of the other problems that were addressed was that it often happened that passengers were busy with other activities (such as shopping) while they were waiting for transport. This may result in the driver either waiting for the passenger to return or leave without the passenger, thus not utilising the vehicle to its fullest. This problem was solved by the notification system that the framework offers.

Other existing problems were that the driver might miss some of the passenger stops, and be unaware as to the number of passengers who have disembarked and the number of vacancies that the vehicle now has. This problem was solved by implementing the reminder facility that warns the driver of the next stop. Furthermore, the IR sensor at the vehicle gate keeps a count of the number of passengers who left the vehicle; thus, the number of vacancies will also be known.

There was also no information available to support the driver when he had to decide whether he had to return to the station to do a late trip for the last few passengers or if he could go home, as no passengers were waiting for transport. However, the designed framework will provide the driver with the opportunity of knowing how many passengers are waiting at the station, especially if it is late in the day. This enables the passenger to determine his decision in terms of either returning to the station for the last trip or going home. This leads to better efficiency, as the number of trips will increase if the driver knows that passengers are still waiting at the station and that he cannot go home yet. The comparison can be seen in Figure 5-14.

		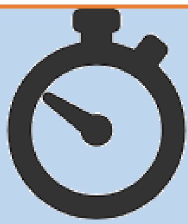		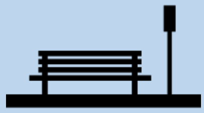
With framework design		Decrease the waiting time in the station.	The number of trips can be increased because a driver's decision-making is supported.	Notify the driver on the next stop, as well as how many passengers are leaving at the stop.
Without framework design		Passengers will have to wait longer before they know if a vehicle is arriving or not.	Drivers might miss a late trip.	The driver has to either stop at each stop and waste time by waiting or skip the stop and miss passengers who might be waiting at or are on their way to the stop.

Figure 5-14: Driver-achieved goals

5.5.3 Vehicle Owners' Evaluation

The biggest challenge for vehicle owners in the current transportation system is managing their vehicles and drivers since the owner does not have any information about his vehicle (number of passengers, and current position). For instance, the owner is interested in the number of trips that the vehicle has made as well as the number of passengers who have used the vehicle. This information is not available in the current system. The proposed framework offers an application that can count the number of passengers and track the vehicle in real-time and allows ubiquitous access (see Figure 5-15). In this manner, the framework fulfils the needs of the vehicle owners.

				
With the framework		The number of passengers who have embarked is known.	The number of trips is known.	The final stop will be known.
Without framework design		No information	No information	No information

Figure5-15: Owners' system limitation

CHAPTER 6

6. Findings and Conclusion

6.1 Evaluation Summary

Taking all of the above into consideration, it is clear that the designed framework succeeds in resolving the challenges that passengers experience, covering the problems experienced by the drivers, and responding to the request from the vehicle owners. Therefore, the designed framework achieved the research goals of the study as it addressed the problems identified successfully.

6.1 Conclusions and Future Work

6.2.1 Results

There is a clear difference in the quality of the public transportation fleet management in the Free State between before and after the application of the framework designed based on IoT. Using the framework should improve the quality of service firstly for the passengers and secondly, for the drivers and the owners. The passengers were divided into three types of phone users, namely no-phone users, non-smartphone users and smartphone users. Because of the different types of participants (passengers, drivers, owners), and the different needs, language and skills, it was quite challenging to achieve the goal of the designed framework based on IoT.

Overall, the study achieves its goal by integrating some of the ICT-devices in the infrastructure of the Free State public transportation, and apply IoT-technology to improve the current management system and offered services.

6.2.2 Conclusion

The study successfully fulfilled the following objectives:

- Identifying the current problems in the Free State public transport station, and finding applicable IoT technologies that solve those problems;

- Designing a framework that enhances the Free State Public Transportation infrastructure by integrating the use of at least five ICT devices (GPS, GPRS, Phones, RFID, Computer, Zigbee, Wi-Fi) to achieve IoT technology; and
- Evaluating the study based on satisfying the participants' needs and recommendations.

6.2.3 Recommendations

The following recommended services will help the framework to achieve its goal by applying them, like the following,

- It is necessary that Unstructured Supplementary Service Data (USSD) command and SMS notifications can be used since not all passengers own smartphones.
- Offer free Wi-Fi service, but with limitations (user can access the web service on the local server, but not all the Internet services, such as the "intranet").
- Make use of a computer at the station that is run by one of the station bodies (information reception) to help the passengers who experience language and technology challenges to register.
- Have a screen at the station that displays all the arrival and departure times of taxis/buses, using either tracking devices or the drivers' smartphones.
- Install an application on the driver's phone or install a tracking sensor in the vehicle to track his current position and display it on the screen at the station.
- The passengers can install the free application on their smartphones, which would enable them to register for trips and to receive notifications on when their transportation will arrive.
- The driver will have an application on his smartphone that he can use as a tracking device and request emergency services at the scene of an accident. This application can also be used to notify the driver how many passengers are currently waiting, as well as the pre-set next stop for the passengers.
- Install security cameras with IR-vision (CCTV) at the bus station and link it to the security guards for safety and security purposes.

The study can be applied to other public transport (e.g. trains), or to other regions by adding/removing some attributes.

- Safety and security measures will have to be implemented to secure ICT sensors.
- The system will work better in term of the passenger counting on larger vehicles such as buses, but not on the taxis, due to enough space for the passenger to move.

6.3 Disapproved Methods

After having interviewed some of the passengers, drivers and taxi owners concerning the method of calculating a number of passengers, the researcher discovered that, due to various constraints, none of these would be effective, as explained on the following:

- Seat sensors will not be effective, because passengers keep moving as they leave/enter the taxis.
- Camera monitoring is time-consuming to determine by monitoring security cameras how many passengers enter and leave.
- Snapshot cameras at open doors produce unique problems as passengers enter and exit at the same door, making it difficult to keep track of the number of people entering or leaving.

In conclusion,

- A facial recognition device placed facing the door to identify different passengers entering is not accurate, because there is no method to force the passenger to do it.
- A digital scale to identify individual passengers by their weight cannot be accurate in case the passenger carries something on entering the vehicle and does not carry it when leaving.
- A recording camera is not efficient, because someone can block the camera eye.

6.4 Achievement

Based on the identified problem, a framework was designed to satisfy most of the needs. The framework makes use of IoT technology, which is supported by ICT-devices. The designed framework produces different layers that serve at different levels (application layer, devices layer, communication layer, service layer, and infrastructure layer).

The application layer is to be designed to cover all different needs of users (passengers, drivers and owners), consider the different levels of knowledge for users (skills, language and technology literate), and the flexibility to support different kinds of devices, like computers by using web applications; Smartphones using Android applications; and non-smartphones that use Unstructured Supplementary Services Data (USSD).

The framework allows passengers to pre-book their trip, be notified of the vehicle arrival, to be provided with real-time tracking, and to notify them of any cancellation or delays that affect the trip/vehicle. Drivers can be notified in advance for the next stop for disembarking and be notified of the current number of booked passengers. The owner can track its own vehicle on real-time and monitor the number of passengers attending the vehicle.

The devices layer is implemented by ICT devices/sensors to improve the current infrastructure at Free State Public Transport Station.

A communication layer will improve the communication field of the current infrastructure at Free State public transport station by using Wi-Fi media communication.

The service layer comprises different services that suit the several needs of different users.

The structural layer is where the background process occurred. The structure layer is responsible for managing all data traffic between reading and writing information from the database, and apply all the processes needed for the data.

The framework design should improve the service level quality for all different types of users, especially the passengers. The passengers waiting time should be saved and managed in a better way. The management's reports should be easily generated and accessible, which can help in decision making to improve service quality. The road safety should be improved by giving a chance to the driver to stop smoothly for disembarking. The ubiquitous availability to all users and the owners to manage their own vehicles will be much easier.

6.5 Limitations

The designed framework has not been tested in the real world due to the cost of some of the pieces of equipment, and the difficulty of permitting authorisation. The USSD method has not been implemented since authorisation from different service providers needs to be obtained beforehand.

The total number of the passengers in taxis will not be an exact number, due to the passenger movement outside the vehicle for disembarking, and loading on each of the journey stops.

6.6 Future Plan

- The IoT framework design can be adjusted to include more regions beside the Free State by adding or removing some objects as they need;
- More surveys can be undertaken, for example, by comparing how literate and illiterate passengers experience and behave to IoT technology;
- The designed framework can be extended to include other transportation facilities such as trains.
- The designed applications can be extended to include more applications such as Apple products.

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APPENDICES
APPENDIX A: Driver Questionnaire

Study for the Development of an Internet of Things Based Framework for Public Transportation Fleet Management in Free State

STUDY INVITATION LETTER (Driver Copy)
I am pleased to invite you to participate in study aimed at identifying challenges currently facing the public transportation sector in Free State. No more than 15 minutes would be required to complete the questionnaire. Be assured that any information you provide will be treated in the strictest confidence and your participation will not be identifiable in the resulting report. You are entirely free to discontinue your participation at any time or to decline to answer particular questions. I will seek your consent on the attached form on which I commit to ensure that your name or identity is not revealed. Direct any enquiries concerning this study to the main researcher (contacts below). Thank you for your assistance. Researcher Central University of Technology, Free State, South Africa

CONSENT FORM

I, the undersigned, confirm that (please tick box as appropriate):	
I have read and understood the information about the study,	☐
I have been given the opportunity to ask questions about the study and my participation.	☐
I voluntarily agree to participate in the study.	☐
I understand I can withdraw at any time without giving reasons and that I will not be penalised for withdrawing	☐
The procedures regarding confidentiality have been clearly explained to me.	☐
If applicable, separate terms of consent for forms of data collection have been explained and provided to me.	☐
The use of the data in study, publications, sharing and archiving has been explained to me.	☐
I understand that other researchers will have access to this data only if they agree to preserve the confidentiality of the data and if they agree to the terms I have specified in this form.	☐
Select only ONE of the following:	
I would like my name used and understand what I have said or written as part of this study will be used in reports, publications and other study outputs so that anything I have contributed to this project can be recognised.	☐
I do not want my name used in this study.	☐
I agree to sign and date this informed consent, along with the Study.	☐

__________________________ ________________ _________________

Name of Respondent Signature Date

__________________________ ________________ _________________

Name of Researcher Signature Date

PART A: INTRODUCTION

Public transportation in Free State is experiencing an array of challenges which although conventional ICT-based solution could address, this currently not possible because of the nature of the existing infrastructure. Preliminary survey (through observation and interviews) by the researcher revealed that these challenges emanate from the passengers' phone ownership pattern (there are three types: with no phones, with simple phones, and with smart phones) which makes it difficult to find one type of solution to apply. The second is language skills; not all the passengers are English speakers. On the bus station infrastructure side; internet connectivity in the stations is not offered free; there is no any facility at the station to give an indication of the current position of the buses (taxis and trains), expected time, or inform on cancelation or accident. There is no person tasked with the job of helping the non-literate passenger with registration, informing them if there is any planned changes, or announce when their transportation has arrived. On the other hand, the drivers have no information on how many passengers are waiting in station at any given time. There is also no way of notifying the driver if someone wishes to leave the bus at the next stop. Such a facility would help in saving time and effort.

Ideally, conventional IoT could be applied to the Free State public transportation sector; however, the existing solutions are designed to work in ideal environment and will not therefore work for the Free State. A home-grown solution that circumvents/addresses these challenges is needed. This study will attempt to fill this gap. You are requested to participate in this valuable study by completing this questionnaire. You are required to put a mark (√ or X) in the checkbox to select an option or write down a response for open-ended questions.

PART C: DRIVER QUESTIONNAIRE

Q 1 Age bracket? ❑ Under 18 ❑ 18-35 ❑ 36-45 ❑ 46-55 ❑ 56-65 ❑ Over 66

Q 2 Highest Education Level: ❑ None ❑ Primary ❑ Secondary ❑ Post-Secondary

Q 3 What is the name of your route? (e.g. Town – Mimosa) [_______________________]

Q 4 Is there a way to know how many passengers are waiting for your vehicle? ❑ Yes ❑ No

Q 5 If you return late from your destination,

❑ Will you try to go to the station to check if there are any passengers waiting for a vehicle?

❑ You will go home, assuming that it is too late for passengers to be there?

Q 6 What decision will you make if you knew there are many passengers waiting for a transport at the station of your destination?

❑ Drive normally ❑ Hurry to get the passengers.

Q 7 A system that is able display (on a screen) information on how many passengers are leaving at the next stop before my last destination is very helpful for smooth driving in terms of traffic and saving time.

❑ Strongly disagree ❑ Disagree ❑ Not Sure ❑ Agree ❑ Strongly agree

Q 8 Do you have a smartphone? ❑ Yes ❑ No (normal phone) ❑ Do not use a phone

Q 9 Are you a hired (do not own the vehicle) driver? ❑ Yes ❑ No

Q 10 If passengers are waiting by the roadside for public transport (outside the station).

❑ You stop to ask for their destination.❑ All the vehicles will always indicate their destination

- If there is an application that can manage the public transport system, I will make use of it? ❑ You knock on the window ❑ You shout ❑ Ask others to tell the driver ❑ Use buzz button.

❑ Strongly disagree ❑ Disagree ❑ Not Sure ❑ Agree ❑ Immediately ❑ Strongly Agree when passenger wants to leave the vehicle before the destination.

Q 11 Using a rating from 1 to 10, Rate the following as useful for you? (Where 1 means not important at all and 10 means that it is highly important to you)

Feature	Rate
Track and monitor a public transportation vehicle.	

Notify passenger when the vehicle is arrived	
Register passengers for each trip	
Use finger print as replacement for the ticket payment (tag payment in the buses) method	
Notify the driver for how many passengers are leaving the vehicle next stop before the station.	
Indicate the destination for each public transportation vehicle.	

PART E: REQUEST FOR RESPONDENT'S FURTHER INVOLVEMENT (OPTIONAL)	
Phase II of this study, will involve development of an IoT system to manage public transportation. Should you be interested to participate, you are requested to provide your contact details below.	
Full Name:	
ID Number:	
E-mail:	
Phone number:	

APPENDIX B: Passenger Questionnaire (Extract)

PART B: PASSENGERS' QUESTIONNAIRE

Q 1 Names:____ (Optional)

Q 2 Gender? ❑ Male ❑ Female

Q 3 Age bracket?

❑ Under 18 ❑ 18-35 ❑ 36-45 ❑ 46-55 56-65 ❑ Over 66

Q 4 Highest Education Level:

❑None ❑Primary ❑Secondary ❑Post-Secondary

Q 5 How often do you use public transport vehicles?

❑ Never ❑ Rarely ❑ Regular

Q 6 Which of the following form of public transportation do you use?
❑ mini busses (taxi's) ❑ Busses(Interstate) ❑ Both

Q 7 How long do you usually wait for your transport vehicle at Bloemfontein station?
❑ 0-5 min ❑ 15-30 min ❑ More than 30 min

Q 8 Using a rating from 1 to 10, how often do you wait for your public vehicle?(where 1 means you do not wait and 10, you wait for very long) [_____________]

Q 9 Have you ever waited for your transport vehicle that never came?
❑ No ❑ Yes

Q 10 Do you have a chance to shop outside the station while you are waiting for your vehicle?
❑ Yes ❑ No

Q 11 Have you ever missed your vehicle you were waiting for because you had left to go shop?
❑ Never happen ❑ It happened

Q 12 What is your regular route of origin? (e.g. Botshabelo) [__________________________]

Q 13 How do you reserve your position in the vehicle?

❑ Wait in queue ❑ Register your name

Q 14 In relation to your destination stop, when does the vehicle stop when you request to disembark?
❑ Immediately ❑ Further down

Q 15 If you are waiting by the roadside for public transport (outside the station):
❑ You stop each public transport vehicle to ask for the destination.
❑ All the vehicles always indicate their destination so I only stop the one I need

Q 16 Making use of tracking system that will indicate the closest vehicle to the station will help manage your time if you need to do some work while you are waiting.
❑ Strongly disagree ❑ Disagree ❑ Not Sure ❑ Agree ❑ Strongly agree

Q 17 Do you have a smartphone?
❑ Yes ❑ No (normal phone) ❑ Do not use a phone

Q 18 Can you read and understand English clearly? ❑ Yes ❑ NO

When a passenger wants to leave the vehicle before the destination:

❑ You knock on the window ❑ You shout ❑ Ask others to tell the driver

❑ Use buzz button.

Q 19 If there is an application that can manage the public transport system, I will make use of it?

❑ Strongly disagree ❑ Disagree ❑ Not sure ❑ Agree ❑ Strongly agree

Q 20 Using a rating from 1 to 10, Rate the following as useful for you? (Where 1 means not important at all and 10 means that it is highly important to you)

Feature	Rate
Track and monitor a public transportation vehicle.	
Notify passenger when the vehicle is arrived	
Register passengers for each trip	
Use finger print as replacement for the ticket payment (tag payment in the buses) method	
Indicate the destination for each public transportation vehicle.	

PART E: REQUEST FOR RESPONDENT'S FURTHER INVOLVEMENT (OPTIONAL)	
Phase II of this study will involve development of an IoT system to manage public transportation. Should you be interested to participate, you are requested to provide your contact details below.	
Full Name:	
ID Number:	
E-mail:	
Phone Number:	

APPENDIX C: Owner Questionnaire (Extract)

PART D: VEHICLE OWNER'S QUESTIONNAIRE

Q 1 Age bracket? ❑ Under 18 ❑ 18-35 ❑ 36-45 ❑ 46-55 ❑ 56-65 ❑ Over 66
Q 2 Highest Education Level: ❑None ❑Primary ❑Secondary ❑Post-Secondary
Q 3 Can you manage your vehicle remotely? ❑ Yes ❑ NO
Q 4 Do you know how many passengers have used your vehicle every day? ❑ Yes ❑ NO
Q 5 Can you track your vehicle? ❑ Yes ❑ NO
Q 6 Do you have a smart phone? ❑ Yes ❑ NO ❑ Not using Phone
Q 7 Do you read English? ❑ Yes ❑ NO
Q 8 Do you have a smart phone? ❑ Yes ❑ NO (normal Phone) ❑ Not using Phone
Q 9 If there is an application that can manage the public transport system, will you use it?

❑ Strongly disagree ❑ Disagree ❑ Not Sure ❑ Agree ❑ Strongly Agree

Q 10 Using a rating from 1 to 10, Rate the following as useful for you? (Where 1 means not important at all and 10 means that it is highly important to you)

Feature	Rate
Track and monitor a public transportation vehicle.	
Register passengers for each trip	
Calculate how many passengers in each trip	

PART E: REQUEST FOR RESPONDENT'S FURTHER INVOLVEMENT (OPTIONAL)

Phase II of this study will involve development of an IoT system to manage public transportation. Should you be interested to participate, you are requested to provide your contact details below.

Full Name:	
ID Number:	
E-mail:	
Phone Number:	