Internet of Things-based Traffic Management System for Maseru, Lesotho.

by

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In my capacity as supervisor of this dissertation, I certify that the above statements are true to the best of my knowledge.

Dr. Muthoni Masinde

Signature: ___________________________________

Date: _______________________________________

Dedication

I would like to dedicate this dissertation to my wife, ‘Mats’epang Liphoto, my daughter Ts’epang Liphoto, and to my mother Mrs. ‘Matlotlisang Liphoto and father Dr. Neo Liphoto.

Acknowledgements

I owe deep appreciation to all those who have contributed to the completion of this dissertation. I would like to convey my sincere gratitude to my supervisor, Dr. Muthoni Masinde. I would like to thank her for her support as well as her patience.

Abstract

The number of vehicles in Maseru has been steadily increasing, leading to heightened intensity of congestion and traffic occurrences. This is further exacerbated by ineffective solutions that are currently in place as well as the absence of tools that facilitate dispersal of information to motorists.

Traffic lights have been put in place to manage flow of traffic but are becoming increasingly inefficient due to their design. The preset timing cycles between green, amber and red disregarding prevailing conditions leads, *inter alia*, to increased wait times, use of additional fuel and air pollution. In addition, lack of equipment that is able to provide motorists with information about prevailing road conditions further increases the possibility of one being stuck in traffic.

To make traffic management more efficient at signaled junctions, the implementation of the Internet of Things (IoT) paradigm is used to create intelligent traffic management systems such as Wireless Sensor Networks (WSN) and fuzzy algorithms to intelligently decide the phases of traffic lights. Road density and vehicles' speeds are collected from the road infrastructure using cameras and are passed to a fuzzy algorithm to determine how congested a road is. Dependent on these parameters, the algorithm will also determine which roads should be given highest priority while maintaining a degree of fairness, thus optimizing traffic flow.

In addition, the ubiquitous provision of road condition information to motorists in various formats such as text and audio is also used. This feature allows for the acquisition of the latest road status, thus making it possible to find alternative routes. The unique feature in this project is the ability to collect road parameters from the road infrastructure itself, using WSN as well as crowd source data from road users using mobile devices.

A study conducted in this research revealed a relationship between the number of cars on a road and concentration of Carbon Dioxide (CO_2); the results showed that as the number of cars increases, so does the measure of CO_2. Questionnaire-based surveys showed that Maseru citizens have noted an increase in congestion which they attributed to the increase in number of vehicles on the road that is not met by the increase or improvement in road infrastructure. The respondents in this survey also noted limited mechanisms that provide them with road conditions and highlighted that such tools may alleviate congestion.

The performance of intelligent traffic lights was conducted via simulations compared with fixed cycle traffic lights. From the simulations it was observed that IoT-based traffic management systems reduced the wait times of vehicles at signaled junctions which would also result in reduction of the pollutant CO_2. It is envisaged that the future implementation will include the ability to manage a network of junctions and ability to predict abnormal traffic flows.

Publications Resulting from Research

1. Liphoto. T, Masinde. M, 2016. Ubiquitous Traffic Management with Fuzzy Logic – Case Study of Maseru, Lesotho: *IST-Africa Week Conference, 2016*, May 11-13 2016, IEEE Xplore Digital Library

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List of Abbreviations and Acronyms

API – Application Platform Interface

BLOB/blob – Binary Large Object

CO_2 – Carbon Dioxide

COMET – Central Office Management for Integrated Traffic

CSV – Comma-Separated Values

EMF – Electromotive Force

EWS – Early Warning System

FTP – File Transfer Protocol

GDP – Gross Domestic Product

GPS – Global Positioning System

GSM – Global System for Mobile Communication

IDE – Integrated Development Environment

IoT – Internet of Things

IPv4 – Internet Protocol Version 4

IPv6 – Internet Protocol Version 6

ITS – Intelligent Traffic Systems

ITU-R – Radiocommunication Sector of International Telecommunications

LOS – Level of Service

OpenCV – Open Source Computer Vision

PPM – Parts per Million

RDMS – Relational Database Management System

ROI – Region Of Interest

SCOOT– - Split Cycle Offset Optimization Technique

Secure Digital card – SD card

SMS – Short Message Service

SPSS – Statistical Package for Social Sciences

SQL – Structured Query Language

TMS – Traffic Management Systems

TN – True Negatives

TP – True Positives

UbiComp – Ubiquitous Computing

UTS – Ubiquitous Transport Systems

V2I – Vehicle to Infrastructure

V2V – Vehicle to Vehicle

Wi-Fi – Wireless Fidelity

WSN – Wireless Sensor Network

Chapter 1 : Introduction and Background Information

1.1 Introduction

Congestion is defined as a situation in which transport participants cannot move in a desired or favorable manner. Congestion is not limited to vehicles; pedestrians can also cause and be involved in congestion. It refers to the phenomenon when capacity of infrastructure is exceeded (Robert, 2013). In Maseru, Lesotho, the city that is being used for the case study, the occurrences of forms of congestion have been observed to be on the increase: traffic jams occur largely during the mornings and afternoons as people travel to and from work. There has also been a very noticeable increase in the average time they take to clear up without the intervention of traffic officers. This city was selected as the case study as it is the city in which the researcher lives.

Effects of congestion were identified as a global phenomenon at a conference held by the Organisation for Economic Co-operation and Development. The conference presented evidence of a steady increase in congestion in many urban areas of member countries (Organisation for Economic Co-Operation and Development, 2007). This was further reiterated at the European Conference of Ministers of Transport (Economic Research Center, 1998).

Apart from additional time spent in transit, there is a financial cost attached to occurrence of these traffic jams. *Fin24* of South Africa stated that total cost of traffic jams to businesses in South Africa is estimated to be R15 million per hour (South African

Chamber of Commerce and Industry, 2011). This is exclusive of cost of fuel and maintenance of vehicles. There is also an environmental impact that is result of exhaust fumes released by vehicles. The overall cost of traffic is calculated in various ways, including but not limited to, assessing outlay needed to reduce traffic volumes to optimal road capacity. One other method is to compute the marginal cost each vehicle entering into the jam imposes on other motorists involved (Litman, 2009).

Traffic lights at multi-way junctions in most medium-sized cities function by allowing entry into the junction using predetermined timing, giving each entry the same duration of time allowed based on historic data but not taking account of the prevailing situation. Consider that in the morning, heavier traffic is flowing towards the city with less flowing in the opposing direction. Traffic lights, however, allocate the same amount of time for traffic to flow in both directions. This is ineffective as wait time of vehicles going into town is prolonged.

1.2 Problem Statement

The increased amount of traffic congestion is attributed to increasing numbers of cars. The most widely practiced solution to congestion is implementation of traffic lights. The problem with this is that the volume of traffic differs at different times of the day leading to problems when the volume is larger on one side and less on others, resulting in a waste of resources. This wasting of resources is one of the problems this research has aimed to eliminate by employing the use of IoT. Figure 1.1 is used to illustrate the problem:

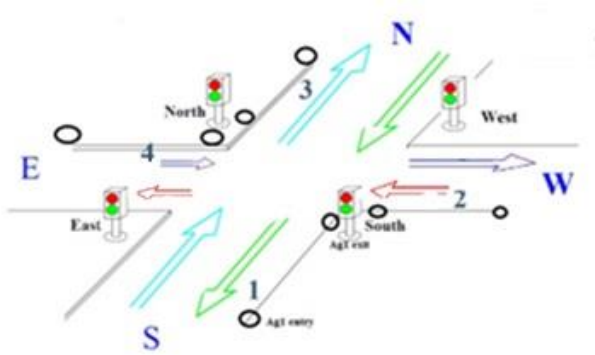

Figure 1.1 Current setup of traffic lights

Traffic lights cycle through the entry points North, South, East and West (N, S, E and W) respectively, giving each point equivalent time to let traffic through. The problem arises when, for example, there is one car on the S entry and four on the E entry. The S entry will be given the same duration as E entry even though there are fewer cars on it, on E. The same argument goes for all adjacent points.

One solution for this problem would be to increase road infrastructure as number of cars increases. The challenge with this solution is that in most medium sized cities like Maseru the land close to the road is already being occupied by buildings that cannot be relocated. The second impediment to this approach is the unavailability of financial means to build new roads.

1.3 Objectives of the Research

The objectives of this research were to solve problems encountered by motorists using IoT; specifically to reduce the occurrences and intensiveness of congestion. The objectives were to: (1) create tools that use IoT to inform motorists of traffic jams, thereby giving them an opportunity to use alternative routes; and (2) use WSNs to control traffic lights in such a way that rate of traffic flow would increase.

This was achieved through the following sub-objectives:

1. To study and analyze the traffic control system of Maseru.
2. To design and implement a system prototype that uses an array of IoT-enabled ‘things’ to alert motorists on congestion as well as suggest alternative routes.

1.4 Research Questions

1. Is there a relationship between congestion and CO_2 emissions?
2. Are there any benefits to implementing reactive traffic lights versus static traffic lights?
3. Would the provision of road status information to motorists have a reducing impact on frequency and intensity of congestion?

The envisaged outcomes of the study include:

1. A tool that can reliably alert motorists of traffic jams.
2. A prototype of a pro-active system that will ensure flow of traffic is more efficient at traffic lights.

1.5 Importance of Research

This research was essential as it demonstrated the possibility of enhancing transport management systems for medium-sized African cities. The improvement of transport management in such cities leads to a reduction in the waste of resources (time and money) that can be more profitably used.

The traffic department in Maseru will benefit from this research as the results will aid in the planning to traffic management as well as provide a means for cheaply implementing a TMS. The tools used in this scheme are relatively cheap and the cost can be outweighed by the benefits. The observations made from phase 2 shows the times at which traffic flow increases; this could benefit the traffic department by depicting the times at which traffic density is high thereby making it possible to better assign traffic officials to monitor the roads.

1.6 Limitations of the Study

It had been envisaged that real traffic lights would be used to monitor the effectiveness of TMS, access to traffic light was however disallowed by city officials citing risks that would be imposed on motorist. A simulations was thus used to investigate the application of IoT in TMS. In addition the study is concerned only with the management of a single isolated signaled junction.

1.7 Contributions

The contributions of this study include the development of relatively cheap tools for intelligently managing traffic. There are traffic management systems that are being used in larger and wealthier cities. The solution being presented here is better suited for African cities as most have limited financial resources. The study also contributes to knowledge of impact of congestion in Maseru to other similar African cities. At present there is no known study regarding vehicular traffic in Maseru.

1.8 Dissertation Structure

This dissertation is structured as follows.

Chapter 2 reviews literature on congestion as a world-wide phenomenon. It looks at causes and possible results of congestion. It also deliberates suggestions on how congestion can be measured and strategies to manage it. The researcher then discourses on the status quo in African countries, followed by technologies that are used in traffic management.

Chapter 3 presents a review of the methodologies and tools that have been employed in the research as well as providing rationale for those tools. Chapter 4 discusses the design and analysis of tools that were employed. Chapter 5 examines results that were observed from the analysis tools while Chapter 6 concludes the research.

Chapter 2 : Literature Review

2.1 Introduction

This chapter looks at relevant literature regarding traffic congestion and technologies that are used to monitor, regulate and possibly eradicate it. Section 2.2 is dedicated to traffic congestion, its causes and measurements, why it is a problem, its results and whether or not it can be completely alleviated. The subsequent sections focus on Wireless Sensor Networks (WSNs), Internet of Things (IoT), and algorithms and technologies that are used to solve problems that arise from traffic congestion.

2.2 Traffic Congestion

2.2.1 Traffic Congestion Definition

There are various definitions of traffic congestion, each depending on the observer's point of view. The first definition relates to *Demand Capacity*, the second to *Travel Time*, and the last to *Cost*, (Aftabuzzaman, 2007). "When vehicular volume on a transportation facility exceeds the capacity of that facility, the result is a state of congestion" (Vuchic, 2005). There has been an increase in the number of road users that has not been met by a corresponding increase in the availability of road networks (Leibling, 2008). The implication is that there are now more cars on roads than when most road infrastructures were built.

In the transportation community, congestion relates to an excess of vehicles on a portion of roadway at a particular time, resulting in speeds that are slower than free-flow speeds (Cambridge Systematics, Inc., 2005). This reflects congestion as a physiological phenomenon experienced by humans. Road users have a pre-determined time-frame (based on past experience) for completing a certain journey. Completing the journey in a longer time than anticipated is taken to imply that the road was congested.

Traffic congestion is otherwise defined as the incremental costs resulting from interference among road users (Victoria Transport Policy Institute, 2014). This definition is based on the accumulative cost a new road participant adds on other road users. The cost is usually in monetary terms attached to making a given trip, either in a form of fuel costs, maintenance costs or tolling.

2.2.2 Traffic Congestion Types

Congestion is divided into three types, these being *recurring*, *non-recurring* (Chow, et al., 2014) and *pre-congestion* (John.M, et al., 2003). *Recurring congestion* occurs at known and expected locations and times; it is known where the congestion is going to take place and in most cases motorists are aware of how to avoid it. This can for example, occur when people travel to and from work. There are also sections in a road network that are known to have bottlenecks not owing to the road infrastructure but to traffic volume.

Non-recurring congestion is defined as unusual or unexpected congestion that happens due to unforeseen circumstances (Cambridge Systematics, Inc., 2005). This type of congestion is not known or anticipated and is usually worse than recurring congestion as more motorists end up being caught up in it and just keep adding to the problem.

The other type of road congestion that is less obvious comes about as result of other road networks being in a congested state. This congestion is called *pre-congestion*, when it has become apparent to road users that there is congestion on a given section of road; motorists who traditionally use that portion of road then transfer to another road (Susan & James, 2006). This results in the formation of 'new' congestion on that road; this may be misconstrued to be non-recurring while it is not so because the cause is congestion elsewhere.

Other types of traffic congestion identified in literature (Vickrey, 1969) are:

- Simple interaction on homogeneous roads which refers to situations that arise, for example when a number of cars are travelling close together, they are bound to travel at a slower speed in comparison to when there was only one car in a particular lane.
- Bottlenecks which occur when several cars move from a network that has more lanes to one with fewer lanes.
- Trigger-neck congestion is created when the narrowing of a lane causes the cars to generate a queue; this queue then impedes the cars that are travelling in the opposing lane.

- Network control congestion: In some countries, there are systems that are created to eliminate congestion; however, these end up being the cause of the congestion. One such example is of a system that was created to maximize traffic flow during peak hours. These systems inevitably end up affecting traffic during off peak traffic and cause traffic jams.
- Congestion due to network morphology: This is where traffic congestion on a segment of road reflects traffic jams on all adjacent sections.

2.2.3 Traffic Congestion Causes

Given the various definitions of congestion and types, it follows that its causes are determined by the definition adopted. The general causes of congestion include: too many cars on a road network, changes in the capacity of road infrastructure, driver behavior, employment patterns, and economic status of a society (Kohei & Steven, 2012). There are three clusters that group causes of congestion depending on their proximity to the actual road network. These clusters are *macro-level dynamics*: causes of traffic that are directly related to the status of the road; *micro-level dynamics*: these relate to causes that are associated with demand of road facilities; and the last is *indirect dynamics,* with random variables that contribute to the commencement of congestion such as weather and events. Figure 2.1 reflects some of the causes of congestion.

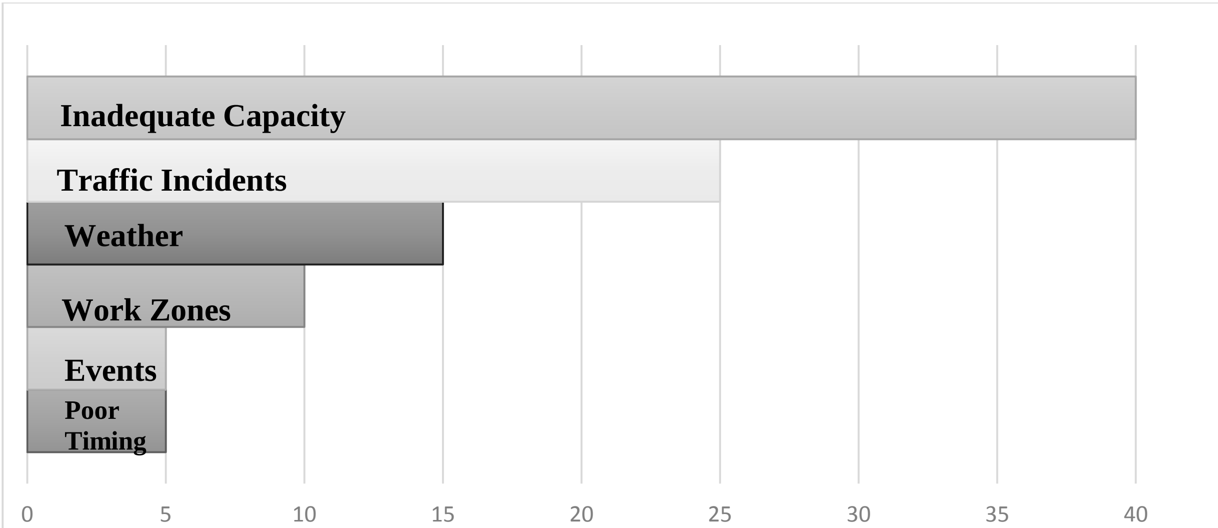

Figure 2.1: Causes of congestion (Chow, et al., 2014)

2.2.4 Costs of Congestion

Costs of congestion involves, amongst others, reduced speeds and increased travel times. All these impose some kind of cost on commuters. In business; these costs are funneled down to consumers of commodities. Some of the costs are environmental (Dachis, 2013), such as noise and air pollution. The costs of congestion are subdivided into two categories.

Direct costs refer to consequences of congestion that are readily observable; when the road network is congested, there are going to be delays. Running and maintenance costs will accrue as a result of the car idling longer than necessary. *Indirect* costs address the less obvious costs of congestion such as loss of life due to accidents and increased commodity prices. Figure 2.2 shows how congestion can be detrimental to a society. The rise in social income leads to the purchase of more vehicles which will in turn lead to less development owing to increased traffic congestion.

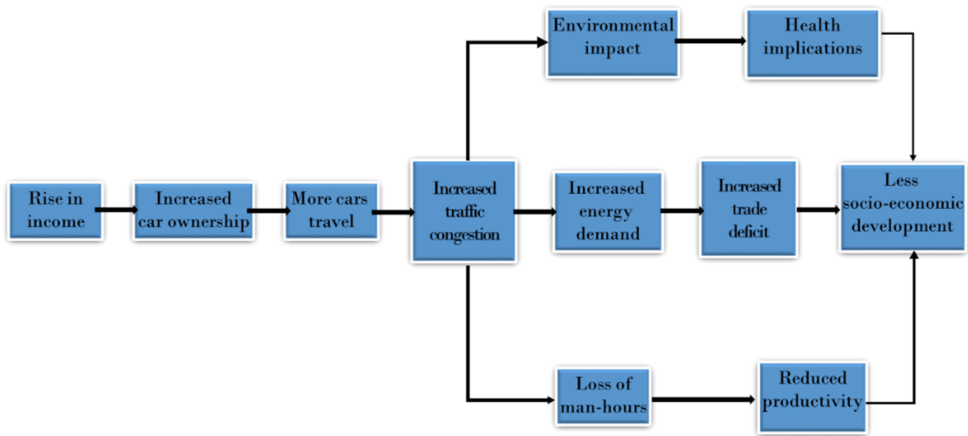

Figure 2.2: Impacts of congestion; adapted from (Takyi, et al., 2013)

2.2.5 Traffic Congestion Measuring

"In order to properly monitor and manage traffic, it has to be quantifiable so as to make it possible to tell if a section of road is in a state of congestion or not" (Bertini, 2006). This requires qualitative or quantitative statistics to ascertain the state of a road facility. Values that are used to measure traffic congestion can be grouped into three groups, these being basic measures, ratio measures, and Level of Service (LOS).

Basic measures are related to the estimation of delay time; delay is defined as the extra time that is imposed on each trip. That is, the additional time that the road user is to travel over a given stretch of road.

Total delay is the sum of time lost on a segment of roadway for all vehicles. This measure shows how improvements affect a transportation system, such as the effects on the entire transportation system of major improvements on one particular corridor. (Medley & Demetsky, 2003). This is used to give the real-time status of the road. The delay is calculated as follows:

Equation 2.1: Calculation of total delay

$$TotalDelay = \lfloor ActualTravelTime(\min) - AcceptableTime(\min) \rfloor \times VolumeOnRoad$$

This measure assumes that there is an already existing value of an acceptable amount of time needed to cover a given stretch of road. However, total delay has a few problems:

- There has to be an already existing metric for acceptable time.
- The measure will be known only after the delay has been encountered, making this measure of delay useless to individuals already stuck in traffic.

Ratio measures are for the most part derived as a quotient of two road congestion factors. Buffer index is the most commonly used ratio and is calculated as follows: The buffer index calculates the extra percentage of travel time a traveler should allow for when making a trip in order to be on time 95 percent of the time. This method uses the 95th percentile travel rate and the average travel rate, rather than average travel time, to address trip concerns (Medley & Demetsky, 2003). The buffer index is in a way predictive and is more useful to individuals who need to undertake a trip and is calculated as follows:

Equation 2.2: Buffer index calculation

$$BufferIndex(\%) = \left(\frac{95^{th}\ \text{percentile travel time-Average travel rate}}{\text{Average travel rate}} \right) \times 100$$

The *Level of Service (LOS)* measure has proved to be most comprehensive measure of traffic congestion due to usage of multiple parameters (William, 1990). The parameters that are used to measure LOS include vehicle density, volume to capacity ratio, average vehicle speed and delay at particular intersections. Figure 2.3 depicts the use of LOS in a multilane highway: the first column is the LOS with ‘A’ being good and ‘F’ being bad.

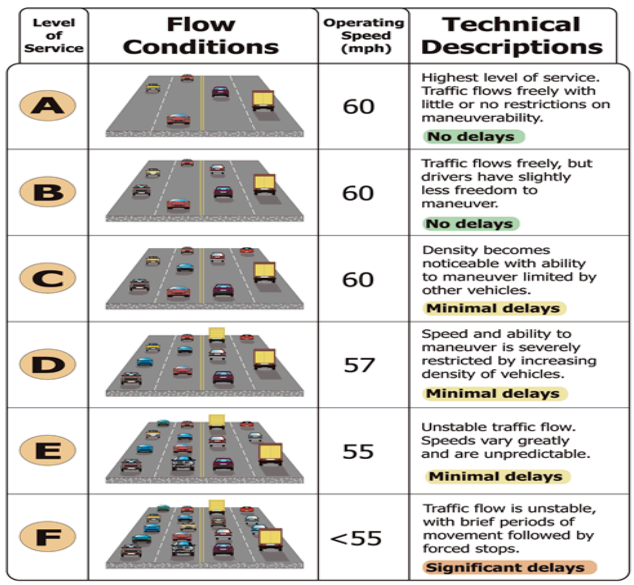

Figure 2.3: Level of service; adapted from (Litman, 2016)

In a 2006 study conducted by Bertini to ascertain a “worthy” measure of congestion, 682 people were asked to mention what measure they would use to quantify congestion; the results are reflected in Figure 2.4.

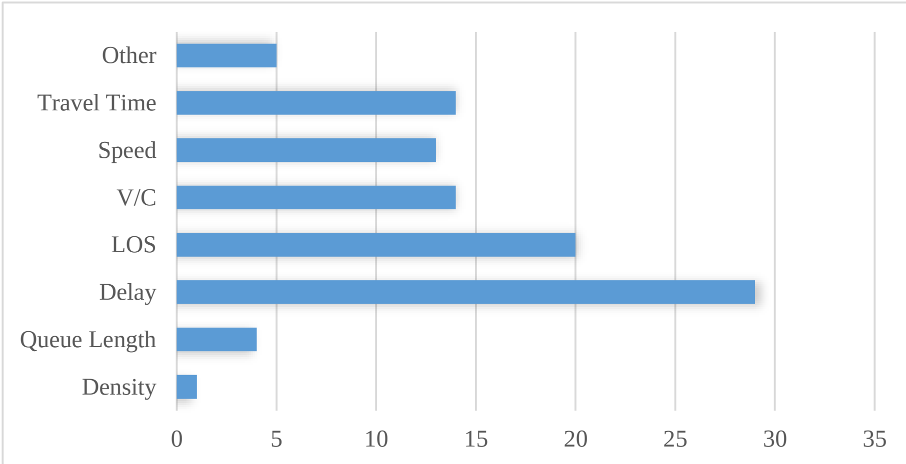

Figure 2.4: Measures of traffic congestion; adapted from (Bertini, 2006)

2.2.6 Traffic Management Strategies

Management and monitoring of congestion has become very important in many countries and has spawned the need for management schemes such as traffic lights and efficient land use (Bhupendra & Gupta, 2015). With regards to traffic lights, there are mainly two strategies that are used: *fixed* and *real time*. The former works with preset timing, the duration of the signal displayed on the light is pre-set from past experience giving no consideration to the current status. The latter relies on real time conditions of the road; decisions of how to manage traffic lights are based on the prevailing traffic parameters such as count of cars, their speeds and direction (Adunya, 2015).

2.2.6.1 *Fuzzy algorithms in traffic management*

The use of fuzzy logic to control traffic was first proposed by Pappis and Mamdani in 1977 (Pappis & Mamdani, 1977). The common parameters used to monitor congestion are number of queued cars, rate at which cars are entering and leaving the queue (hence speed) and average wait time. The implementation of fuzzy logic in traffic management is as a result of unstructured parameters with no empirical method of comparison (Eze, et al., 2014).

Consider that when controlling traffic at a four-way junction, an official might think in this manner: “If traffic is heavier on the north or south lanes than traffic on the east and west, then allow more traffic to flow from the north or south”. ‘If–then’ rules can be used in fuzzy algorithms with the added advantage of quantifying parameters with terms such as ‘longer’ and ‘shorter’. Using intelligent traffic lights will optimize the flow of traffic and reduce congestion (Javed & Pandey, 2015). The idea behind fuzzy logic in traffic management is the algorithm’s ability to draw conclusion on ‘incomplete’ data.

2.3 Congestion in Medium-sized African Cities

African cities have not been left behind when it comes to traffic congestion. The causes of congestion in Africa are, however, custom to the Continent, so may not be solved using solution applied in Western countries.

*Poor public transport facilities**:*** Most public transport operators are more concerned about making money than transporting the public. Buses and taxis are usually overloaded, leading to the vehicles not being able to perform as needed as well as breaking down, leading to congestion.

Poor cycling and walking facilities: In the implementation of systems like the extra charge for congestion, it was made possible for those who chose to cycle and walk to do so in particular lanes (Kayode, 2015).

No such measures have been implemented in most African cities, forcing pedestrians and cyclists onto the road. As a result, motorists drive at reduced speeds to ensure the safety of others, which in turn leads to congestion.

Poor roads: Most roads in African cities are not well maintained owing to financial constraints. This translates to motorists driving at slower speeds, which adds to congestion. In addition to driving slowly, motorists end up driving in lanes they should not be using in trying to avoid potholes, consequently resulting in accidents which create congestion (Thwala, et al., 2012).

Below are examples from African cities:

Lagos Is the largest city in Nigeria, with an annual population growth of 3.9%, expected to be 24 million in 2020 (Ajah, 2016). This makes it the third most populous city in the world (Ajay & Fanny, 2008). A study conducted by Bashiru and Waziri in 2008 found that 57 % of commuters spent an additional 30 to 60 minutes in transit due to congestion (Joseph & Anderson, 2012). A study by Popoola found that 95% of respondents felt they had at some point been stuck in congestion; the same study also revealed that 30% of its respondents felt congestion was at its highest during religious programme days (Popoola, et al., 2013)

Nairobi: It is estimated that the population of Nairobi will reach 5 million by 2020 (Mairura, 2011). It therefore suffices to conclude that if the infrastructure is not massively overhauled, Nairobi will end up congested. It is reported that it takes as much as two hours to travel a distance of 30 to 40 km.

Cairo: One cause of traffic congestion is unique to Cairo which a consequence of the government's fuel subsidies: the implication is that more people can afford to travel in comparison to other countries (Abdul-Wahab, 2013). For this reason and others, such as poor driver responsibility, the travel or drive time is usually increased. The cost of congestion in Cairo is estimated to be at 4% the GDP (Speed, 2014).

Table 2.1 summarizes the status quo regarding congestion in some African cities.

Table 2.1: Congestion in African Cities (Numbeo, 2016)

World Rank	Rank Africa	City , Country	Traffic Index	Time Index (minutes)	CO_2 Emissions Index
2	3	Nairobi, Kenya	313.11	71.05	6687.38
5	7	Pretoria, South Africa	275.67	52.71	12660.00
11	10	Cairo, Egypt	264.87	53.34	9871.50
23	18	Johannesburg, South Africa	227.53	46.13	10485.58
38	35	Cape Town, South Africa	198.69	41.60	9350.44
97	71	Durban, South Africa	146.24	34.43	6008.66

The indices used in Table 2.1 are defined as follows:

- Traffic Index: An average time needed for a one-way trip
- CO_2 Emissions Index: An estimation of CO_2 due to traffic for a two-way trip
- Time Index: Average additional time for a one-way trip.

2.3.1 Congestion in Maseru, Lesotho

Maseru is the capital city of Lesotho; the district in which the city Maseru is situated is called Maseru. The city has a population of 431 998 with the city holding 53% of that population, and has a density of 1652/km^2 (Lesotho Bureau of Statistics, 2010). The Lesotho Demographics Survey stated that there is a general increasing trend of persons coming from other districts to Maseru.

There is a higher population in Maseru due to centralization of business activities (Lesotho Bureau of Statistics, 2010). Migration from other districts to Maseru stood at 19048 individuals in 1986; this grew to 40 774 in 2011. People come to Maseru for employment and later acquire property, such as cars, which adds to the demand on road facility increasing in intensity and consequent occurrence of congestion. There are no known studies that have been done to ascertain the impact of congestion in Maseru.

The number of cars in Maseru has steadily increased over the past 5 years. It was observed by the researcher that an average of 14 ‘new’ cars are registered in Maseru each day, amounting to about 5 079 cars annually. There is no data to corroborate this; the number of new registrations was ascertained using the manner in which vehicles are assigned registration plates: on an incremental manner of a combination of one or two letters and four or three letters respectively.

The relatively cheap Japanese models imported into the country have spawned a new industry: they serve as city cabs. This industry has increased the demand for road facility within the city, hence increasing congestion. This is worsened by reckless drivers who do not adhere to regulations and are often the cause of accidents and congestion.

Overall length of tarred roads has not matched the large increase in the number of cars. Maseru is a small city, with buildings already built on the sides of the road and there has not been any significant expansion in available road infrastructures (Personnel, 2014). This has inevitable led to increasing congestion.

2.4 Wireless Sensor Networks (WSNs)

A Wireless Sensor Network can be defined as a network of devices which can sense their environment and communicate the information gathered through wireless links (Babiker & Bashi, 2015). The data is forwarded, possibly via multiple hops, to a sink that can use it locally or is connected to other networks (e.g., the Internet) through a gateway. The nodes can be stationary or movable and be aware of their location (Buratti, et al., 2009).

The nodes for WSNs are relatively cheap, in relation to the amount of data they are able to collect. WSNs can be used, together with other technologies, to control the environments in which they are placed. Figure 2.5 depicts a variation of Wireless Sensor and Figure 2.6 represents the sensors in a network.

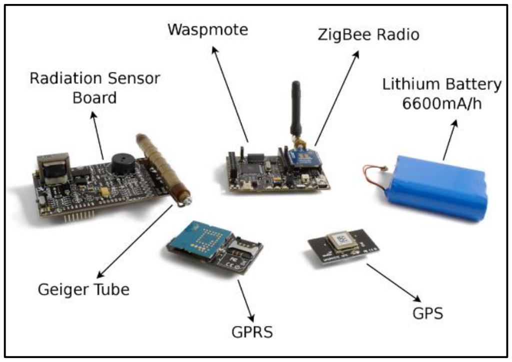

Figure 2.5: Wireless sensor

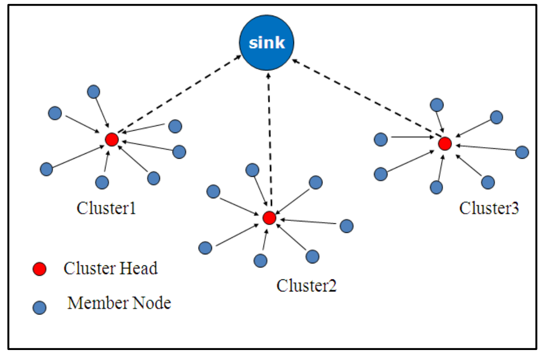

Figure 2.6: Sensors in a network

WSNs are no different from other kinds of networks, with the general idea being the ability to share information. There are several applications of WSNs such as in the security industry, agriculture and smart cities. Table 2.2 portrays the evolution of WSNs. respectively.

Table 2.2: Evolution of WSNs

Quality	First Generation (1980's—1990's)	Second Generation (Early 2000)	Third Generation (Late 2000)
Size	Small as briefcase	Small as books	Small as coins
Weight	Grams*1000	Grams * 100	Grams*10
Deployment Method	Physically set up	Hand Placed	Embedded
Node Architecture	Separate sensing and power modules.	Integrated sensing and power modules.	Integrated sensing, power and communication modules.
Protocols	Proprietary	Proprietary	Wi-Fi, ZigBee, FTP, Xbee
Topology	Point to point	Client server	Peer to peer
Power Supply	Large batteries	AA and AAA batteries	Nanotechnology based, solar and lithium
Life Span	Hours to Days	Days to Weeks	Months to years

2.4.1 Internet of Things (IoT)

Kevin Ashton coined the term the 'Internet of Things' (IoT) while working at Proctor and Gamble (Rose, et al., 2015). The idea of objects with embedded sensors or chips that communicate with each other had been around for over a decade, going by terms such as 'ubiquitous computing' and 'pervasive computing'. What was new was the idea that everyday objects – such as a refrigerator, a car or a wallet – could connect to the Internet, enabling autonomous communication with each other and the environment (The Economist Intelligence Unit, 2013).

The term IoT can be defined as "a self-configuring and adaptive complex system made up of networks of sensors and smart objects whose purpose is to interconnect 'all' things, including every day and industrial objects in such a way to make them intelligent, programmable and more capable of interacting with humans" (Berndt, 2015). Karen, however, states that there is no widely universal definition (Rose, et al., 2015).

IoT is currently a hot topic for research. Some businesses are already making use of this technology: insurance companies are using IoT to provide car insurance based on driver behavior (Young, E, 2016). Although it can be developed such that these objects are able to communicate with humans, the automated communication between these objects may be more beneficial (Srdjan, et al., 2011).

2.4.2 Applications of IoT

The number of physical objects connected to the Internet is constantly growing and has resulted in an increase of environments in which IoT is employed. IoT enables physical object to see and be seen by others as well as enabling communication. IoT is applied in domains such as smart homes and cities, wearables, healthcare, industry and agriculture (Rahul, 2016).

A smart home is a home equipped with devices capable of communicating with each other as well as their environment. A smart home, for instance, gives the owner the ability to close their garage door from a remote location using actuators and the Internet.

A smart city is one that has city-wide monitoring systems capable of managing its various parts, which can include energy management and environmental monitoring (Zanella, et al., 2014).

In healthcare, hospitals are embedding sensors into patients' bodies to monitor their health and in some cases take corrective measures when needed. Patients are fitted with sensors able to assess an individual's cardiovascular systems, alerting doctors when patients suffer a heart attack (Ashrafuzzaman, et al., 2013). Some people wear sensors on their bodies to measure their general health care, for instance sensors that monitor their sleep patterns and heart rate during exercise.

IoT is also being applied in agriculture; there are several aspects of agriculture that determine the quality of produce. IoT is being used to properly manage activities such as watering crops with the correct amount of water at the right time. Drought has a big impact on food sources, so the ability to predict and mitigate the effects of drought is being made possible with IoT (Masinde, 2014).

2.4.3 IoT Framework

The framework for IoT is composed of four layers as presented in Figure 2.7.

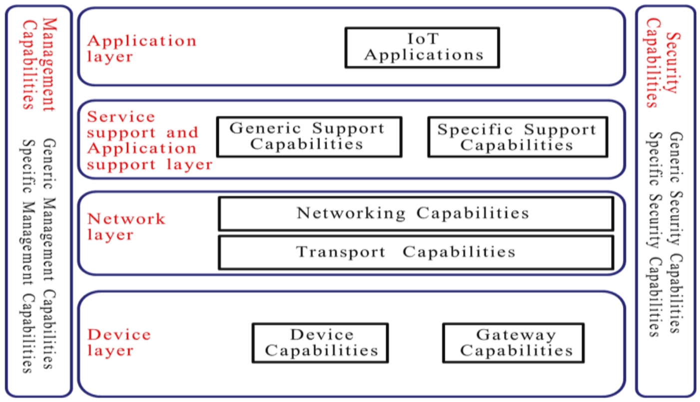

Figure 2.7: IoT reference model (International Telecommunication Union, 2012)

Application layer: This layer is made up of a variety of applications that are used either directly by human beings, or other systems. Further discussion into applications is presented in section 2.3.2.

Service support and application support layer: This layer comprises two entities, the first of which is the generic support capabilities. This component is responsible for the provision of support data applicable to disparate types of applications such as data storage and processing. The second component is the specific support capability; this is responsible for the provision of application-specific functions.

Network layer: The two functions that are handled at this layer are the transport and networking capabilities. 'Networking capabilities' relates to the rules of connection to a given network such as routing and security. 'Transport capabilities' pertains to the transportation of application-specific data.

Device layer: The device layer has two subdivisions, device and gateway capabilities; 'device capabilities' implies that a single device is able to act alone as an end node and sensor while 'gateway capabilities' refers to a device's ability to act with other devices under the direction on one central node.

2.4.4 Ubiquitous Computing

Ubiquitous Computing (UbiComp) is characterized by the use of small, networked and portable computer products in the form of smart phones, personal digital assistants and embedded computers built into many devices, resulting in a world in which each person owns and uses many computers (Bardram, et al., 2010). The consequences include enhanced computing by making computers available throughout everyone's daily life while those computers themselves and their interaction are 'invisible' to the users. The term 'invisible' in this context is used to mean interaction between computer and user in in a more natural manner such as speech and physical interaction, with the computer itself automatically capturing its external parameters while concurrently communicating with other computers (Friedewald & Raabe, 2011). UbiComp proposes many minute, wireless computers that are able to monitor their environments, and communicate and react to monitored parameters.

The use of ubiquitous computing in mobility and transport is regarded as a basis for a new generation of networked and integrated systems to control transport flows (Friedewald & Raabe, 2011). Use of UbiComp makes it possible for drivers to be aware of prevailing conditions before they set out on a trip; with people having access to information in numerous forms, it will be easy and profitable for road users to readily get this information. With UbiComp it will be possible to create Intelligent Transport Systems

(ITS); these are systems that are able to gather data about road networks, make decisions based on the gathered data and provide formatted information to individuals (Bhupendra & Gupta, 2015).

Some present-day vehicles are equipped with sensor and communications capabilities; these capabilities can be used to enable intelligent car and driver assistance, hence increasing safety and efficiency (Fei-Yue, et al., 2006). There has been an advent of cars that are capable of 'self-parking', using proximity sensors to ensure that they do not collide with any physical objects. The concept of intelligent vehicles suggests a need for intelligent environments.

Intelligent environments are applied in transportation by continuously monitoring what is happening and communicating to other users or systems, facilitating 'intelligent' decisions (Saju, 2013). There are vast applications of UbiComp in transport; for this research the focus is on reducing congestion, thereby costs.

With the application of UbiComp in transportation, the following should be realized:

1. Road networks that are able to sense road parameters such as number of cars on the road, the speed of vehicles as well the possibility that accidents have occurred.
2. Real-time reaction to the condition of roads.
3. Real-time dispersal of information in different formats and devices.
4. An ability to learn and predict transportation parameters.

2.5 Intelligent Traffic Management Systems (ITMS)

2.5.1 IoT in ITMSs

There are many applications of IoT in traffic management such as non-stop electronic highways, violation monitoring, and security systems (Linna & Chunli, 2013). The ubiquitous use of IoT in transport management produces Ubiquitous Transport Systems (UTS) – the combination of data sourced from Intelligent Transport Management Systems (ITMSs) and UbiComp. In this context, ITMSs are transport management systems that are able to monitor their own environments. Figure 2.8 depicts the merging of the two technologies, leading to UTSs.

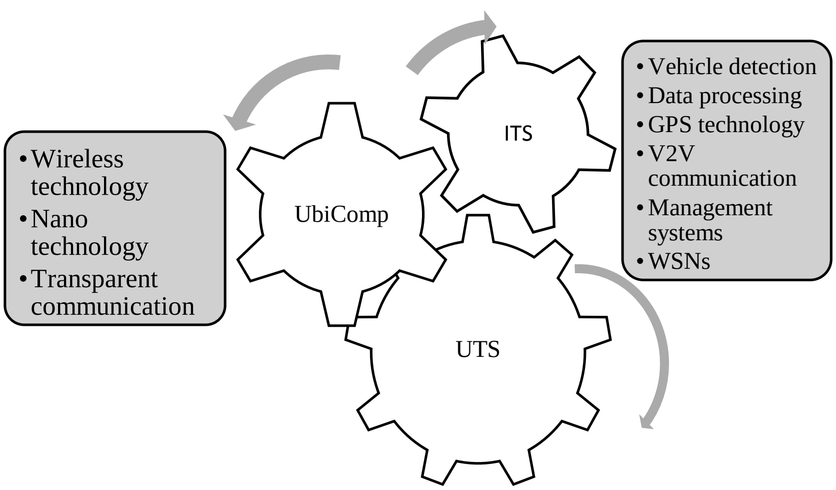

Figure 2.8: Ubiquitous Transport Systems adapted from (Sanches & Rossetti, 2009)

In order for UTSs to be effective, they need to satisfy four outstanding characteristics criteria (Sanches & Rossetti, 2009). These are: (1) transportation services must be available anywhere, anytime; (2) information provided is environment-dependent and device-independent. The interactions with the user are transparent and the services provided are real time. The desired qualities of UTS are that information provided is trustworthy and that it can be accessed by any individual from any location. With technological advancements, UTS will be used not only for provision of traffic information but also Vehicle-to-Vehicle (V2V) communication and Vehicle-to- Infrastructure (V2I).

2.6 Image Processing and Analysis

The rapid development in technology has made research into image processing and analysis very attractive to many researchers. Image processing and analysis have resulted in what has been aptly termed ‘computer vision’. The accelerated interest is born out of the fact that computational expenses have been diminished (Suresh & Lavanya, 2014). This has made it possible to collect and manipulate multi-dimensional signals such as video and pictures. The goals of this manipulation can be spilt into three categories: (1) image processing, (2) image analysis, and (3) image understanding. The remainder of this section will focus on image processing and analysis, concentrating on traffic monitoring and management.

2.6.1 Image Processing

A digital image is described as a 2-dimensional matrix p [*m, n*] that is a representation of an analog signal derived via digitization; the intersection of *m* and *n* is called a pixel. Associated with each pixel is a number that determines its colour, the combination of those pixels results in one image (see Figure 2.13). A true colour image comprises 24-bit colour depth and ability to show about 16 million different colours. A grayscale image has an 8-bit colour depth enabling representation of 256 different shades of grey; this type of image is often called black and white. In addition to above types of images, there is binary image that becomes very important in computer vision. It is known that computers ‘understand’ only binary signals. The ability to convert images from full colour to binary images makes it possible for a computer to 'see'. A binary image has 2-bit depth, resulting in the ability to show exclusively one of two colours, black or white.

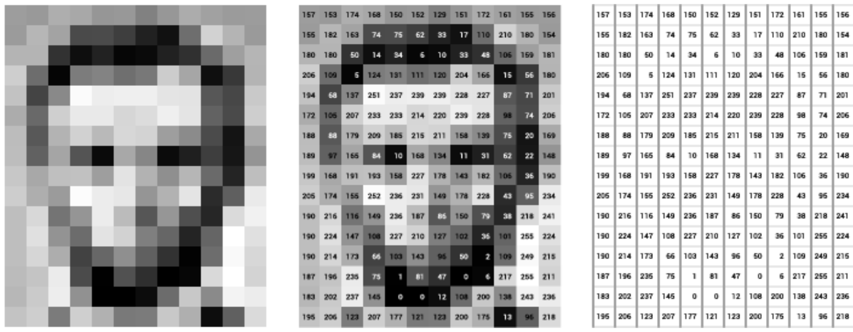

Figure 2.9: Pixel view (Golan, 2016)

2.6.2 Image Analysis

Image analysis is concerned with the making of quantitative measurement from an image to aid in production of models and image interpretation (Young, et al., 2007). The simplest example of image analysis is reading the barcodes off the packaging of items. Complex analysis is required in less mundane applications that necessitate the utilization of more complex algorithms; these range from the power to have robots analyze their surroundings to visual diagnosis of diseases. Image analysis requires the extraction of features that will aid in identification of certain objects. Extraction of these features requires image segmentation such that points of interest may be extracted to isolate objects of interest.

2.6.3 Traffic Management Using Computer Vision

Vehicle identification and tracking approaches are classified based on methodology used. The methodologies through which vehicles are identified include outline, shapes and object models (Meshram & Raskar, 2015).

The earliest approaches to vehicle identification and tracking included the combined or separate application of spatial and temporal analysis on video sequences (Chintalacheruvu & Muthukumar, 2012). In general, vehicle detection and tracking has been performed using one of the following methodologies: (1) point detection and tracking; this methodology is fast and provides consistent results independent of illumination (Hadi, et al., 2014); (2) edge detection, which employs morphological algorithms and which, in comparison to point detection, is negatively affected by diminishing illumination (Shobha, et al., 2015) (3) Frame differencing techniques are relatively easier to implement and yield better consistency and accuracy in comparison to the above-mentioned while also being computationally cheap, although it requires usage of a reference image (Chaple & Paygude, 2013).

Many researchers have attempted to use visual input to count and ascertain speed of vehicles. Rahman proposed the application of stereoscopic vision, using two cameras placed at a known distance apart; this approach, however, requires the calibration of two cameras (Ab-Rahnan, et al., 2005). To mitigate this, a camera that can acquire two images at different viewpoints can be used, but this still presents a problem of reduced resolution limiting the accuracy of detection (Lee, et al., 2015).

2.7 Conclusion

Congestion may be unavoidable as it comes as a result of advancing societies; the number of cars on the roads is constantly increasing and is not met by an equal increase in road infrastructure. The results of congestion have an inherently negative impact on the growth of society; these negatively impact on the environment and general quality of life. Many cities are affected by high volumes of congestion regardless of their size; most

African cities are not directly in the grip of congestion-related problems but are indirectly affected consequent to larger Western cities enduring this problem.

The huge dependency on transportation necessitates better traffic management, and IoT presents methods and tools that can be used to monitor and manage traffic more efficiently. UbiComp introduces a way for provide relevant information to road users in all forms of communication, which should improve traffic patterns. The presentation of traffic information on various transparent platforms may reduce the impacts of congestion.

Many cities are finding it necessary to employ Traffic Management Systems (TMSs); with the advance in computing and paradigms such as IoT coupled with UbiComp, it is now possible to construct intelligent TMSs that are able to react to real-time road conditions and make decision more like a human would while also having the ability to learn from the past. The decisions can then be ubiquitously made available to road users everywhere without them having to source the information themselves.

Chapter 3 : Research Methodology

3.1 Introduction

This chapter outlines the research methodology that was used in the study as well as providing rationale. The chapter also discusses the population and sampling techniques that were employed, and instruments used to collect and analyze the data, including methods implemented to maintain validity and reliability of the instrument. The research was conducted in four phases and the research design will thus be discussed in four phases.

Data in phase 1 was collected using a qualitative approach, while phase 2 was quantitative. Phases 3 and 4 were on use of cameras to collect traffic parameters and comparison between preset timing and reactive traffic lights respectively. Phase 3 was an experiment while phase 4 was a simulation.

Phase 1 involved finding out views and perceptions of road users about congestion in Maseru. The data for this phase was collected through structured questionnaires, while the goal of phase 2 was to discern if there is any relationship between number of vehicles on roads and concentration of CO_2. Descriptive research was implemented in which observations were recorded and later analyzed. Two classes of observations were made, first of which was to monitor concentration of CO_2, while the second was counting number of cars that passed given points in the city.

Phase 3 concentrated on determining a count of vehicles on a section of infrastructure as well as their speeds. The sensor that was used for this experiment was a camera. Phase

4 focused on the comparison of effectiveness in reducing wait times of fixed timing and intelligent traffic lights. A simulator was used in the experiment as access to traffic lights could not be secured due to safety reasons.

3.2 Research Setting

‘Research setting’ refers to the location in which data was collected, which was Maseru, Lesotho. There is no known literature regarding some of the subjects of interest in this study. No literature was found that discussed congestion and its impact on the city and its citizens. In addition, no current data was found that discussed vehicular traffic in the city. For that reason, the research made use of observations and knowledge that the researcher had about the city as a resident of the city.

3.3 Phase 1 (qualitative methodology)

3.3.1 Populations and Sampling

A population is a collection of all entities involved in a study on which a researcher wants to generalize findings. In this study the population was all road users whose total number is unknown and assumed to be large. As a result, a sample was used to gather data, a sample being a smaller but representative subset of a population. The sample size needed to be large in order to reduce the sampling error but remain manageable. A 95% confidence was desired on the sample data, so a sample of 370 individuals was calculated as necessary.

Stratified sampling was implemented on the population. Stratified sampling is a sampling technique that allows for the population to be broken up along discernible borders. The sample size was then equally shared between the strata, resulting in 94 respondents per stratum. The strata are shown in Table 3.1. Simple random sampling was employed to locate respondents of each stratum.

Table 3.1: Road user's categories/stratum

Category	Description	Types of Vehicles
Public transport operators	These are the individuals that provide shared transport that is available to the general public.	• Taxis • Cabs • Buses
Private transport	These are the individuals who drive their own cars and use them to perform their own private tasks.	• Sedan • Vans
Delivery personnel	These are persons that are hired to transport products from one location to another.	• Trucks • Van • Motorbikes
Pedestrians	Persons who are travelling on foot.	• N/A

3.3.2 Questionnaires

Data was collected using questionnaires from the noted strata from April 2015. This method of data collection was selected because it permits the solicitation of a large number of opinions. To validate the questionnaires, a pilot study was run and collected data was used to ascertain if questions were clear and would be helpful in meeting objectives.

Questionnaires were printed in both Sesotho and English and were read to those who could not read; however, there was the challenge of people's unwillingness to get involved. In order to reach the desired sample sizes, in addition to questionnaires that were manually distributed, Google Forms were used to run the same surveys online.

The links to the questionnaires were shared on social media; one online questionnaire is available at liphoso.site11.com/Questionnaire/PrivateCarDrivers and is also provided as appendix.

3.3.3 Data Analysis

3.3.3.1 *Questionnaire coding*

Questionnaires were separated into four sections; section 1 was to gather respondent's demographics, section 2 their driving pattern, section 3 their views on congestion in the city, and section 4 was reserved for their consent to use provided data in the study.

Analysis is the activity of examining presented data with the goal of gaining a deeper understanding. Possible responses from questionnaires were coded using SPSS (Statistical Package for Social Sciences); Likert Scale was used for sections 2 and 3. Questions to which respondents had not replied due to questions not being applicable to them were given a code of '999'. Missing values were coded '99' and invalid responses were coded '-1'.

3.3.3.2 *Statistical analysis*

The analysis sort to find relationships between variables involved running amongst others correlation analysis. Descriptive functions were also run on the data, the results of which were graphs and charts that showed frequencies given variables had assumed. Figure 3.1 gives an outline of how the survey was conducted.

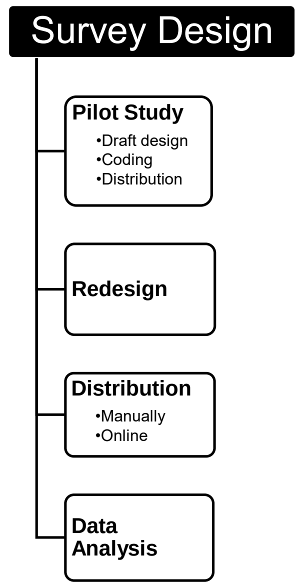

Figure 3.1: Survey design

3.4 Phase 2 (quantitative methodology)

For this phase, two observations were made; the first concerned with monitoring concentration of CO_2 was conducted from September to August 2014, The second whose goal was to find the number cars was conducted from April to May 2016. Each of the two is discussed below. This phase was conducted to find out of there is a relationship between the number of vehicles in a vicinity and concentration of CO_2 within the same vicinity. It was also of interest as the results would show whether the carbon footprints of cities may be reduced using IoT based TMS.

3.4.1 Carbon Dioxide Concentration

3.4.1.1 *Populations and Sampling*

As there were many intersections and roads making up a large population, a sample of 10 roads and 10 intersections was decided on. The 10 roads were selected such that five were major roads entering/exiting the city while the remaining were 'smaller' roads. On the other hand, five intersections selected were signaled with the remaining not signaled. Purposive sampling was employed to select the roads and junctions; this sampling technique was selected as it would allow observations to be recorded in areas that would not easily be impacted on by environmental factors such as proximity to industrial areas.

3.4.1.2 *Data Collection Procedure*

These observations were intended to reveal a relationship, if any, between traffic congestion and CO_2. There is a general agreement that the Earth's temperature is increasing, a phenomenon called global warming. There is, however, disagreement on causes and consequences of this increase (Southwick, 2016). There are scientists who insist global warming is manmade and that increased CO_2 is one of the causes of global warming, while others consider it to be a natural occurrence (Hollander, 2003).

To monitor levels of CO_2, Waspmote Gases 2.0® developed by Libelium designed to monitor gaseous parameters was used. The technical specifications of the board are listed below and the board shown in Figure 3.4 (Libelium Comunicaciones Distribuidas, 2013).

Weight: 20 grams

Dimensions: 73.5 x 51 x 1.3 mm

Temperature Range: [-20ºC, 65ºC]

Board power voltage: 3.3V and 5V

Sensor power voltage: 5V

Maximum admitted current: 200mA

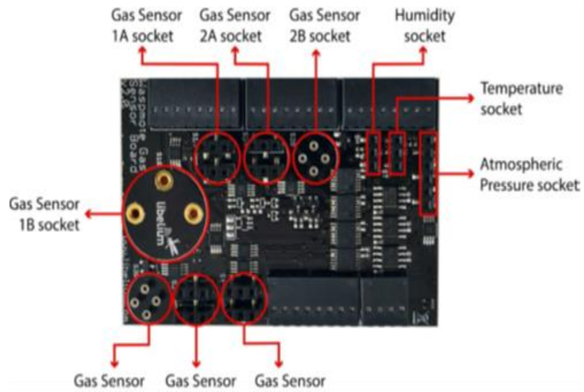

Figure 3.2: Waspmote Gases 2.0

The CO_2 sensor recommended by Libelium is the TSG4161; it is responsible for collection of levels of CO_2. It works by providing a voltage output relative to concentration of the gas; it has two inbuilt electrodes that have a solid electrolyte in between them together with a heated substrate. The concentration of CO_2 is given in volts and is monitored by observing change in Electromotive Force (EMF) generated between the two electrodes (FIGARO USA, 2012). Parts per million (PPM) is the proportional measurement of a quantity of a certain contaminant contained in a million parts of another substance. As the sensor gives readings in voltage, equation 3.1 (recommended by Libelium) was used to convert values to PPM. The sensor motes were programmed using the Waspmote Integrated Development Environment (IDE).

In order to improve sensor's functionality, accuracy and data consistency the sensors were calibrated before being used and two sensors were used concurrently. Concentration of CO_2 was monitored every 5 minutes from time of deployment and collected data was sent to a remote database via the GSM module on the board as it did not have sufficient memory. For each record that was made, concentration of CO_2, current time, name of the road/junction and GPS coordinates of that location were recorded.

The following challenges were met: (1) The mote's Global Positioning System (GPS) and Global System for Mobiles (GSM) modules were affected by its positioning and availability of cellular coverage respectively; (2) rainy weather made performing the observations impossible as the mote is not to come in contact with liquids and covering it would affect the accuracy; (3) uploading data was not constant as it failed at times – this was attributed to availability and strength of GSM coverage, mitigated by simultaneously storing results on the SD card residing on the mote and periodically recovering it.

The general work flow that was followed is presented in Figure 3.3.

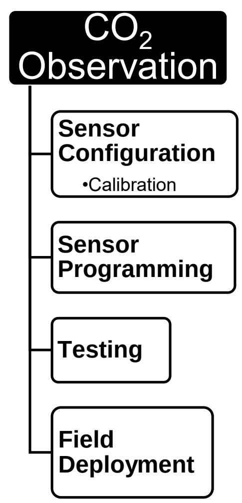

Figure 3.3: CO_2 observation design

3.4.2 Car Counting Observation

The count of vehicles passing a road or junction was gathered and the data was used in collaboration with data from previously discussed observations. The same roads and junctions as used for CO_2 observations were used to ensure data consistency. The assumption made was that the day-to-day density of a road or junction would not have changed significantly in-between the two observations, allowing for data to be used as one set.

3.4.2.1 *Data Collection Procedure*

To count cars, an Android mobile application was used. The application, called TallyTimed Counter and developed by apps cooker, was freely available in the Google Application Store. It allowed for easy counting of cars by simply tapping on a button. The applications also captures the time each car ‘passed’, thus facilitating easier analysis. Data was collected over a *daily* period from 6 am to 6pm. Comma-Separated Values (CSV) files generated by TallyTimed Counter were converted to spreadsheets.

3.4.3 Data Analysis

The results of the two above observations were analyzed using SPSS and Excel. Times and locations during which observations were recorded made it possible to merge their data such that the number of cars observed at a given time could be matched to a certain degree with a time at which a record about CO_2 concentration was made. The statistic that was of interest here was correlation between concentrations of CO_2 and number of observed cars.

3.5 Phase 3 (camera experiment)

This experiment was intended to observe if count of vehicles and their speeds could be accurately recorded using a visual sensor; to validate the results the real speed and count of vehicles were recorded and compared. Use of a radar gun was negated by its cost; this would have been advantageous as it is *very* accurate. A vehicle with cruise control was used with set speeds used as *real* speeds.

3.5.1 Data Collection Tools

The camera that was to be used was the Libelium Video Camera Board. The sensor was eventually not used as a result of unclear pictures; a Panasonic G80 was used instead. The programming language used was C++ and OpenCV was implemented. The camera was mounted on a tripod for stability and recordings of vehicles made on the road.

3.5.2 Data Analysis

What was of interest in this phase was finding how close the calculation made would be to the *real* speeds. The experiment was repeated numerous times and comparisons of the times made.

3.6 Phase 4 (traffic flow simulation)

A simulation program called Traffic Light Controlling Comparator (TLC Comparator) developed by Intelligent Systems Group at the University of Utrecht was used for simulation. This program is an extension of a program called Green Light District. The application employed several algorithms such as fixed timing, longest queue and machine learning algorithms to simulate the flow of traffic. The program then calculated average wait times encountered at traffic lights. A four-way junction was built using this program, and then simulations for fixed durations and FuzzyN algorithms were run.

Fixed durations algorithms simulate traffic lights with fixed durations for each phase while FuzzyN allowed the use of N fuzzy parameters. The parameters used were vehicle count and average speed. The parameter of interest was the comparison between the wait times of the two algorithms. Figure 3.4 shows the GUI of the used application.

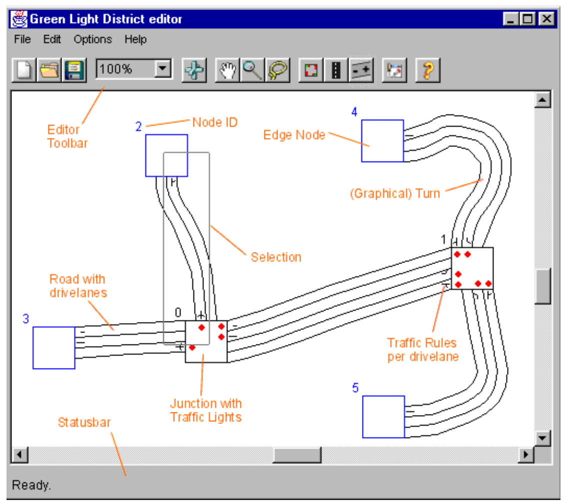

Figure 3.4 GUI of TLC Comparator

3.7 Conclusion

The research design and methods of analysis were described in this chapter. The populations as well as sampling techniques that were used during data collection were also discussed. The analysis and results will be discussed in later chapters.

Chapter 4 : Analysis, Design and Implementation

4.1 Introduction

This chapter discusses the design of the proposed solution. Section 4.2 sets out the architecture/framework of the solution. A software framework is a collection of computational components or components together with a description of the interactions then (Cristina, et al., 1995).

4.2 Early Warning System (EWS)

The proposed system is an Early Warning System (EWS). An effective EWS needs to be low-cost, applicable and usable.

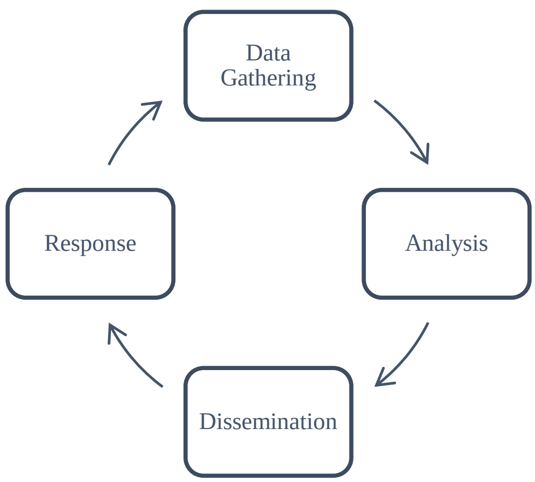

Figure 4.1: Components of an Early Warning System

Figure 4.1 depicts the general structure of an EWS; the four components can be applied in intelligent traffic monitoring whose possible implementation is given below (Masinde, 2012):

1. Data Gathering: in intelligent traffic management, this is the collection of real time traffic conditions being done in one of two ways.
   a. Use of mobile devices to gather data directly from road users.
   b. Employment of WSN in the collection of real time traffic data.
2. Analysis of collected data: the collected data needs to be processed in order to present it in a manner that can be understood and useful to others to enable the discovery of congestion.
   a. Use of fuzzy methods to ascertain levels of congestion.
3. Disseminate information to users and other external systems:
   a. Communication of traffic data via multiple channels such as sms, emails, public broadcasts (television and radio).
4. Based on resultant information, use actuators to effect the environment:
   a. Use of fuzzy methods to extend 'green' time on traffic lights with intention to ease traffic.

4.3 Generic Architecture

Putting together the various components of an EWS resulted in an architecture that was employed in the development of an ITS with three main components: (1) data collection, (2) integration and analysis, and (3) control and dissemination. The architecture is shown in Figure 4.2.

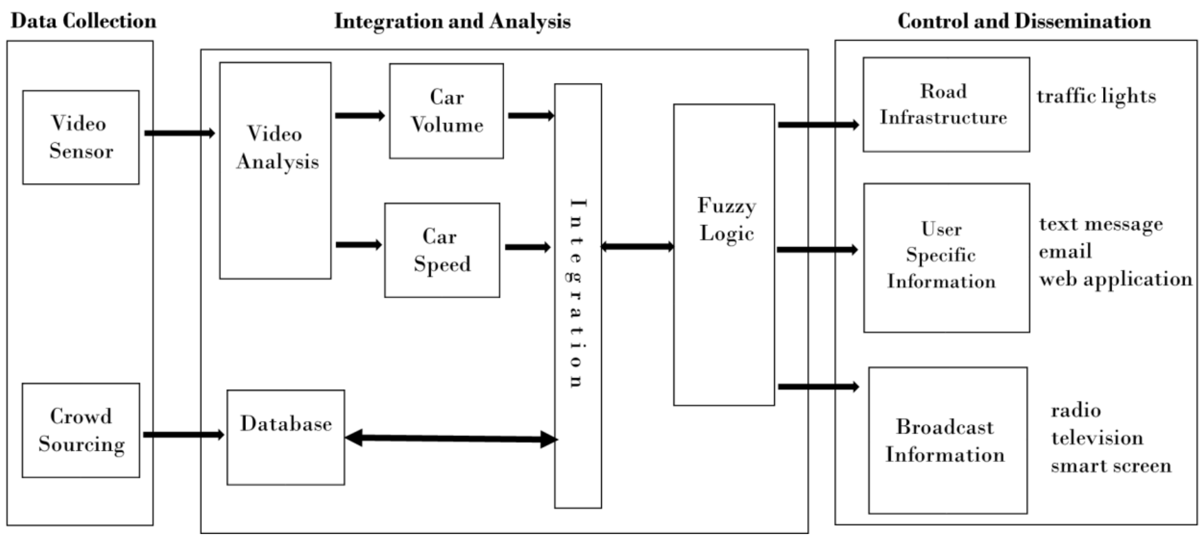

Figure 4.2: Intelligent traffic systems framework (source: author)

4.3.1 Data Collection

This layer is responsible for the collection of actual traffic data from the road. Data from the road is sourced in one of two ways: (1) Data is collected through wireless sensors; in this case the sensor is a camera. (2) The second manner in which data is collected is from motorists (crowd-sourced) via any computer that the motorist is using and is regarded to be the sensor. The collected data needs to be real time so that the ITS can provide reliable and usable information. The traffic parameters that are collected are number of cars counted and speed of individual cars; this counting of cars then makes it possible to calculate the 'needed' parameter – *road segment density*. Data that is gathered from road users includes type of phenomenon on the road and the observed or expected duration of delay resulting from that obstruction if any. The ways of collecting data is discussed below.

4.3.1.1 *Crowd Sourcing*

This is achieved via a web application (web app). The web app has more functionality than gathering traffic data from users; however, in this section only its functionality of gathering data is considered. A web app was selected because it removed architectural dependency which would have been encountered if development was done natively.

A user can navigate to *update* where they have the opportunity to modify road parameters such as expected additional time to spend. A user can also add a *new* point; however, in adding this new road, the user will need to be on that segment of road at the time with Global Positioning System (GPS) enabling on their device. Figure 4.2 shows the views for adding and updating road status respectively (as viewed from a cellphone) while table 4.1 lists the causes of congestion.

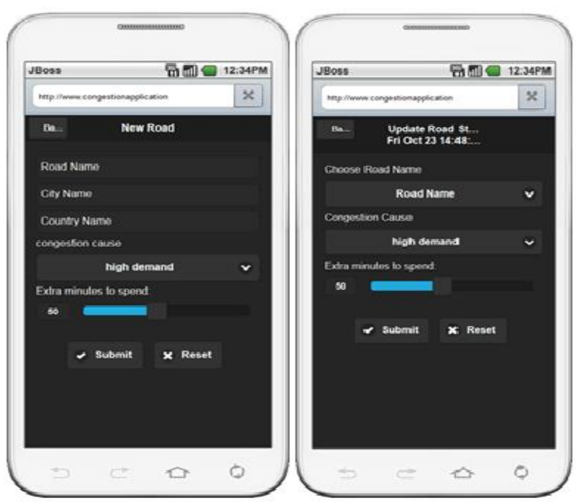

Figure 4.3: Web pages for adding and updating a road status

Table 4.1: Description of causes of congestion

Cause	Description
High demand	Resulting from a non-clear cause, there is more demand for road infrastructure than "conventional".
Accident	There has been a collision on the segment that is making drivers drive slower than "normal".
Road works	There is construction on the road as a result of which the flow of traffic is impeded.
Poor timing	The traffic light cycle does not allow for best flow of traffic.
Weather	As a result of weather, traffic is flowing at a less than optimal rate.
Events	There is an event that is occurring nearby which is has an adverse effect on traffic flow.
Other	The flow of traffic is hindered due to other reasons.

4.3.1.2 *Video Sensor*

The main objective of the sensors in this study is to gather traffic parameters. The parameters of interest are (1) count of cars on the road (2) the speeds of travel. There are several technologies that can be implemented to collect these parameters; including inductive loops, acoustic sensors and visuals. Inductive loops have an installation drawback as the road infrastructure will need to be excavated.

The drawback with using acoustics is that a city is an inherently noisy place, so the noise from the surroundings would have an adverse impact on the quality of the data that is gathered. Using pneumatic tube**s** would need excavation on the road which would be costly and disruptive to the flow of traffic. Consequently, the use of video cameras presents a 'better' solution. Below follows a discussion on how parameters of interest will be extracted from the video recording.

Counting cars involves segmenting the video stream into frames, then observing the changes from one frame to another. The calculations of speed involve the use of intrinsic and extrinsic components of the camera.

4.3.2 Integration and Analysis

This element of the framework is responsible for:

Analyzing the video that has been received from the cameras. The video analysis in performed using OpenCV (Open Source Computer Vision), which is a set of libraries that are aimed at computer vision, launched in 1999 by Intel Research. The storage of crowd-sourced data and data received from 1 was handled using MySQL which is a Relational Database Management System (RDMS) which uses Structured Query Language (SQL). Lastly, making decisions based on the data from the database, which is handled using fuzzy logic.

4.3.3 Control and Dissemination

This module contains three subcomponents. Two modules (user-specific and broadcast information) are used to present information to motorists in a ubiquitous manner. The ubiquity comes as a result of the information being provided seamlessly to the road user on multiple platforms. The road information can be targeted to a user based on requests as email or sms. The status can otherwise be broadcast to many users at once using either radio or television. The third subcomponent is responsible for controlling the phases of the traffic lights. The resulting decisions from the fuzzy logic will be sent to the traffic lights which will then show different lights.

4.4 Working Environment

The environments chosen are C++ and Java, the computer used was a 64 bit dual-core 2.20 GHz with 4GB of RAM. OpenCV was used as the video input-processing tool. To handle the sending and receiving of text messages, Ozeki SMS gateway was used, which allows for text messages to be sent directly to an application. For the design of the web application, a combination of Hyper Text Markup Language (HTML), JQuery, JavaScript Object Notation (Json) and Java Servlet Packages (JSP) was used. The web app is accessible from a device that has a web browser such as computers and mobile devices, given that the browser is compatible with the coding used. The implementation was handled in Java Servlet Pages (JSP) with jQuery Mobile embedded.

4.5 Video Processing to Acquire Speed and Count

Figure 4.4 reflects the chronological order of obtaining the count and speed of vehicles as observed on the video stream.

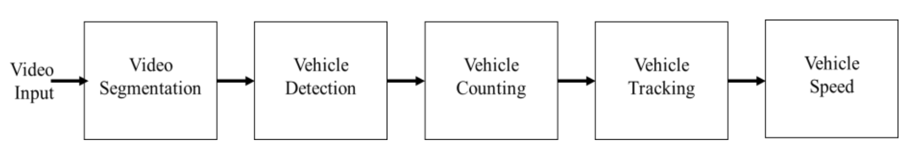

Figure 4.4: System overview

4.5.1 Convert video from RGB to grayscale

A grayscale image contains only 8-bit data per pixel, resulting in a smaller dataset in comparison to an RGB image. To convert an image from RGB to grayscale, one of the methods uses the average values of the RGB colour pixels using the equation shown in equation 4.1.

Equation 4.1: Average conversion to grayscale

$$Y = \frac{R+G+B}{3}$$

The *Y* variable is the grayscale value, R the red, G the green and B the blue respectively. This method is computationally cheap and easy to implement but yields an unnatural greyscale image. The unnatural colour may come about when for two different pixels the numerator in equation 4.1 gives the same result while the actual RGB values are different.

To mitigate this, a conversion method recommended by the Radiocommunication sector of International Telecommunications was implemented (ITU-R) and is also used in most televisions. The conversion method is shown in equation 4.2. This method yields a more natural grayscale.

Equation 4.2: Weighted conversion to grayscale

$$Y = 0.299R + 0.587G + 0.114B$$

Function 4.1 Gaussian filter function

$$G(x,y) = \frac{1}{2\pi\sigma^2} e^{\left(\frac{-\left(x^2+y^2\right)}{2\sigma^2}\right)}$$

Following grayscale conversion, most studies smooth out the image using noise removal algorithms such as the Gaussian Blur. In this study this was not implemented as the resulting image was clear enough and the camera used was stabilized with a tripod during testing. The mechanism for Gaussian Blur (Smoothing) is done at pixel level using the function shown in Function 4.1, where x and y are the row and column locations of each pixel on the image and σ the standard deviation. The before and after images of the conversion to grayscale are reflected in Figures 4.5 and 4.6 respectively.

Figure 4.5: RGB image

Figure 4.6: Grayscale image

4.5.2 Foreground Estimation

There are various techniques that are used for foreground estimation within a video stream. The method chosen and implemented in this study is frame differencing. This method is easy to apply and computationally inexpensive. It relies on comparing two consecutive frames. With this, it is taken that the video stream was recorded with one camera; therefore the sizes of the images and frames are the same.

The result of comparing two consecutive frames is a new image that shows all the differences between them. The difference is then translated to the presence of motion from the first frame to the second. Let f_k be the *k*th frame and f_{k+1} be the neighboring *k+1*th frame with $P_t(x, y)$ being the pixel at location (*x*, *y*) in on the *t*th frame and δ be set threshold values, function $FE_{f_k, f_{k+1}}(x, y)$ is used to estimate the foreground between frames f_k and f_{k+1} is defined in function 4.2.

Function 4.2 Frame differencing

$$FE_{f_k, f_{k+1}}(x, y) = \left(\left| P_{f_{k+1}}(x, y) - P_{f_k}(x, y) \right| > \delta \right)$$

$$FE_{f_k, f_{k+1}}(x, y) = \begin{Bmatrix} 1, \ P_{f_{k+1}}(x, y) - P_{f_k}(x, y) > \delta \\ 0, \ otherwise \end{Bmatrix}$$

The result of the function is a binary image in which every pixel whose result of $FE_{f_k, f_{k+1}}(x, y)$ is set to 1 and will be white if the difference is larger than δ and set to 0, hence black otherwise. The threshold to which the pixel difference is compared is used to reduce the noise within the video stream. The value of the threshold lies on intrinsic and extrinsic parameters of the camera being used.

4.5.3 Vehicle Detection and Counting

In order to establish whether the detected motion is a vehicle or not, Binary Large Object (blob) detection was implemented. The frame differencing methodology is very sensitive and would be able to detect moving branches of a tree. Given that the camera is within a city, it was also desired for the motion of people not to be considered.

The blob detection function in OpenCV is a function that groups pixels that are in "motion" together, bounded by those that are not moving. This would consequently group those pixels within the same area of the frame together if the pixels are white and surrounded by black pixels.

The function then allows for the storage of each blob, also availing parameters about the blob such as size, circularity and convexity. In a city cars – or vehicles in general – will be the largest moving objects, hence the size parameter was used to then classify a blob of a given size as a vehicle. The exact size of a blob that would then be classed as a vehicle was reliant on the location of the camera in relation to the road.

As each blob enters the region of interest (ROI), it is assigned an identification number, a frame number, a time stamp, the (*x, y*) coordinates are extracted and this value are stored. A bounding box is also created on the blob with the center of the blob being used as the center if the box. As each box in created, a counter keeps count of all the blobs in the RIO and this parameter serves as the count of cars that are in the scene. The red box around the vehicle in is the bounding box that has been drawn, see figure 4.7.

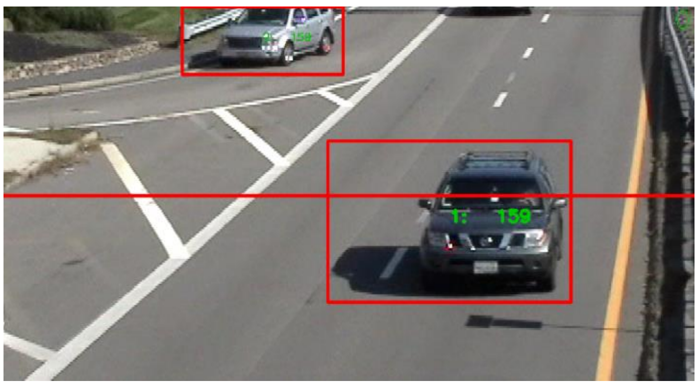

Figure 4.7: Object detection

4.5.4 Vehicle Speed

The speeds at which individual vehicles are travelling is calculated using the parameters stored for each blob as well as the parameters of the video stream. Using the blob data that has been maintained from the initial detection of a blob to the time at which the blob is destroyed, the average speed of the vehicle is calculated using the linear motion formula $v = d / t$ where v is the velocity of the vehicle, d is the travelled distance and t is the travelled time.

The time t in seconds during which the blob was in the scene is calculated using the frame at which the blob started being tracked (*blobcreated*, *blobdestroyed)* which is the frame at which the blob was destroyed as well as *framerate,* which denotes the frame rate of the video in seconds, see figure 4.5.

Equation 4.3: Time calculation

$$t = \frac{(blobdestroyed - blobcreated)}{framerate}$$

Let *D also* denote the distance in meters of the ROI – this is the distance that the cars in the ROI would travel while being observed. The speed v at which vehicles are travelling in *m/s* is calculated using equation 4.6 and converted to speed in *km/h* using equation 4.7

Equation 4.4: Speed calculation

$$v = \frac{distance}{\frac{(blobdestroyed - blobcreated)}{framerate}}$$

Equation 4.5: Conversion from m/s to km/h

$$averagespeed(km/h) = 3.6 * averagespeed(m/s)$$

4.6 Fuzzy Logic

Conventional traffic control management at a signaled intersection is implemented with circulation through all entry points into a junction; this methodology fails to deal efficiently with varying degrees of LOS (Javed & Pandey, 2014). The layer is also responsible for assigning each entry point a level of priority; that is, each point is allocated a weight that determines when the lane is to be allowed to enter the intersection. The layer makes use of the collected traffic parameters which are stored in a database. The parameters are extracted from the database and fed to the fuzzy algorithms. The control layer is continued by two main components.

4.6.1 Lane Priority

This module make use of two input parameters, these being the length of the queue on an entry point that is in the red phase (this is the lane that is currently not entering the intersection) and the wait times of each of the entry points; the output parameter is the priority the lanes will each be allocated. Some of the fuzzy rules that are used to determine the wait are illustrated in Table 4.2. The lane that has the highest priority is given right of way on the ‘next’ circulation but will not be allowed entry into the intersection again before each lane has been given the opportunity at least once, as Table 4.2 illustrates.

Table 4.2: Lane priority rules

Queue length	rule	Wait Time	rule	Priority
Short	*AND*	Short	*THEN*	Low
Short	*AND*	Medium	*THEN*	Low
Medium	*AND*	Medium	*THEN*	Medium
Medium	*AND*	Long	*THEN*	Medium
High	*AND*	Long	*THEN*	High
High	*AND*	Short	*THEN*	Medium

4.6.2 Green time extension

The duration of time each lane is allowed entry into the junction (green phase) is also determined using fuzzy logic. This module is responsible for determining how long (in seconds) the green phase of an entry point should be extended; the extension time is capped at 60 seconds with a minimum of 10 seconds. Some of the fuzzy rules that are used to determine the extension time are illustrated in Table 4.3.

Table 4.3: Extension time rules

Queue length	**rule**	**Wait Time**	**rule**	**Extension time**
Short	*AND*	Short	*THEN*	Short
Short	*AND*	Medium	*THEN*	Short
Medium	*AND*	Medium	*THEN*	Medium
Medium	*AND*	Long	*THEN*	Medium
High	*AND*	Long	*THEN*	Long
High	*AND*	Short	*THEN*	Medium

4.7 Integration Framework Ubiquity

This section looks at the relationship between ITS and ubiquitous computing; ubiquitous or pervasive computing refers to computer systems that facilitate communication or interactions between devices in a transparent manner to the humans who are using those devices (Sanches & Rossetti, 2009).

An ITS has been defined as a transportation system that is able to sense its own environment and intelligently react to the prevailing conditions. Coupling that with ubiquity yields what has been coined as Ubiquitous Transport Systems (UTS). UTS is not an entirely new concept; it was intended to be ubiquitous in nature, providing real- time information to road users. Technological breakthroughs like miniaturization of transistor electronics has fueled the need to fully implement ITS as ubiquitous systems. This has further been made possible by the advancement in communication technology and mobile devices. It is now the case that a large percentage of the population has access to some kind of mobile device; by the end of 2014, there were 329 million unique subscribers in Sub-Saharan Africa (GSMA Intelligence, 2014).

UTS can be better explained following a clear description of UbiComp's more eminent characteristics. Firstly, in ubiquitous systems, services must be accessible everywhere, every time and to anyone; a user shall not be required to carry a device around in order to have access to information. In this study, this is taken care of by the provision of value-added traffic information to road users on platforms such as smart screens. With smart screens installed in locations that are frequented by road users, such as malls and bus stops, people will be able to view traffic information without really making the effort to source such information.

Secondly, it is not the devices that are used by humans but their responsiveness to the environment that gives real value to the information provided. The real value of UbiComp lies not in the abilities of devices used by humans but in the value of tools that are able to sense their environment and their ability to analyze the gathered data, make decisions and provide information to all platforms. This is where WSN gets involved for this project.

The bulk of this study lies on the ability to sense the environment, this being the prevailing condition on our road networks. Cameras are in this case used to collect data from the road itself. In addition to this, there is also an implementation of crowd-sourcing; crowd-sourcing has been made possible owing to the increased number of mobile devices and constant connection to some kind of network. The third pillar of UbiComp speaks of provision of information. A ubiquitous system must provide information without users being conscious of the devices used, which will allow the user to focus on more important tasks.

In this research, this has been carried out by supplying traffic information over the radio. The last component of UbiComp is that services must be available dependent on time, location and occasion; there is no value in one knowing that at 13:30, a given street in New York is congested while they are in Cape Town at 17:00. Information must be provided in real time and be of valuable where the consumer is located.

This was implemented in this research in the form of a mobile app that gives the user traffic information on map showing the status where there are or going. The display in Google Maps allows a person to view the road status on any road the wish at any time. The SMS query also facilities acquiring information as and when needed.

4.7.1 Short Message Service (SMS)

The provision of traffic information via SMS works in a series of steps. The figure below is used for illustration; the steps for both an intersection and road query are the same, but only that of a road is shown in Figure 4.8.

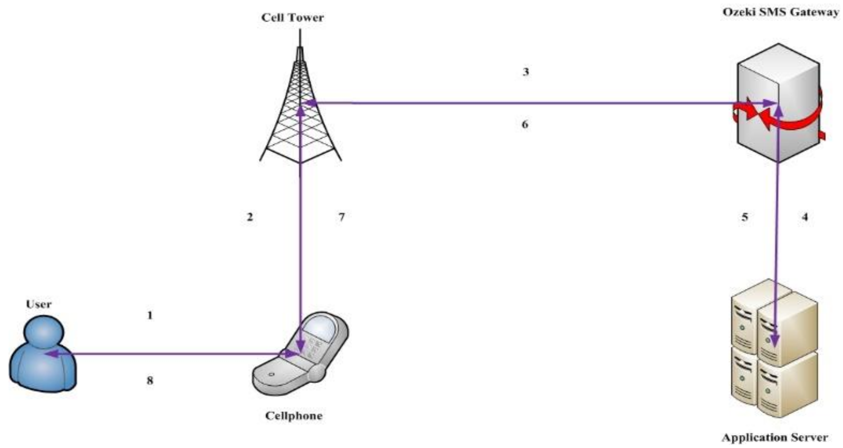

Figure 4.8 Steps for sms query:

1. A user types an sms on a cellphone:
   a. The sms needs to be in a predetermined form; "*City, RoadName".*
2. The sms is sent to known number.
3. From the network, the sms is routed to the sms gateway.
4. The sms is relayed to the application server:
   a. The requesting number is extracted and stored.
   b. The string is extracted to two strings being the "*City"* and "*RoadName".*
   c. The two strings are translated into SQL query and the query is run by the applications server.
   d. The query yields a response; which is the LOS of the road in the particular city.
5. The LOS and the requesting number are sent back to the sms gateway.
6. The gateway converts the LOS to the text of an sms and the querying number is used as the receiving number, the sms is then relayed to the network.
7. From the network, the sms is routed to the correct phone.

8. The user receives and reads the LOS

- For the system to work, the user needs to know the number to which they will sms the querying sms.
- Should the querying sms not meet the predetermined format or the road not be in the database, the responding sms will be "*Something has gone wrong*".
- The user will incur standard sms charges as per provider.
- The speed at which the reply sms will be delivered to the user will depend on their network as well as the network to which the gateway is connected.
- The system may fail to respond if there is no airtime on the SIM card that is used on the gateway.

The relaying of the querying sms from a user's phone to the application layer is made possible by the gateway. A sms gateway is an application that allows text messages to be sent from a phone to an application residing on a given computer. The gateway facilitates the extraction of the sms from the SIM card to by an application, beyond that, the gateway also makes it possible to pass along a message from the application to a phone as a text message.

4.7.2 Radio

This part of the presentation layer regards the display of road status on radio; this is handled by the presentation of information in audio format. Depending on the observed LOS, a road is assigned an audio file that describes the status of the road. It was realized that it will be a challenge to actually broadcast the status of a road on radio;

audio files were then created which would then be played for each road. The envisaged implementation of providing road status in an audio format to the public would be that an audio file would be availed to radio station and have it played periodically during the course of a day.

4.7.3 Web Application

The web app presents the status of the road on a map. The map shows roads that are in the vicinity of the user; this then implies the user will need to have geolocation enabled on their device in order to view the condition of a road. The status of a road is presented with overlays, the colour of the overlay of a road having different meaning, i.e., green means the LOS is at its highest while red means least LOS. The design of this part of the system is handled with Google Maps Application Platform Interface (API).

4.7.4 Smart Screens

In this research, a smart screen is considered as any large visual display unit that is connected to the internet and is viewable by any individual. The smart screens are used to provide traffic information to everyone. Traffic information is perpetually uploaded to the screen, either in the form of tables or a map display.

4.7.5 Email

People who have subscribed get traffic information on roads they have pre-selected at times. One example of usage is that an individual may request to have traffic updates on *Pioneer Road in Maseru* every working day at 16:30. The system would then make a request from the database about this street and email it to the user at the stated time.

Chapter 5 : Evaluation and Testing Results

This chapter provides a detailed account of the findings from observations, surveys and simulations that were presented. Two fundamental goals drove the collection and analysis of data. The goals were to develop a base of knowledge regarding traffic and congestion in Maseru. The second goal was the development of IoT-based tools that can be used to manage traffic effectively by reducing congestion and its consequences by reducing wait times at traffic lights and alerting motorists to congestion.

The chapter is structured in three parts, the first of which discusses the results of the CO_2 observation, followed by the survey on congestion, and finally presents the result of simulations.

5.1 CO_2 Survey

The design of observations both for car counting and CO_2 measurements have been discussed in Chapter 3.

5.1.1 Car Counting

The number of cars was counted using TallyTimed Counter and the results exported to a spreadsheet, the resulting graph is presented in Figure 5.1. The graph shows the average number of cars that were observed per day for 30 days. The total number of cars was recorded to be higher on Fridays and lower on Sundays compared to other days. In contrast, Figure 5.2 shows the number of vehicles recorded against time. The number of cars is seen to be increasing from the morning hours (7 am to 8 am) as motorists travel to work, then decreasing.

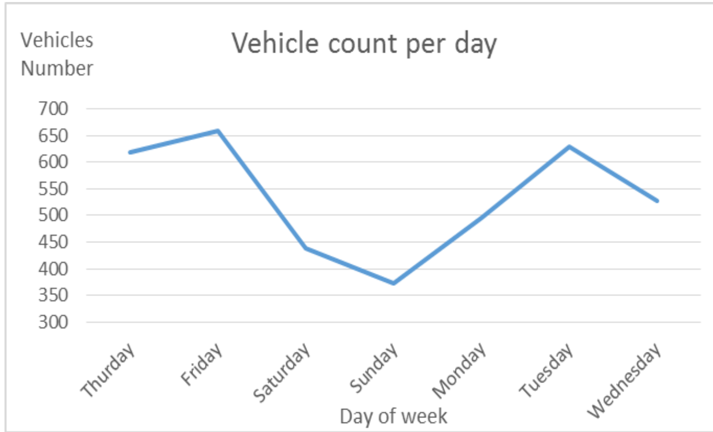

Figure 5.1 Count of cars per day

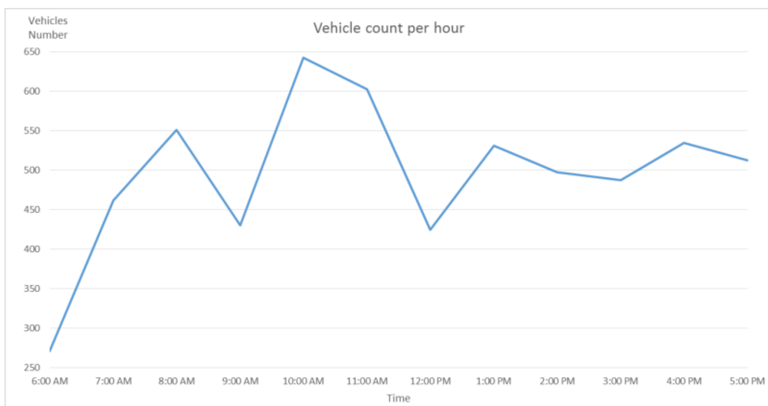

Figure 5.2 Count of cars per hour

5.1.2 CO_2 Measuring

Measuring of CO_2 was conducted with a Libelium gas sensor; Figure 5.3 reflects the results. The graph shows that concentration of the gas was at it maximum in the evening. The gas was at its minimum in the morning hours and steadily increased from then on.

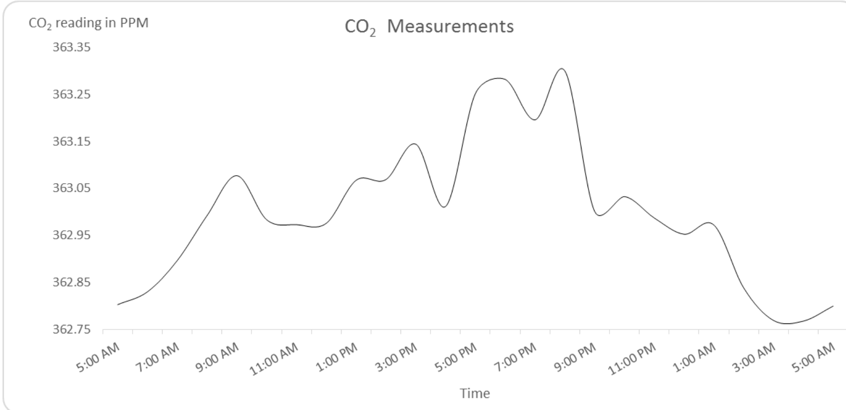

Figure 5.3: Carbon dioxide measuring

The results of the car counting experiment and CO_2 monitoring were combined to establish whether there was any relationship. These results are presented in Table 5.1: the correlation between the two parameters was found to be 0,286, which is very low but positive; a higher correlation had been expected.

Table 5.1: Correlation of CO_2 and count of cars

Correlations

		Carbon Dioxide	Vehicle Count
Carbon Dioxide	Pearson Correlation	1	.286
	Sig. (1-tailed)		.183
	N	12	12
Vehicle Count	Pearson Correlation	.286	1
	Sig. (1-tailed)	.183	
	N	12	12

5.2 Congestion Survey

The design of the congestion survey was discussed in Chapter 3. More tables showing results of the analysis of data are attached as Appendices.

5.2.1 Private motorists

A total of 104 respondents completed the questionnaires and the data was analyzed using SPSS. Findings are discussed as per sections of the questionnaire.

Section A: Demographics

Section B: Driving Patterns

Section C: Congestion

5.2.1.1 *Demographics*

The respondents were asked to select age groups and gender to which they belong. Of the 104 respondents 58 were males and the remaining female; 40% of the respondents were in the age group 25 to 30; 83% of the respondents had smart phones and 80% had constant access to the Internet. A total of 86 respondents had smart phones and 83 respondents had access to the Internet, as seen in Tables 5.2 and 5.3 respectively. It would therefore be possible to provide many users with road conditions using the Internet.

Table 5.2 Smart phone usage

Smart phone

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	No	15	14.4	14.4	14.4
	Yes	86	82.7	82.7	97.1
	Missing	3	2.9	2.9	100.0
	Total	104	100.0	100.0	

Table 5.3 Internet access

Access to the internet

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	No	17	16.3	16.3	16.3
	Yes	83	79.8	79.8	96.2
	Missing	4	3.8	3.8	100.0
	Total	104	100.0	100.0	

5.2.1.2 *Driving Patterns*

This section was to view motorists' observations and feelings regarding congestion. It was observed that 17 of 38 private vehicle owners who travel less than 20 km a day mostly travel with two other passengers. Motorists who travel less than an average less than 20 km noted the most increase in trip duration during congested times (see Table 5.4). This could be resulting from the fact that the density of vehicles is going to increase as distance to town decreases and the level of congestion will also increase.

Table 5.4: Travel time with increase

Distance traveled * Additional Time Crosstabulation

			Additional Time				
			0 (zero) minutes	Less than 20 minutes	Less than 30 minutes	More than 30 minutes	Total
Distance traveled	0 kilometers	Count	1	0	1	0	2
		% of Total	1.0%	0.0%	1.0%	0.0%	1.9%
	Less than 10 kilometers	Count	6	7	10	7	30
		% of Total	5.8%	6.7%	9.6%	6.7%	28.8%
	Less than 20 kilometers	Count	10	8	10	10	38
		% of Total	9.6%	7.7%	9.6%	9.6%	36.5%
	More than 20 kilometers	Count	4	7	12	4	27
		% of Total	3.8%	6.7%	11.5%	3.8%	26.0%
	Missing	Count	2	1	1	3	7
		% of Total	1.9%	1.0%	1.0%	2.9%	6.7%
Total		Count	23	23	34	24	104
		% of Total	22.1%	22.1%	32.7%	23.1%	100.0%

Forty-two percent of respondents reported to have gone against the rules of traffic in order to avoid being stuck in congestion while 37% agree to have been stuck in congestion at some point in time (see Table 5.5). No respondent reported to have received traffic updates on their mobile devices and 26% reported to have received these on television.

Table 5.5 Stuck in congestion

Stuck in congestion

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Always	23	22.1	22.1	22.1
	Frequently	16	15.4	15.4	37.5
	Occasionally	19	18.3	18.3	55.8
	Rarely	26	25.0	25.0	80.8
	Never	20	19.2	19.2	100.0
	Total	104	100.0	100.0	

5.2.1.3 *Congestion*

Respondents were also asked if they felt that congestion had a negative impact on the environment. The results are shown in Table 5.6: of the 105 respondents 37% agreed that congestion added to the cost of maintaining their vehicles; 40% of the respondents felt that routine updates would decrease their chances of being stuck in congestion.

Table 5.6 Responses to negative impacts

Negative impact

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Strongly Agree	19	18.3	18.3	18.3
	Agree	23	22.1	22.1	40.4
	Undecided	19	18.3	18.3	58.7
	Disagree	18	17.3	17.3	76.0
	Strongly Disagree	25	24.0	24.0	100.0
	Total	104	100.0	100.0	

5.3 Vehicle Simulation

Two simulations were run with the statistic of interest being the average junction wait time. Fixed-timing simulation was run in such a way that every entry point into the junctions was given 25 seconds per phase. The results of the simulation are shown in Figure 5.4. The total number of cars that crossed the junction was 302 and the average wait time was 56 seconds. The simulation that used fuzzy logic was ran and the results are shown in Figure 5.5. The total number of vehicles that crossed the junction are 629 with an average wait time of 48 seconds representing a 14% decrease in wait time.

The above result indicates that reduced wait times and increased rate of flow at traffic lights can be reduced using IoT. This will lead to a reduction in the concentration of pollutants that result from exhaust fumes as the number of vehicles stationary will be reduced. The benefits of reduced CO_2 concentration in cities is beneficial as it would reduce the carbon footprint of the city and make for a cleaner environment.

Statistics (at cycle 1016)

File Options

Statistics for simulation "Fixed-Timming (25 sec)" (at cycle 1016)

Infrastructure: "Four Way Junction" by Tumisang Liphoto

node	ru type	# roadusers	avg waiting time
Special node 0	All	72	381.95834
Special node 0	Car	72	381.95834
Special node 0	Bus	0	0.0
Special node 0	Bicycle	0	0.0
Special node 1	All	71	360.66196
Special node 1	Car	71	360.66196
Special node 1	Bus	0	0.0
Special node 1	Bicycle	0	0.0
Special node 2	All	75	380.37332
Special node 2	Car	75	380.37332
Special node 2	Bus	0	0.0
Special node 2	Bicycle	0	0.0
Special node 3	All	80	334.3375
Special node 3	Car	80	334.3375

Figure 5.4 Fixed-Timing results

Statistics (at cycle 1020)

File Options

Statistics for simulation "Fuzzy algorithm" (at cycle 1020)

Infrastructure: "Four Way Junction" by Tumisang Liphoto

node	ru type	# roadusers	avg waiting time
Special node 0	All	117	112.931625
Special node 0	Car	117	112.931625
Special node 0	Bus	0	0.0
Special node 0	Bicycle	0	0.0
Special node 1	All	130	106.96923
Special node 1	Car	130	106.96923
Special node 1	Bus	0	0.0
Special node 1	Bicycle	0	0.0
Special node 2	All	168	65.83929

Figure 5.5 Fuzzy Logic results

5.4 Vehicle Counting and Speed Detection

In this section the results are discussed that were obtained from the experiment whose goal was to count as well as get speeds of vehicles in a video stream.

The number of cars recorded were counted manually and compared to number of cars identified and counted by the system. Table 5.7 shows the results of the vehicle counting. The system was found to be 82% accurate using equation 5.1.

Equation 5.1 Calculating accuracy

$$accuracy = \frac{TP}{TP + TN} \times 100$$

Table 5.7 Results of car counting

Number of manually counted cars	89	Number of cars counted by system	94
		Counted once	67
		One vehicle counted more than once	12
		Not counted	15

The speeds of the vehicles were also recorded and compared to speeds that were set on the cruise control; Table 5.8 shows the results. The observed standard deviation is 3.24 km/h. The error in the calculations of speeds increases as the true speed of the vehicle increases. This error will, however, not be of significance as cars in a city travel at lower speeds than they would on the highway.

Table 5.8 Vehicle speed measurements

Trial	Program speed (km/h)	Cruise control speed (km/h)	Difference (km/h)
1	50	46	4
2	55	53	2
3	60	64	-4
4	70	72	-2
5	80	82	-2
6	90	89	1
7	100	105	-5
8	120	124	-4

Chapter 6 : Conclusion and Future Works

6.1 Conclusion

In this dissertation an Internet of Things-based traffic management system is presented. The major aim of the system is to mitigate the impacts of congestion, whether environmental or societal. The system is able to relay traffic information to motorists on multiple platforms. The information may either be 'pushed' to motorists or the user may 'pull' the information. In this work video-based sensors are used to collect traffic parameters from the road infrastructure. The parameters of interest are the number of cars and the speeds at which the cars are travelling. The other parameter that was of interest in this dissertation was the observations made by motorists on a road. Various techniques of video analysis were presented, as well as discussions on why the methods used were preferred over the others.

The parameters obtained were analyzed and subjected by fuzzy algorithms. The resulting values are the extension time of the green phase on traffic lights as well as the determination of the congestion level of a road network. This research has responded to the first research question by confirming that there is a positive correlation between traffic flow and concentration of CO_2, the higher concentration of vehicles in a given area the higher concentration of CO_2.

The second research question has been answered in that the research showed via simulation that rate of traffic flow is increased in reactive traffic lights compared to static traffic lights. The last research question was responded to by reflecting that the respondents of the survey showed a belief that constant provision of road status would reduce the frequency and intensity of congestion.

6.2 Future works

Overall, the work presented here is a step in the right direction to limit the impact of congestion in African cities. However, more work still needs to be done in order to expand the current system in to a fully-fledged traffic management system. Here some of the improvements are presented that are intended to be incorporated in future works.

At present the current system works only for an isolated road, it is therefore envisaged that a more comprehensive solution be provided that is able to manage and disperse traffic information about an entire road network. Above that, it is also envisaged that a solution that is able to predict traffic flow be implemented. With privacy taken into account, more research is planned into having mobile devices to automatically provide their locations and travel speeds, resulting in a truly ubiquitous system.

It is also envisaged that a more robust detection algorithm that may be able to separate vehicles and shadows be used. This will be beneficial as it will reduce the error rate of the detection. In addition, the detection algorithm should also be able to continue tracking vehicles that at some point were hidden in the scene, maybe as a result of being 'behind' another larger vehicle.

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Appendix

Private car owner's questionnaire

Central University of Technology (CUT)

Dear Participant

I invite you to participate in a research study entitled **Internet of Things-Based Traffic Management System**. I am currently enrolled in the Information Technology Faculty at CUT in South Africa and am in the process of writing my Master's Dissertation. The purpose of the research is to determine the possibility of using Internet of Things (IoT) to solve or diminish traffic congestion.

The attached questionnaire has been designed to collect information on your driving patterns and the overall views that you may have regarding your usage and observations made of the road networks.

Your participation in this research project is completely voluntary and will not be compensated. You may decline altogether, or leave blank any questions you do not wish to answer. There are no known risks to participation beyond those encountered in everyday life. Your responses will remain confidential and anonymous. Data from this research will be kept under lock and key and reported only as a collective combined total. No one other than the researcher will know your individual answers to this questionnaire.

If you agree to participate in this project, please answer the questions on the questionnaire as best you can. It should take approximately fifteen (15) minutes to complete.

Thank you for your assistance in this important endeavor.

For additional comments, please contact me at liphoso@gmail.com or *+266 6309 7293.*

Sincerely yours

Sechocha Liphoto

Section 1 (Individual's Demographics)

Please answer this section by placing a tick (√) in the correct box

Question	Options	Place Tick
2. Please indicate your age.	Under 25	
	25 to 34	
	35 to 44	
	45 to 54	
	55 and over	
3. Please indicate your gender.	Male	
	Female	
4. Please indicate your highest educational qualification.	High School	
	Bachelor's Degree	
	Master's Degree	
	Ph.D.	
	Other (specify)	
5. Do you own a smart phone?	No	
	Yes	
6. Do you have constant access to the Internet?	No	
	Yes (Specify how)	
7. Please indicate the number of vehicle(s) you own.	0	
	1	
	2	
	More than 2	
8. How long have you held your driver's license?	I do not have one	
	Less than 2 years	
	2 to 4 years	
	More than 4 years	
9. Please indicate your current occupation.	Scholar	
	Work at home	
	Work in town	
	Unemployed	
	Other (specify)	
10. Please indicate the additional number of people you normally travel with.	0	
	1	
	2	
	3	
	More than 3	
11. Please indicate the average distance you travel each day.	0 kilometers	
	Less than 10 kilometers	
	Less than 20 kilometers	
	More than 20 kilometers	
12. How long do you take to travel the above mentioned distance.	Less than 10 minutes	
	Less than 30 minutes	
	Less than 60 minutes	
	More than 60 minutes	
13. On average how much more time does congestion add.	0 (zero) minutes	
	Less than 20 minutes	
	Less than 30 minutes	
	More than 30 minutes	

1. In which town do you live…………………………………………………………………...

Traffic congestion is a condition on road networks that occurs as usage increases, and is characterized by slower speeds, longer trip times and increased vehicular queueing.

Section 2 (Driving Patterns)

Question	Options				
	Always	Frequently	Occasionally	Rarely	Never
14. I use public transport.					
15. I run pre-trip inspections on my vehicle.					
16. I have had my vehicle break down on the road.					
17. I have been stuck on the road due to traffic congestion.					
18. I have been stuck in traffic for more than 30 minutes.					
19. I have seen congestion at signaled intersections.					
20. I have seen congestion at **non-signaled** intersections.					
21. I listen to the radio (FM, MW, SW) when driving.					
22. I have seen traffic officials directing traffic.					
23. I have broken road regulations to avoid being stuck in congestion.					
24. I have seen traffic congestion mostly in the mornings.					
25. I have seen traffic congestion during the daytime.					
26. I have noticed traffic congestion mostly in the afternoons.					
27. I have watched traffic updates on my local television channels.					
28. I have heard traffic updates on my local radio stations.					
29. I have seen traffic updates on billboards in my town.					
30. I have gotten traffic updates on my cellphone.					
31. I consider congestion when planning my route.					

Please answer this section by selecting the option that tells how often it occurs.

Traffic congestion is a condition on road networks that occurs as usage increases, and is characterized by slower speeds, longer trip times and increased vehicular queueing.

Section 3 (Congestion)

Question	Options				
	Strongly Agree	Agree	Undecided	Disagree	Strongly Disagree
32. Congestion has a **negative** impact on the environment.					
33. Traffic congestion adds to frequency of accidents.					
34. Being stuck in traffic increases my maintenance costs.					
35. Being stuck in traffic causes me stress.					
36. I would pay extra to **not** be stuck in traffic.					
37. Traffic lights do manage traffic flow effectively.					
38. Levels of congestion increased over the last 5 years.					
39. Levels of congestion will increase over the next 5 years.					
40. The number of cars in town increased over the last 5 years.					
41. The state of the roads in my town is satisfying.					
42. There are enough road networks in my town.					
43. Routine traffic updates would decrease congestion.					
44. Being stuck in traffic increases my travelling costs.					
45. It is the government's duty to decrease congestion.					
46. It is my duty to decrease congestion.					
47. Public transport operators are largely responsible for congestion.					
48. Private cars are largely responsible for congestion					
49. Carpooling may reduce congestion.					

Please answer this section by selecting the option that you agree with.

Section 3 (Consent)

I, the undersigned, confirm that (please tick box as appropriate):		
I	I have read and understood the information about the research.	
II	I have been given the opportunity to ask questions about the research and my participation.	
III	I voluntarily agree to participate in the research.	
IV	I understand I can withdraw at any time without giving reasons and that I will not be penalized for withdrawing.	
V	The procedures regarding confidentiality have been clearly explained to me.	
VI	If applicable, separate terms of consent for forms of data collection have been explained and provided to me.	
VII	The use of the data in research, publications, sharing and archiving has been explained to me.	
VIII	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.	
IX	Select only **ONE** of the following: • I would like my name to be used and understand what I have said or written as part of this research will be used in reports, publications and other research outputs so that anything I have contributed to this project can be recognized. • I **do not** want my name used in this research.	
X	I agree to sign and date this informed consent, along with the Researcher.	

Participant:

______________________ ______________________ ______________________

Name of Participant **Signature** **Date**

Researcher:

<u>Sechocha Liphoto</u> Liphoto

Name of Researcher **Signature** **Date**

thank you!

Private car owner's questionnaire responses

Age

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Under 25	18	17.3	17.3	17.3
	25-34	41	39.4	39.4	56.7
	35-44	17	16.3	16.3	73.1
	45-54	15	14.4	14.4	87.5
	55 and over	9	8.7	8.7	96.2
	Missing	4	3.8	3.8	100.0
	Total	104	100.0	100.0	

Stuck for more than 30 minutes

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Always	20	19.2	19.2	19.2
	Frequently	21	20.2	20.2	39.4
	Occasionally	22	21.2	21.2	60.6
	Rarely	25	24.0	24.0	84.6
	Never	16	15.4	15.4	100.0
	Total	104	100.0	100.0	

Congestion at signaled intersections

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Always	22	21.2	21.2	21.2
	Frequently	23	22.1	22.1	43.3
	Occasionally	15	14.4	14.4	57.7
	Rarely	20	19.2	19.2	76.9
	Never	24	23.1	23.1	100.0
	Total	104	100.0	100.0	

Congestion at non-signaled intersections

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Always	9	8.7	8.7	8.7
	Frequently	29	27.9	27.9	36.5
	Occasionally	19	18.3	18.3	54.8
	Rarely	24	23.1	23.1	77.9
	Never	23	22.1	22.1	100.0
	Total	104	100.0	100.0	

Broken regulations

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Always	22	21.2	21.2	21.2
	Frequently	22	21.2	21.2	42.3
	Occasionally	19	18.3	18.3	60.6
	Rarely	19	18.3	18.3	78.8
	Never	22	21.2	21.2	100.0
	Total	104	100.0	100.0	

Morning traffic

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Always	29	27.9	27.9	27.9
	Frequently	13	12.5	12.5	40.4
	Occasionally	18	17.3	17.3	57.7
	Rarely	19	18.3	18.3	76.0
	Never	25	24.0	24.0	100.0
	Total	104	100.0	100.0	

Daytime traffic

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Always	16	15.4	15.4	15.4
	Frequently	17	16.3	16.3	31.7
	Occasionally	33	31.7	31.7	63.5
	Rarely	12	11.5	11.5	75.0
	Never	26	25.0	25.0	100.0
	Total	104	100.0	100.0	

Afternoon traffic

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Always	12	11.5	11.5	11.5
	Frequently	21	20.2	20.2	31.7
	Occasionally	31	29.8	29.8	61.5
	Rarely	18	17.3	17.3	78.8
	Never	22	21.2	21.2	100.0
	Total	104	100.0	100.0	

Television updates

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Always	33	31.7	31.7	31.7
	Frequently	16	15.4	15.4	47.1
	Occasionally	17	16.3	16.3	63.5
	Rarely	14	13.5	13.5	76.9
	Never	24	23.1	23.1	100.0
	Total	104	100.0	100.0	

Radio updates

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Always	22	21.2	21.2	21.2
	Frequently	21	20.2	20.2	41.3
	Occasionally	29	27.9	27.9	69.2
	Rarely	20	19.2	19.2	88.5
	Never	12	11.5	11.5	100.0
	Total	104	100.0	100.0	

Route Planning

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Always	17	16.3	16.3	16.3
	Frequently	18	17.3	17.3	33.7
	Occasionally	29	27.9	27.9	61.5
	Rarely	14	13.5	13.5	75.0
	Never	26	25.0	25.0	100.0
	Total	104	100.0	100.0	

Negative impact

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Strongly Agree	19	18.3	18.3	18.3
	Agree	23	22.1	22.1	40.4
	Undecided	19	18.3	18.3	58.7
	Disagree	18	17.3	17.3	76.0
	Strongly Disagree	25	24.0	24.0	100.0
	Total	104	100.0	100.0	

Increase accidents

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Strongly Agree	22	21.2	21.2	21.2
	Agree	23	22.1	22.1	43.3
	Undecided	26	25.0	25.0	68.3
	Disagree	16	15.4	15.4	83.7
	Strongly Disagree	17	16.3	16.3	100.0
	Total	104	100.0	100.0	

Causes me stress

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Strongly Agree	17	16.3	16.3	16.3
	Agree	22	21.2	21.2	37.5
	Undecided	22	21.2	21.2	58.7
	Disagree	24	23.1	23.1	81.7
	Strongly Disagree	19	18.3	18.3	100.0
	Total	104	100.0	100.0	

Traffic lights effectively managed

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Strongly Agree	21	20.2	20.2	20.2
	Agree	20	19.2	19.2	39.4
	Undecided	19	18.3	18.3	57.7
	Disagree	21	20.2	20.2	77.9
	Strongly Disagree	23	22.1	22.1	100.0
	Total	104	100.0	100.0	

Congestion@Signaled

		Value	Count	Percent
Valid Values	1	Always	22	21.2%
	2	Frequently	23	22.1%
	3	Occasionally	15	14.4%
	4	Rarely	20	19.2%
	5	Never	24	23.1%
	99	Missing	0	0.0%

Congestion@NonSignaled

		Value	Count	Percent
Valid Values	1	Always	9	8.7%
	2	Frequently	29	27.9%
	3	Occasionally	19	18.3%
	4	Rarely	24	23.1%
	5	Never	23	22.1%
	99	Missing	0	0.0%