DESIGNING AN IOT TRAFFIC MANAGEMENT FRAMEWORK IN KENYA: A CASE OF NAIROBI CITY COUNTY

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DECLARATION

I declare that this document and the research it describes are my original work and that they have not been presented in any other university for academic work.

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DEDICATION

I wish to dedicate this research work to my family for their immense support and inspiration. A special feeling of gratitude goes to my dear sons, Jayden, Kyle and my dear wife, Carolyne for inspiring me to work hard and fulfil my dreams.

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I would like to sincerely express my gratitude to Dr. Amos Gichamba and Dr. Emily Roche for their guidance and advice as my thesis supervisors. Lastly, I would like to express my special thanks to my family and friends for their tremendous support and endless love.

ABSTRACT

Internet of Things (IoT) is a system of interrelated computing devices, mechanical and digital machines, objects, animals or people that are provided with unique identifiers (UIDs) and the ability to transfer data over a network without requiring human-to-human or human-to-computer interaction. Nairobi city residents encounter a myriad of problems on the roads every day, thanks to the increasing population in the city and also due to the influx of motor vehicles in the city using a constrained road network. Some of these problems include failure to find parking spaces in the central business district and the lack of enough drop off and pick up points. Traffic index report released by Ynumbeo (2017) revealed that on average, residents of Nairobi spend 62.44 minutes in traffic every day. This research aims to advance an endurable traffic management design framework based on IoT and to help resolve some of the traffic issues of Nairobi City. The specific objectives of the study were: To assess and review current generic design frameworks of IoT sensors available in the market today with regard to traffic management, To analyse the benefits therein associated with the IoT implementation on traffic management as opposed to the Manual traffic management and to develop an endurable IoT traffic management design framework for Nairobi city. The research was cross sectional with analytical component and through simple random sampling, comprising of 21 officers from the city inspectorate and enforcement, 9 from the traffic police department and 162 private drivers. A sample of the respondents was drawn using stratified sampling. Each respondent filled and submitted a structured self-administered questionnaire. The processed data was analyzed using descriptive statistics. Statistical Package for Social Sciences (SPSS) Version 25 and Excel spreadsheet were used to analyse the findings. Private cars spent an average of 1.6 hours in the morning while in the evening they spent an average of 2.0 hours stuck in the traffic jam. This was aggravated by the fact that drivers sometimes fail to identify existing parking slots in town with drivers spending an average of 30 minutes looking for parking slots in the morning. This research provides an analysis of how different sensors can communicate and help improve the current traffic congestion in the city and how other different facets like, smart parking sensors, smart streetlights, smart highways and smart accident assistance can be integrated in the same study. For the full scale adoption of IoT in parking management, the system requires data sensors (RFID tags) to give the location of the cars in the parking lots, WIFI with IPv4 or IPv6 for receiving and transmitting information regarding the cars parked, cloud computing technologies to process the information as well as back-end management for the entire system.

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DEFINITION OF TERMS

Project: A temporary endeavour undertaken to create a unique product or service. Temporary means the project has a beginning and an end.

Redundancy: A process through which additional or alternate instances of network devices, equipment and communication mediums are installed within network infrastructure. It is a method for ensuring network availability in case of a network device or path failure and unavailability.

Bluetooth: A standard for the short-range wireless interconnection of mobile phones, computers, and other electronic devices.

ZigBee: An open global standard for wireless technology designed to use low-power digital radio signals for personal area networks. ZigBee operates on the IEEE 802.15.4 specification and is used to create networks that require a low data transfer rate, energy efficiency and secure networking.

WiMax: A wireless communications standard designed for creating metropolitan area networks (MANs). It is similar to the Wi-Fi standard, but supports a far greater range of coverage. While a Wi-Fi signal can cover a radius of several hundred feet, a fixed WiMAX station can cover a range of up to 48 kilometres. Mobile WiMAX stations can broadcast up to 16 kilometres.

ABBREVIATIONS/ ACRONYMS

ARPANET	Advanced Research Projects Agency Network
Auto-ID	Automatic Identification
CO2	Carbon Dioxide
DARPA	Defense Advanced Research Projects Agency
EPC	Electronic Product Code
GPS	Global Positioning System
HCI	Human-Computer Interaction
HD	High Definition
ICT	Information Communication Technology
IoT	Internet of Things
IP	Internet Protocol
IT	Information Technology
LCA	Lane-Centering assist
LDW	Lane-departure warning
LKA	Lane-keeping assist
PDQ	Process Data Quickly
RFID	Radio-Frequency Identification
TMN	Telecommunications Management Network
TSA	Transportation Security Administration
UIDs	Unique identifiers

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CHAPTER ONE

INTRODUCTION AND BACKGROUND INFORMATION

1.1 Introduction

McFarlane (2015) states that the term “Internet of Things” was in fact coined by Kevin Ashton in 1999 during a presentation he made at Procter & Gamble (P&G). Around that time, he observed that they were developing an extension of the Internet to accommodate Things and hence the term “Internet of Things” evolved. He goes on to say that during the same year, Auto-ID (for Automatic Identification) Centre was founded, which subsequently formed a unique partnership between around 100 international companies and 7 of the world’s leading research Universities, including the MIT and University of Cambridge. The Auto-ID Centre’s aim was to investigate and understand what came next after the barcode – and particularly what an electronic barcode would look like and ways of using barcodes and RFID as an electronic replacement.

Foote (2016) provides another twist by saying that the Internet, which forms a significant component of the IoT, started out as part of DARPA (Defense Advanced Research Projects Agency) in 1962, and evolved into ARPANET in 1969. In the 1980s, commercial service providers began supporting public use of ARPANET, allowing it to evolve into the modern Internet. Global Positioning Satellites (GPS) became a reality in early 1993, with the Department of Defense providing a stable, highly functional system of 24 satellites. This was quickly followed by privately owned, commercial satellites being placed in orbit. Satellites and landlines provide basic communications for much of the IoT.

According to Lueth (2014), the concept of IoT started to gain some popularity in the summer of 2010. Information leaked that Google’s StreetView service had not only made 360 degree pictures but had also stored tons of data of people’s Wifi networks. People were debating whether this was the start of a new Google strategy to not only index the internet but also index the physical world. In the same year, Google launched their self-driving car concept, taking a huge leap forward in the development of connected and autonomous cars. Also in 2010, two former Apple engineers started Nest Labs, the company that produces smart thermostats and smoke detectors. In 2014, Google acquired Nest Labs for $ 3,2 billion to speed up their Internet of Things division. In 2014, Apple launched HomeKit, which is a framework in iOS 8 for communicating with and controlling connected accessories in a user's home (Rijmenam, 2014).

Maddox (2018) reckons that one of the most helpful aspects of a smart city is using technology to ease traffic and parking woes. Sensors in the street can be used to determine if a parking spot is empty, and anyone who accesses an app on a smartphone can find out in real time the location of the closest parking spot. Data shows that 30% of all traffic congestion in cities is the result of drivers looking for a parking space (TSA, 2018). Cities can increase revenues by more closely monitoring parking, and there are several other conveniences stemming from HD cameras in smart streetlights and parking sensors. There are sensors in the roads so that you don't need to worry about paying for your parking because the sensors will determine how long you're parking there. Cities will also be able to clear away accidents much more quickly since they won't need to wait for tape measurements. And they can link this information to insurance companies and claims so that they can be processed much more quickly. A lot of those things are seen and perceived as benefits in a smart city environment (Durbin, 2018).

1.2 Background of the Study

Rouse (2016) defines the IoT as a system of interrelated computing devices, mechanical and digital machines, objects, animals or people that are provided with unique identifiers (UIDs) and the ability to transfer data over a network without requiring human-to-human or human-to-computer interaction. A thing in the internet of things can be a person with a heart monitor implant, a farm animal with a biochip transponder, an automobile that has built-in sensors to alert the driver when tire pressure is low or any other natural or man-made object that can be assigned an IP address and is able to transfer data over a network. Increasingly, organizations in a variety of industries are using IoT to operate more efficiently, better understand customers to deliver enhanced customer service, improve decision-making and increase the value of the business.

According to Ranger (2018), almost any physical object can be transformed into an IoT device if it can be connected to the internet and controlled that way. A light bulb that can be switched on using a Smartphone app is an IoT device, as is a motion sensor or a smart thermostat in your office or a connected streetlight. An IoT device could be as fluffy as a child's toy or as serious as a driverless truck, or as complicated as a jet engine that's now filled with thousands of sensors collecting and transmitting data back to make sure it is operating efficiently. At an even bigger scale, smart cities projects are filling entire regions with sensors to help us understand and control the environment.

The term IoT is mainly used for devices that wouldn't usually be generally expected to have an internet connection, and that can communicate with the network independently of human action. Singapore is the best performing smart city globally ahead of London, New York, San Francisco, and Seoul, according to a study by technology company Juniper Research. The concept of smart city involves the use of IoT technologies such as connected sensors, metres and lights to collect and analyse data to improve public infrastructure and services. As such, the study rank top 20 global smart cities against four key areas: mobility, healthcare, public safety, and productivity (SBR, 2018). In terms of mobility, Singapore’s smart, connected traffic solutions combined with its strong policy help improve the country’s traffic system. The study noted that gridlock causes drivers to lose up to 70 hours per year; as such an integrated IoT-enabled infrastructure can save drivers 60 hours per year.

Ashe (2015) adds that an intelligent city is a city that can collect data efficiently and bring it in a way that is meaningful to them. It can enhance revenue, or ultimately offer citizens new services that they never before had. More insight into that comes from Menon (2015) who believes that a smart city is a city that uses digital technologies or information and communication technologies, connected via an intelligent network, to address challenges within city communities and across vertical industries. These challenges may include parking, traffic, transportation, street lighting, water and waste management, safety and security, even the delivery of education and healthcare. A smart city relies on technological solutions that enhance its existing process to better support and optimize the delivery of urban services, to reduce resource consumption and contain costs, and to provide the means and the opportunities to engage actively and effectively with its citizens, with its visitors and with its businesses.

1.3 Statement of the Problem

According to Moudgil (2018), as our cities get bigger and our citizens more mobile, our roads will become more congested and gridlocked unless we can find better solutions for everything from parking to car sharing to public transport. Nairobi city residents encounter a myriad of problems on the roads every day, thanks to increasing population in the city and also due to the influx of motor vehicles in the city using a constrained road network. Some of these problems include, failure to find parking spaces in the Central Business District, lack of enough drop off and pick up points and minor traffic offences which translate to ugly snarl ups along the roads. There is a lack of all in one platform to access the shortest route. Traffic index report released by ynumbeo.com in 2017 revealed that on average, residents of Nairobi spend 62.44 minutes in traffic every day, making Nairobi the world's second worst city in traffic congestion after Kolkata (formerly Calcutta) in India (Wasonga, 2018). This has a spiral effect on various aspects of the County's economy in terms of time wasted and environmental pollution. Accidents are also a common scenario around the city.

According to a study conducted by UN-Habitat and published by Dzikus (2017), an analysis of the road pattern of Nairobi based on satellite images, shows the city has 23 different street patterns. One reason for traffic-congestion is that streets are not fully connected to their vicinities. In the Central Business District, approximately 12 per cent of the land is allocated to streets. A functioning traffic system in a modern capital generally requires around 30 per cent of land allocated to streets. These two major findings lie at the heart of the traffic jam problem in Nairobi: Too many street patterns and too few streets that are adequately connected (Dzikus, 2017). According to Masood, Khan and Naqvi (2011), some of the problems encountered in the developing countries are as a result of:

i. Lack of modern multi-modal transportation system.
ii. Population growth resulting in increased transportation needs and over-supply of vehicles.
iii. Serious road safety problems.
iv. Proliferation of smaller vehicles.
v. Environmental pollution.
vi. Flouting of traffic rules by motorists.
vii. Lack of coordination among transport related agencies.

1.4 General Objective of the Study

The main objective is to design an IoT management framework in Kenya.

1.5 Specific Objectives of the Study

The study was guided by the following objectives:

i. To assess and review current generic design frameworks of IoT sensors available in the market today with regard to traffic management;
ii. To undertake an analysis of the benefits associated with the IoT implementation on traffic management as opposed to the Manual traffic management;
iii. To develop an endurable IoT traffic management design framework for Nairobi City County.

1.6 Research Questions

To achieve the above objectives, the study sought to answer the following questions.

i. What are current generic design frameworks of IoT sensors available in the market today with regard to traffic management?
ii. What are the costs and benefits associated with the IoT implementation on traffic management as opposed to the Manual traffic management?
iii. How can we come up with an IoT design framework in enhancing traffic management in Nairobi City County?

1.7 Significance of the Study

Traffic management is one of the biggest infrastructure hurdles faced by developing countries today. Developed countries and smart cities are already using IoT and Big Data to their advantage to minimize issues related to traffic. The culture of the car has been cultivated speedily among people in all types of nations. In a common scenario in most of the cities, people prefer riding their own vehicles no matter how good or bad the public transportation is or considering how much time and money is it going to take for them to reach a particular destination (Parakh, 2018). This study will provide a better analysis of how different sensors can communicate and help improve the current traffic congestion in the city. In addition, it will show how other different facets like, smart parking sensors, smart streetlights, smart highways and smart accident assistance can be integrated in the same study. Different categories of the population will be the ultimate gainers when this research is implemented. Drivers can benefit from ease of parking and improved traffic flow, less congestion. Different authorities on the other hand can benefit from real-time visibility of traffic violations and better decision making when undertaking their day to day planning. Consequently, pedestrian and residents of the City County in general will benefit from improvement of lifestyle as a result of better environment due to less pollution and also save on time which is normally lost on our roads due to traffic congestion.

1.8 Scope of the Study

According to Wordometer (2017), 26.7 percent of Kenyan Population lives in urban centres. This number is growing steadily. While population surge is good for the economic health of a city, this increase often strains transportation systems. 50 percent of the world's population lives in cities, and this population is growing by almost 2 percent every year on average. The US Census data, Piletic (2017) shows that the average American worker today spends 20 percent more time commuting than they used to do in the 1980s. It is a positive move for cities to attract more people and business. However, scaling up road capacity to keep up with additional traffic is never easy. This study was conducted in the Nairobi Central Business district area and also collected more information from the traffic department in the county since they are the day-to-day users of the stakeholders and they are likely to provide the relevant information.

1.9 Delimitation of the Study

Traffic has a significant impact on the liveability and efficiency in cities. Efficient use of data and sensors will help to manage traffic efficiently, regardless of the population surge. Smart traffic management aims at making urban driving more seamless and efficient. As smart cities evolve, services and infrastructure will be more integrated. As time moves by, issues such as traffic, waste management and energy conservation will greatly benefit from the concept of Internet of Things (Piletic, 2017). This research will focus mainly on the opportunities that the IoT can offer in this transport sector and since Nairobi City County is a populous county, we will main focus in the central business district and thereabouts. This is because most of the traffic operations outside Nairobi can easily be mirrored in the central Nairobi region and thus the generality and inference would not be lost by narrowing it to Nairobi which will in effect lead to ease of data collection, correlation analysis and inference.

1.10 Limitations of the Study

Parakh (2018) clearly and rightly puts it that all pros become more quantifiable with cons. While IoT and big data present a path-breaking opportunity in smart traffic management and solutions, they also have some limitations. Firstly, current cities already suffer from infrastructure issues like road planning, zoning, and other construction-related issues that could potentially pose problems when implementing IoT technology. In this regard, the research will seek to work closely with all the stakeholders concerned. Secondly, all these fancy, hi-tech solutions need high-speed data transfer techniques and, thus, can work only in cities with great internet connectivity. If for any reason, this connectivity is hampered, the entire smart city could fall apart. Luckily for Nairobi, data speeds are not a big problem. Thirdly, the number of devices accessing the central network means more opportunities for hackers to conduct their malicious attacks. This study proposes an added layer of security, apart from the usual one and another on top of that, will be needed to make an impenetrable hack-proof smart traffic solution. Data privacy will also have to be maintained, looping in suggestions to the lawmakers and engineers.

1.11 Assumptions

Dzone's 2017 Guide to Micro services reckons that traffic is a crucial aspect that determines a city's liveability factor and efficiency status (Goralski, 2017). Population surge will stop mattering if data and sensors are used capably to manage traffic. As smart cities evolve and increase in number in the coming years, IoT and big data will play a key role in the development and integration of services and infrastructure. This research assumes that the sample will be representative of the entire county and that the respondents will be truthful in answering all questions pertaining to the study. Introduction letters from the university were sent out to the respondents and promised confidentiality on any information given. This study took a lot of time and resources to conduct and collect data but it purposed to use and apply appropriate tools during data collection and data analysis and that the findings will be useful to the whole county and the country at large.

1.12 Theoretical Framework

Ashton (1999) first came up with the concept of IoT when he said that RFID (Radio-frequency identification) is a necessity for the Internet of Things. It was mentioned that, "If all objects and people in daily life were equipped with identifiers, computers could manage and inventory them." This theory states that the Internet of Things are all electronic devices that exchange data or information through the Internet using a local or wireless network. Anything that can be connected will be connected as long as it involves the internet. This theory also pertains to the possibility of inanimate objects to speak and interact with people. The theoretical framework in this research consists of different strands of literature. Notions of complex technical systems, dominant design theory, standardization and lead users will together form the theoretical perspective that has been used in order to answer the research question.

In cases where the market and technology are both new and consequently poorly understood, like with IoT, the product or system is classified as 'complex' (Tidd & Bessant, 2009). Complex technical systems are technologies that are defined by a set of components and an architecture that specifies how to arrange these components into a system (Henderson & Clark, 1990). Complex products typically consist of a number of components or subsystems. For bundled or closed systems, customers evaluate purchases at the system level, rather than the component level (Tidd & Bessant, 2009). For Example, a manufacturer can offer the customer a complete IoT application, consisting of several interoperable components. This can offer the customer an enhanced performance due to the presence of optimized components using proprietary interfaces (Tidd & Bessant, 2009). However, such a bundled system does not allow the customer to adjust the system to their own needs. To enable the customer to configure its own system, open complex technical systems are required. Open systems display a greater degree of looseness than closed systems, and become systems only in the light of local contingencies (Peine, 2008). In open technical systems, only a range of components is defined. The selection of the exact set of components to be included as well as the plan how to arrange these components is dependent on the context in which a particular system operates. This specific arrangement can be denoted as a configuration. In other words, the system does not define clear choices in the first place (Peine, 2009). Configurations bring together technical components, software, standards, services and user practices in more or less unique ways, and they are thus dependent on specific contexts of applications. Understanding the dynamics of systems, therefore, makes it necessary to take into account two levels of dynamism: changes in component knowledge and changes in architectural knowledge (Peine, 2009).

1.13 Conceptual Framework

According to Zaina (2009), a conceptual framework is a diagrammatic presentation of the relationship between the independent and dependent variables; it forms the basis of the research. The conceptual framework illustrates influence of three variables on the application the IoT in the traffic management in the county.

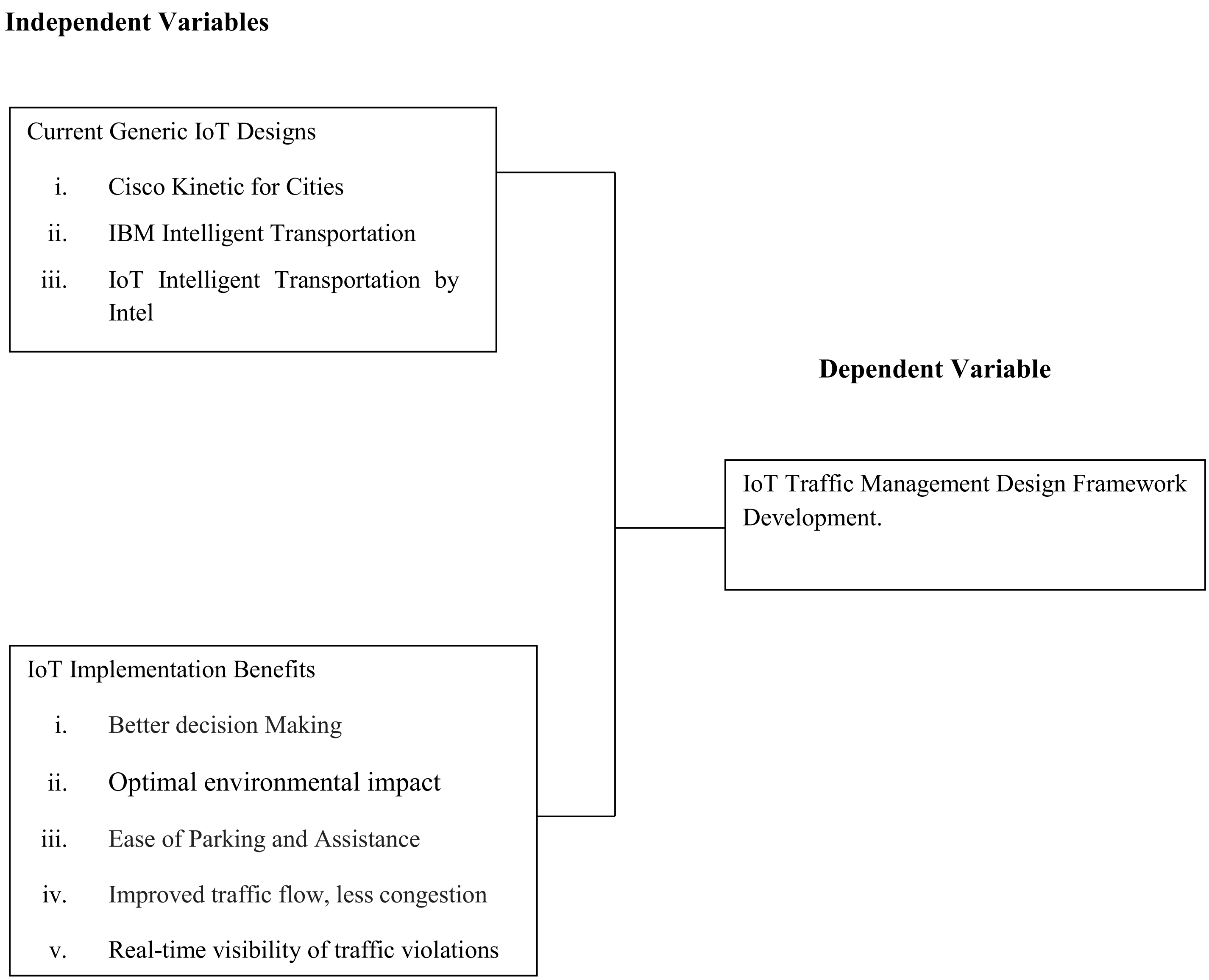

Figure 1-1: Conceptual framework

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

Hart (2006) defines literature review as a number of documents that have been selected, both published and unpublished covering topics that contain the information, ideas and evidence written from a particular stand point to express certain views on the topic. This study advanced an endurable traffic management design framework based on IoT to enhance traffic management and help resolve some of the traffic issues of Nairobi City County. Information generated by traffic IoT and collected on all roads can be presented to travellers and other users.

2.2 Theoretical Review of Literature

There are a number of the theories that have been compiled regarding the Internet of Things implementation in various sectors. The theoretical foundations for component-based IoT systems are classified under four broad categories: End User Design, End User Programming, Semantic Web / Internet of Things (IoT) and Co-evolution of Users, Artifacts, and Applications (that relates to the evolution of the total system, and the perspective that is assumed in this research).

2.2.1 End User Programming Foundations

Social constructivism theory (Vygotsky, 1978) refers to the individual making meaning of knowledge within a social context. It suggests that our lives are constantly formed through the dialectical process of socialization. It is through the social process that reality takes on meaning. People's understanding of science follows a similar dialectic. The artifacts that people invent are continually shaped in order to be adapted to the continually evolving context of the human life and environment. People and artifacts are interdependently shaped: people are shaped by their interactions with artifacts and tools (of physical or conceptual nature) and at the same time artifacts and tools, (such as machines, notions, or language), evolve and change in response to the use that is made of them by human communities. The theory of Social Constructivism applies the general ideas of constructivism into social settings.

Social constructivism, in effect, extends constructivism theory by introducing the role of other actors and culture in human development. According to social constructivism, social groups create common knowledge by sharing objects and meaning, subsequently creating a culture by collaboratively formed constructs and artifacts. At the same time, immersion in a culture of shared meanings, concepts, artifacts, and tools, requires learning how to be a part of a specific cultural group. In this framework, constructionism corresponds to end-user programming activities in application development and subsequently steers better understanding of the IoT environment and its mechanisms.

2.2.2 End User Design Foundations

Gibson (1979) came up with Design Rationale theory based on the ecological approach has stressed the value of capturing design rationale during the design process in order to understand and reflect upon system design. Design Rationale is the reasoning that leads to design decisions. It is an important tool itself for arriving to a design decision in the first place. The captured rationale should list advantages and disadvantages of a certain choice and include rejected alternatives, so that those alternatives don't keep re-appearing for reconsideration. Documenting design rationale is important for understanding the context behind design decisions and validating them. It helps in trying to interpret ambiguous design decisions or examples that don't fall clearly within a design principle, and to avoid going back and challenging/changing design decisions without knowing the reasons that led to them in the first place.

Design Rationale in the context of this framework can be applied not only to the design of systems (by teams of engineers and experience design specialists), but can also be used as a methodological foundation for end users to act as designers of their own applications. Its scenario based design methods can provide insight and inspiration for mechanisms supporting scenario based development as a means to conceptualize and express application ideas.

2.2.3 Theoretical Foundations for Internet of Things

This study will also consider the Activity theory (Vygotsky, 1920) which is a philosophical framework has influenced education, organizational design, and human computer interaction. It puts emphasis on social factors as shapers of interaction between agents and their environments. The premise of activity theory is that a collective work activity, with the basic purpose shared by others (community), is undertaken by people (subjects) who are motivated by a purpose or towards the solution of a problem (object), which is mediated by tools and/or signs (artefacts or instruments) used in order to achieve the goal (outcome). The activity is constrained by cultural factors including conventions (rules) and social organisation (division of labour) within the immediate context and framed by broader social patterns (of production, consumption, distribution and exchange). Activity theory provides a conceptual framework from which we can understand the inter-relationship between activities, actions, operations and artefacts, subjects' motives and goals, and aspects of the social, organisational and societal contexts within which these activities are framed. Activity Theory separates internal from external activities. Mental processes are internal activities. Transformations between these two kinds of activities are mutual and are intertwined, in such a way that activities.

According to Bannon (2012), tools are evolving carriers of a culture as they are made and shaped while the activity is performed over time and throughout human history. Social knowledge is gathered and transmitted via the use of tools, which, in turn, are influencing the very nature and cognitive processes of people. When people are introduced to a certain activity, the artefacts they use are shaped already, but they are also evolving as the result of that activity; they are constantly changed within the socio-cultural context of human evolution through the process of that activity.

Having human activity as its focus, Activity Theory has gained an international and multidisciplinary importance, and is especially influential in guiding human computer interaction especially computer mediated communication and computer supported collaborative environments. Activity theory can be used as a conceptual framework addressing how human thinking could advance further via the use of (technological) tools. In this framework's context it provides insight on how IoT constructs, technology and people (social, internal and external people's processes) can evolve as an ecosystem.

2.2.4 Theoretical Foundations for the Co-evolution of Users, Artefacts and Applications

The typical approach on cognition widely established in the HCI field treats the perception and motor systems as input and output of humans. Embodied Cognition on the other hand, considers the mind and body as a single entity, in continuous interaction. Knowledge happens via the body interacting with the world. Moreover, in the Situated Cognition approach, knowledge is determined by both the agent and the context. "Knowing is inseparable from doing" while "knowledge is situated in activity bound to social, cultural and physical contexts". Gibson's views on visual perception have influenced Situated Cognition Theory (Brown, Collins &

Duguid, 1989). To Gibson, visual perception is not solely about input from the eyes providing the brain with symbolic representations, but rather about people perceiving certain elements, by selectively viewing from a huge amount of information and identifying certain elements of the environment, that change or remain stable. Such perceptions of the environment, motivated by people's intentions and evolving over time, co-determine the possibilities for use of the environment or the artefact. This process of perception evolves in time, for persons and societies alike.

Situated cognition is influenced by Ecological Psychology's perception-action cycle. A key principle of the Ecological perspective, adopted by the Situated Cognition approach, is the notion of *'affordances'*, a popular design conceptual construct, originally introduced by Gibson describing the relationship between objects and tasks that can be performed with them. Gibson defined affordances as properties that present possibilities for action that are directly perceptible by people to act upon. He focused on the affordances of physical objects and suggested that affordances were directly perceived instead of mediated by mental representations. Cummins (2014) adds that the key to this idea is the importance of the viewpoint of a community for learning. Different people and communities have different ideas about how the world works. When we situate ourselves in different communities, we learn how they use knowledge, and this enriches our understanding of the world.

Situated cognition is referring to street smarts, in a way. This is the kind of knowledge that we gain by being in a particular situation, and it's different than what we learn via formal education. Brown, Collins and Newman (1989) developed the Cognitive Apprenticeship Model, which is closely linked to the Situated Cognition Theory. This model also relies upon practical teaching methods, whereby context learning is key. For example, if learners were trying to acquire the basic concepts of architecture, they would not only take theoretical courses associated with the specific topic, but they would also seek out real world experiences which would allow them to become fully immersed in the field. As the name implies, in the case of the Cognitive Apprenticeship Model, learners are encouraged to acquire the necessary skills by working alongside a master that serves as the subject matter expert in the field, next to whom they are expected to develop their cognitive and metacognitive skills.

Actor-network theory is a 'material-semIoTic' method, in that it maps material (involving things) and semIoTic (involving concepts) relations. It is assumed that many relations are of dual nature, both material and semIoTic. Actor-network theory tries to explain how material–semIoTic networks come together to act as a whole, looking at explicit strategies for relating different elements together into a network so that they form an apparently coherent whole (for example an establishment that consists of networked operations between its agents and artefacts, can act as a system itself, such as for example a book-store or a bank). Actor-network' structure is seen as constantly in the re-making and thus its nature is transient. It follows a constructivist approach in that it avoids simplistic explanations of events (Latour & Callon, 1992). Actor-Network Theory incorporates what is known as a principle of generalized symmetry; that is, what is human and non-human (e.g. artefacts, organization structures) should be integrated into the same conceptual framework and assigned equal amounts of agency. In this way, one gains a detailed description of the concrete mechanisms at work that hold the network together, while allowing an impartial treatment of the actors.

2.3 Empirical Review of Literature

2.3.1 Current Generic IoT Designs

A smart city is classified as a place where citizens live well-organized urban life with the help of information and communication technology (ICT) while maintaining sustainability and causing the least harm to the environment. In greater detail, this means living in a city that plans smart infrastructure and urban services to keep them as efficient as possible. Citizens can easily interact with local bodies, thus, playing a larger role in the city's management (Parakh, 2018). Began (2018) insinuates that like car and home automation, roads are now being considered a candidate for smart technologies. Interstates, back roads and city streets can provide passage for Internet of Things (IoT) networks, communication systems, data grids, electronic enclosures and a range of other 21st century technologies on the pavement. Smart road IoT development faces the same integration challenges as any new generation of technology. To add the network, contractors would have to retrofit the current infrastructure while integrating the material into new or renovated roads. One way they will approach this is by rethinking how roads are manufactured. For instance, engineers are now looking at the possibility of creating roads made from a specialized hard plastic that demonstrates incredible durability. This type of progressive material could lay the groundwork for the kind of cable and wiring needed for IoT networks. Another possible solution is to connect sensors that transportation departments are already using. Although the sensors provide information about weather patterns, road conditions and traffic, there has yet to be a way to connect them. Thus, all the data collected is fragmented. New roads could supply the framework for bridging the sensors to give analysts a more definite picture of the entire highway landscape.

The wave of automated vehicle systems would make communications between transport tech and pavement components the next logical step. Leading automobile manufacturers have already added many of their newer models with advanced safety systems such as lane-departure warning (LDW), lane-keeping assist (LKA) and lane-centering assist (LCA). Each of these systems contains onboard sensors that watch the road for the driver. If the driver falls asleep or commits an error and swerves off the road, the safety-assist systems will veer the car back onto the road. Many of these systems, however, rely on reflectors or rumble strips that cue the vehicle to reposition the wheels. While it is true that safety systems work quite well, they still lack in consistent performance. Smart roads could fine-tune these systems and improve their accuracy by communicating with the safety devices in real time. The IoT network can provide essential data to the car's safety system such as impending weather, oncoming traffic conditions, road conditions and other information that would warn the car to adjust its driving or alert it to possible hazards a few miles away (Began, 2018). Although these systems have demonstrated that smart roads are a viable asset to motorists, it will be quite some time before they are more widely used. As of now, the ideas are way ahead of the innovations, as engineers are trying to determine how to implement smart road technology in a way that is cost effective, durable and practical. The purpose of smart roads will be to enhance driver experience while making highways safer.

Cisco Kinetic for Cities

Formerly known as Cisco Smart+Connected City parking, it is solution that provides intelligent parking services through public Wi-Fi, video cameras, video analytics, and sensor-enabled parking management. This leads to the reduction in traffic congestion and builds a more effective partnership between cities, citizens, local businesses, and parking-enforcement agencies. Parking can be a challenging issue, especially in urban areas where 30 percent of all traffic congestion is caused by drivers circling to find a space. Add to that the amount of time wasted and the limited data available to guide motorists' decision making, and it's easy to see why they get frustrated. Cities are also losing out. Aside from the damaging environmental effects, they often lose revenue due to inadequate meter enforcement and no-parking, standing, and loading zone violations. Income for shops and local businesses is also heavily affected by the availability of parking. Cisco, together with Streetline, offers the Smart+Connected Parking Solution. Using Streetline's Parker™ motorist guidance application, Guided Enforcement™ application, ParkSight™ analytics application and Streetline parking sensors, Cisco and Streetline deliver a solution which helps to reduce traffic congestion and improve city liveability.

The model's benefits include:

City Benefits

i. Improved traffic flow, less congestion, and better mobility and living conditions.
ii. Additional revenue through increased capture rates and pricing changes powered by analytics.
iii. Higher enforcement-officer productivity, ultimately leading to smarter policing with smaller workforce.
iv. Increased success rate in parking ticket disputes.
v. Optimal environmental impact with lower carbon emissions.
vi. Greater efficiency of traffic monitoring and improved planning, driving better return on investment and savings.

Citizen Benefits

i. Reduced circling, leading to savings in time and fuel
ii. Less overall congestion and general improvement in quality of life

Local Business Benefits

i. Ease of parking, resulting in greater customer footfall.
ii. Ability to generate targeted offers and promotions for citizens, based on parking data.

Enforcement Officer Benefits

i. Real-time visibility into parking violations.

ii. Improved workforce management capabilities.

iii. Improved results through better use of time and effort.

The figure below shows Cisco's Smart+Connected Digital Platform is a unifying, cloud-based set of tools that, together, creates a centralized layer for addressing the infrastructural need to connect cameras, water meters, traffic meters, and so on in a reliable, secure, robust and seamless manner. The platform allows the city to capture, analyze and share data across city agencies and departments, across domains and with also with city residents, visitors and businesses—making the Internet of Things (IoT) a reality in cities.

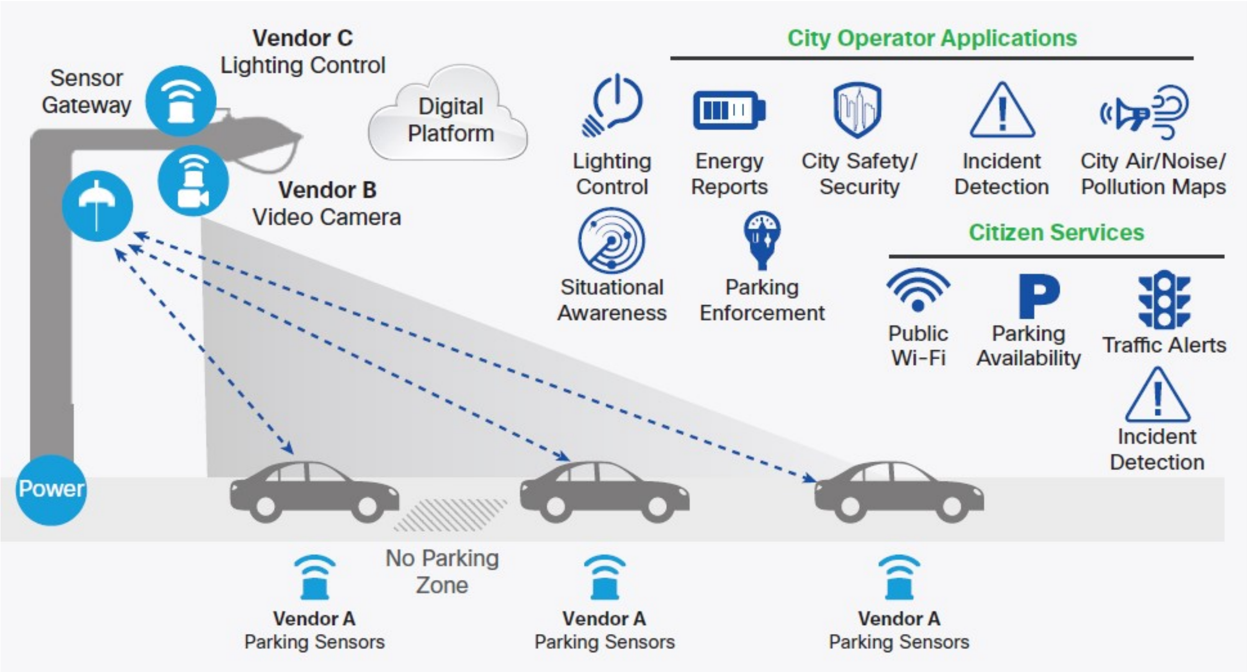

Figure 2-1: Combining Video and Sensor Technology in Smart+Connected City Parking

(Source: URENIO Research, 2011**)**

Intelligent parking services, accessed via the Cisco Smart+Connected City WI-Fi infrastructure, are at the heart of the solution. Figure 2-1 shows how other technologies such as video and sensors combine to create an effective solution for parking issues.

IBM Intelligent Transportation

Intelligent Transportation provides awareness, analysis, and prediction capabilities for traffic operations and transit fleet operations. IBM Intelligent Transportation integrates traffic and transit data from disparate transportation systems by using integration protocols that are recognized by the worldwide transportation industry. IBM Intelligent Transportation provides on-demand geographical visibility, analysis, and reporting of traffic and transit data. It is a portal-based solution that runs on top of the IBM Intelligent Operations Center. IBM Intelligent Transportation leverages the base architecture and features of the IBM Intelligent Operations Center to enable real time communication and collaboration with other city agencies to effectively supervise, coordinate actions, and resolve operational issues efficiently.

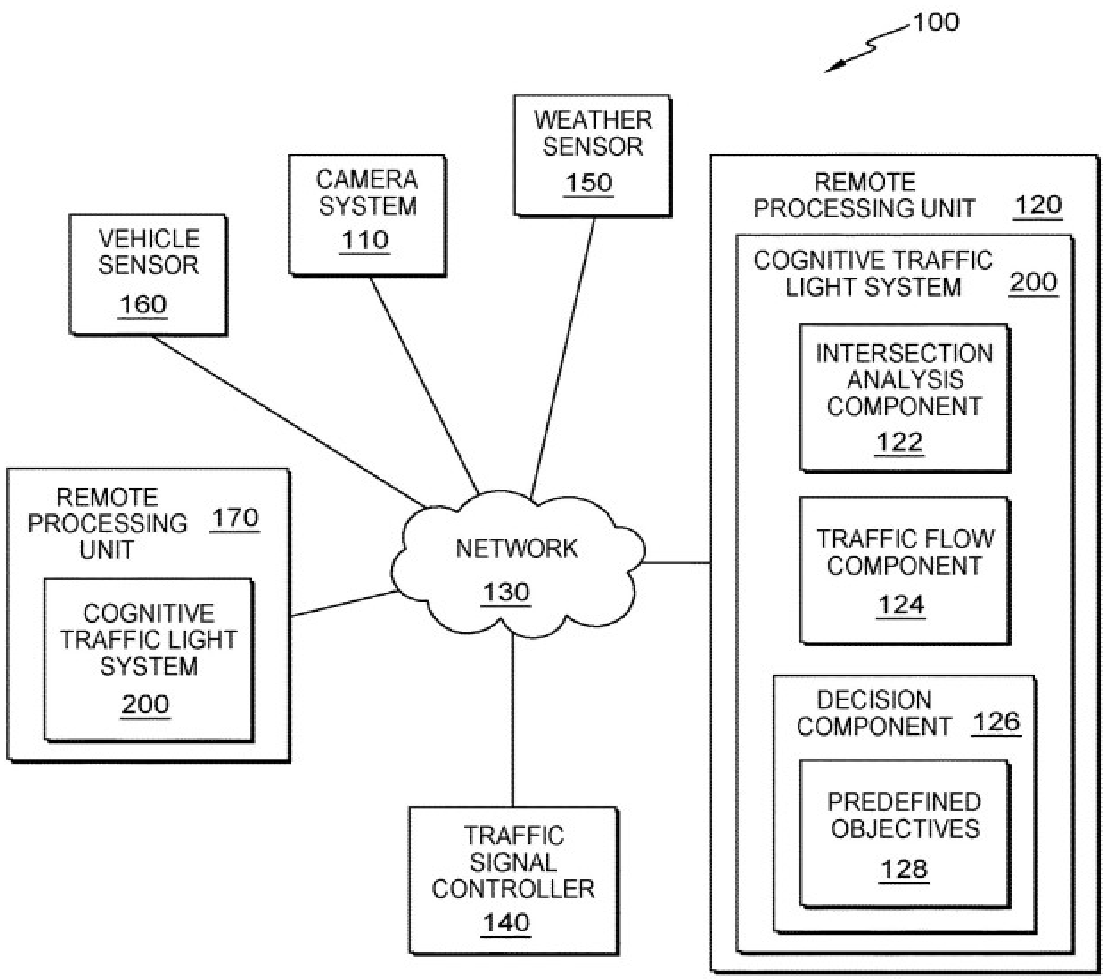

Figure 2-2: IBM Intelligent Transportation employing AI models and algorithms.

(Source: Scherer, 2018)

IBM Intelligent Transportation can be deployed in two ways, either on premises or as a cloud-based offering on the IBM SmartCloud®. IBM Intelligent Transportation can also be integrated with other products in the IBM Smarter Cities® Software Solutions portfolio. The features in traffic operations and transit vehicle operations include:

Traffic Awareness. Traffic Awareness is the foundational traffic operations feature of IBM Intelligent Operations for Transportation. It supplies the transportation information model and basic platform for visualization and analysis of traffic operations data. The Traffic Awareness feature integrates data from disparate traffic and road data capture systems by using integration protocols that are recognized by the worldwide transportation industry.

Traffic Prediction. The Traffic Prediction feature of IBM Intelligent Operations for Transportation provides traffic prediction capabilities for transportation authorities. The Traffic Prediction feature uses the historical and real-time traffic data that is collected by the Traffic Awareness system to predict future traffic levels of a geographical area, up to an hour in advance.

Vehicle Awareness and Prediction. Vehicle Awareness and Prediction provides vehicle awareness and arrival time prediction capabilities for transit systems. Vehicle Awareness and Prediction is the foundational feature of IBM Intelligent Transit Analytics, helping both transit operations departments and passengers to get a clear picture of the vehicle service in the transportation network.

IoT Intelligent Transportation By Intel

The solution incorporates technologies from the Internet of Things (IoT) that can connect nearly anything with an electronics subsystem to the existing Internet infrastructure. Commercial vehicle terminals securely connect to a cloud-based platform running big data analytics. Intel® architecture computing platforms products are used to build an end-to-end solution that enhances the user experience, improves reliability and security, and helps reduce operational costs.

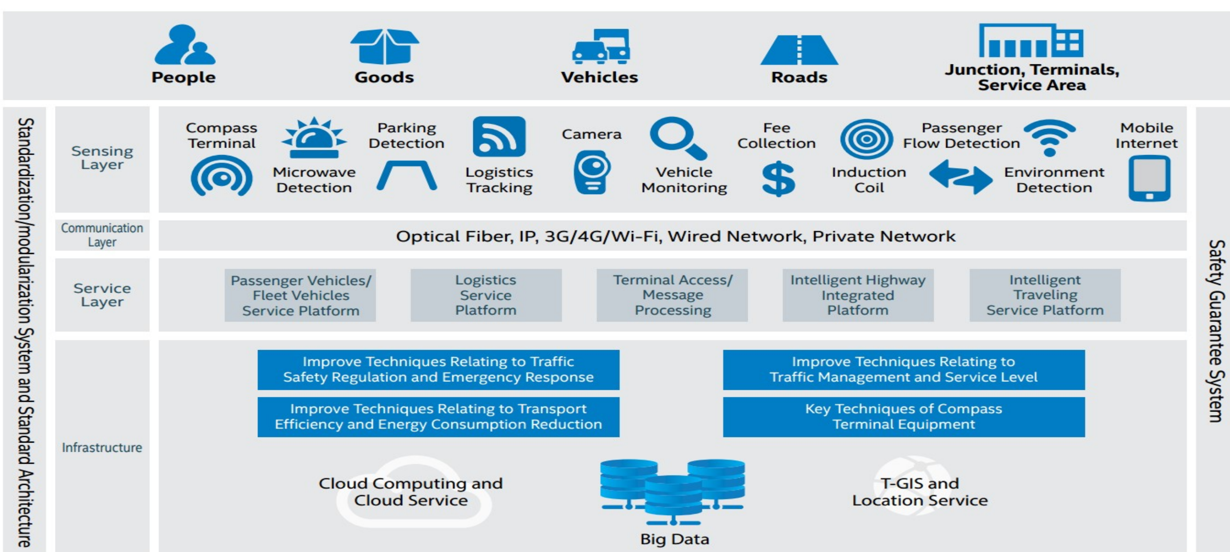

Figure 2-3: Intelligent Transportation System with the IoT by Intel

(Source: Advantech, 2016**)**

Kansas City has over 300 CCTV traffic cameras deployed along its highways, and the video streams are monitored by only three operators — an unmanageable task. To increase effectiveness, the city deployed an image-processing solution from TrafficVision to more effectively collect data and detect traffic incidents in real time. The solution presents traffic information in a web interface and then the information is captured for database storage, analysis, and reporting. The software identifies relevant incidences including wrong-way drivers, current accidents, and debris on the road, and sends the video clips to the cloud (Lowe, 2018). On average, cameras equipped with TrafficVision enable incidents to be detected 14 minutes faster than operators monitoring cameras without this software. This allows operators to quickly send emergency response teams to the scene of an accident, aid and assist, and to notify other vehicle operators of hazards or help reroute traffic as necessary making roads safer and more efficient for the public.

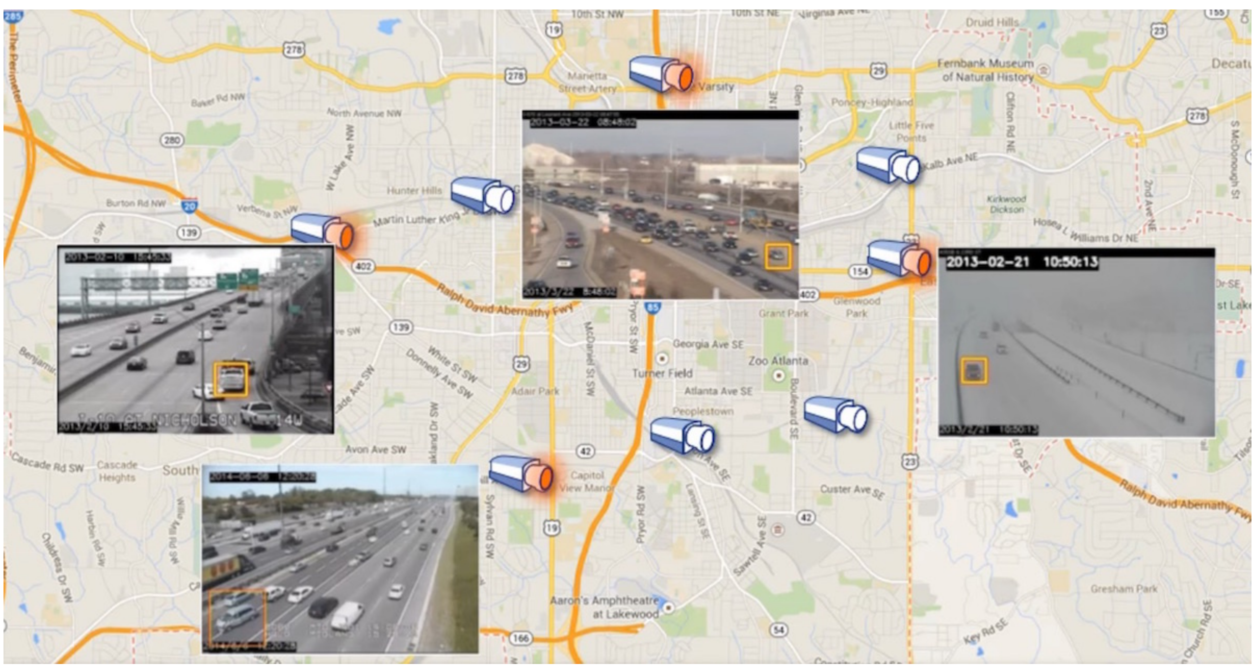

Figure 2-4: Kansas City Traffic Management Overview

(Source: Maddox, 2016)

According to Adler (2015) while IoT offers unparalleled opportunities to enhance efficiency, improve public safety, and support development, it also presents several important challenges that cities will have to negotiate in order to realize these benefits. These include IoT Design and data Privacy. Cities already have lots of data in their existing systems; the challenge is often that they lack the skills or the technology to use it. In order to make the Internet of Things valuable, cities must ensure that the data-gathering systems are designed together with analytics: the data that is collected should be easily understood and to put to use by the governments that collect it. In addition to enhancing the systems for data collection and analysis, governments must also focus on recruiting tech-savvy leaders who can envision and implement cutting-edge systems. Privacy and security: Cities must take seriously their role in ensuring the privacy and security of citizen data. Unless citizens trust their governments to ensure privacy, it will become increasingly difficult for cities to get this data at all. Defense from cyber attacks is also a growing concern, particularly with regards to critical infrastructure, hacking smart meters can cost millions, but a more malicious intruder could compromise safety for residents. In order to successfully implement IoT, cities should make privacy and security a top priority. With smart and forward-looking leadership, IoT has the potential to create a revolution in city planning and management. By embracing the potential of IoT, governments can improve service delivery, increase sustainability, and make their cities safer and more liveable places for all residents.

2.3.2 IoT Implementation Benefits

According to Koeneman (2017) Smart cities rely heavily on the Internet of Things (IoT). IoT devices can help the public transportation industry reduce costs in significant ways. Traffic management is one of the biggest infrastructure hurdles faced by developing countries today. Developed countries and smart cities are already using IoT and big data to minimize issues related to traffic. In most cities, people prefer driving their own vehicles no matter how good or bad the public transportation is or how much time and money is it going to take for them to reach a particular destination. Thus, increase in use of cars has caused an immense amount of traffic congestion. Several countries are overcoming this traffic bottleneck by fetching information from CCTV feeds and transmitting vehicle-related data to city traffic management centres to help smoothen the traffic run. A better-organized traffic system means the better flow of vehicles on the road and means no idling vehicles in traffic jams. Emission of gases is highest during stop-start driving which happens in traffic-light regulated spots. Hence, smart traffic helps in pollution reduction throughout an entire city. However, smart traffic management also involves other factors like smart parking sensors, smart streetlights, smart highways and smart accident assistance amongst other things. Some of the ways IoT is impacting the transportation industry's bottom line include the following:

Real-time vehicle location information and data: Via mobile application, location-enabled IoT devices can alert waiting passengers with real-time vehicle location information and data, estimated trip times, and notifications when they should leave their current locations to catch a bus or train. These IoT devices also allow transit officials to analyze and improve routes and options based on aggregated data.

Predictive, preventive maintenance: IoT sensors allow administrators to monitor the health of a fleet from any connected device. Predictive maintenance utilizes IoT to assess the condition of vehicles and foresee failures before they occur. Condition-based maintenance can prevent failures, extend vehicle life, and improve the reliability of monitored vehicles. The ability to set up alerts for low battery, check engine, oil change, coolant temperature, inspection reminders, and more, allows vehicles to run safely and stay on the road longer.

Safety compliance

Federal and state regulations dictate everything from the maximum amount of time a driver can be on the road without rest, to bus and train size, weight, and signage limitations. IoT devices can ensure drivers are adhering to established industry and/or employer guidelines. Organizations can track how fast vehicles are moving, how long they remain idle, and enable Global Positioning System (GPS) tracking to know exactly where any fleet vehicle is at any point in time. The aggregated IoT solution data can help transit authorities identify operation areas with high risk and develop new safety measures to keep workers and passengers safe.

Smart parking

Parking has become an Achilles' heel in urban planning scenarios. Lack of parking spaces, as well as parallel parking, has heightened traffic snarls at important junctions in cities. IoT-based sensors in parking lots can give out real-time information of empty spots to cars approaching from a long distance looking for a parking space. Such sensors have already been installed in European cities like Paris, France as well as Kansas, US. They have all seen remarkable results with a double-digit percentage reduction in parking issues observed in a span of a year (Parakh, 2018).

Smart assistance

Road accidents have been one of the top causes of deaths across the world. However, what adds to this gloomy fact is the prevalence of untimely help and assistance to victims of such accidents. CCTV and sensors on roads can help in locating accident spots and communicating these to the nearest emergency rooms. If this communication is established in time, all else can be better handled.

Traffic lights

Traffic lights that use a real-time data feed are being used to mitigate the traffic load. Sensors mounted at strategic places can use IoT technology to gather data about high traffic junctions and areas by diverting vehicles from these places. Big data can analyze this information further and figure out alternative routes as well as better traffic signalling to ease congestion. Meanwhile, road-side lights can also work according to weather sensors mounted on them. Dimming of light happens not only at the day-night transition but also when weather conditions turn murky. Roadside light sensors can pick up these signals and turn on and off accordingly.

Manohar (2018) further states that traffic is a crucial aspect that determines a city's liveability factor and efficiency status. A population surge will stop mattering if data and sensors are used capably to manage traffic. As smart cities evolve and increase in number in coming years, IoT and big data will play a key role in the development and integration of their services and infrastructure. With time, other issues besides traffic like waste management and energy conservation will benefit greatly from the concept of IoT and big data. Unger (2015) adds that the prediction is that 2020 will see 50 billion devices communicating with the internet and with each other. The transport industry will be one of the first industries dealing with The Internet of Things. Smart transport solutions will lead to 15% savings, which works out to approximately 1 billion pounds. This means that we not only relieve traffic pressure, but we will also need to invest less in building new roads, leading to a reduction in CO_2 emissions as well. With the advent of smart transport, other problems will also be solved in the process. It won't take you (as) much time to drive around Amsterdam to find a parking space because your car will independently find a space for you. This will give you more time to shop and more time to spend money. These are just some of the ways in which the economy will benefit from the innovations within the transport industry. He goes on to say that the central control room to which all these sensors are connected will receive a continuous stream of data. When the control room notices that a certain traffic node is showing signs of congestion, it will communicate with the sensors in the cars and roads and temporarily adjust the maximum speed limit from 100 km/h to 60 km/h. This will give drivers more time to slow down which will result in fewer accidents and less congestion. Meis (2016) also makes a contribution and goes ahead to give us a list of cities that have benefited or are about to reap enormously from the IoT incorporation in traffic management. These include:

Congestion relief in Los Angeles: Los Angeles uses data from an array of magnetic road sensors and hundreds of cameras feed through a centralized computer system to control 4,500 traffic signals citywide to help keep traffic moving. Completed in 2013, the $400-million system is credited with increasing travel speeds around Los Angeles by 16 percent, and shortening delays at major intersections by 12 percent.

Smart parking in San Francisco: To determine the right price to charge for parking to meet parking-space availability targets, SFpark used wireless sensors to detect parking-space occupancy in metered spaces. Installed in 8,200 on-street spaces in the pilot areas, the wireless sensors detected parking availability in real time. Sensors also were placed in three control neighbourhoods to provide baseline data for evaluation purposes. In 2013, two years after launching SFpark, San Francisco published a detailed report showing that the program had reduced weekday greenhouse gas emissions by 25 percent. Traffic volume went down, and drivers cut their search time nearly in half. They achieved these results by adjusting pricing to incentivize drivers to do things such as park in less congested areas, or arrive at a parking garage before the morning rush and leave after the evening rush. San Francisco also increased revenues by about $1.9 million by making it easier to pay for their parking. It turns out that, before SFpark, only 45 percent of drivers fed the meter during the work week. During the pilot, that number rose to 54 percent. The difference was enough to offset the revenue lost to decreased parking tickets.

Sonoma County, California. These were the exact problems faced by transport officials in Sonoma County, California. The county's traffic intersections were connected via a wired SCADA system at a cost of $750,000 per intersection. While this allowed administrators to monitor traffic flow throughout the county, the 20-year-old system was increasingly unreliable. Breakdowns every few days, a lack of notification when signals went down, and difficulties downloading new signal timing intervals meant that the cost of 24/7 operation was approximately $220,000 per year. Having tested a number of options, which all proved unsuccessful, the county looked at Sierra Wireless' AirLink RV50, a low-power, LTE gateway. Deployment was simple: the RV50 was configured straight out of the box and activated within one day, and the county now has a system that immediately notifies them if a signal goes down. Operators can also download new software to the entire system at once, and officials are able to alter signal sequences in real time, helping control traffic congestion during peak travel times or special events. Arguably the biggest benefit, however, was the county's significant cost savings. The $220,000 per year required by the wired SCADA system was slashed to $16,000—a 93% saving. The system paid for itself within four weeks.

Innovative Traffic Management in Cambridge, England. Other cities around the world are following suit. In Cambridge, England, city officials plan to use smart traffic lights to give public transport vehicles priority at junctions, phasing traffic lights so that buses get the 'green wave' throughout their entire journey. This gets people to work faster (boosting productivity), and reduces wasted fuel—and it just might encourage more people to opt for public transportation, further cutting down on gridlock. These applications are just scratching the surface. We're already looking at a future in which smart traffic lights will be able to communicate with an ever-increasing number of smart vehicles. A recent hypothetical study by the Universitat Politecnica de Catalunya estimated that these types of smart traffic systems could cut CO_2 emissions in half—from roughly 110g of CO_2 per vehicle to roughly 50g. When applied to thousands of vehicles, this adds up significantly. As the technology develops, we will likely see traffic signals combined with other LTE-connected devices as well, like as traffic cameras, sensors and signage, to reduce congestion even further, helping cities boost productivity, lower

CO_2 levels, and improve quality of life for their citizens. It's a future that's rapidly approaching. To be a part of it, or for more information on Sierra's LTE gateways for traffic management and transport communication, Start with Sierra, and read more about our product offerings.

2.3.3 IoT Traffic Management Design Framework

Houghton (2010) gives his insights into the traffic management discussion by alluding that cities face urgent transport challenges. Many are starting to tackle them by implementing new intelligent transport systems, and some have achieved impressive benefits. However, many cities are at the "early adopter" stage. We believe five recommendations can assist cities in using new technologies to achieve optimized, integrated transport services. The world is urbanizing rapidly, however, the constraints of the ever increasing population are putting pressure on these developments. According to Laffoon and Mourad (2011), the growing Intelligent Transportation Systems (ITS) industry is becoming increasingly important across the globe as cities try to reduce congestion, reduce emissions, and offer better services to citizens. In the ITS industry, open standards play a critical role in helping government organizations to:

Save on costs when integrating solutions.

Reduce the risks of building and procuring new systems that can solve problems.

Build a common platform to enable future innovation.

IBM Intelligent Transportation*:* This platform conforms to the National ITS Architecture, and follows the ITS common structure for the design of an intelligent transportation systems framework. The IBM Intelligent Transportation architectural design was developed around this framework. IBM Intelligent Transportation is tailored to meet the needs of the end user while maintaining the benefits of a common architecture.

"Centre" subsystems deal with the functions typically assigned to public or private administrative, management, or planning agencies. IBM Intelligent Transportation implements the centre subsystems highlighted in green in Figure 2-5, which include roadway information and reporting, traffic management, archived data management, and core services (such as administration, authentication, and authorization).

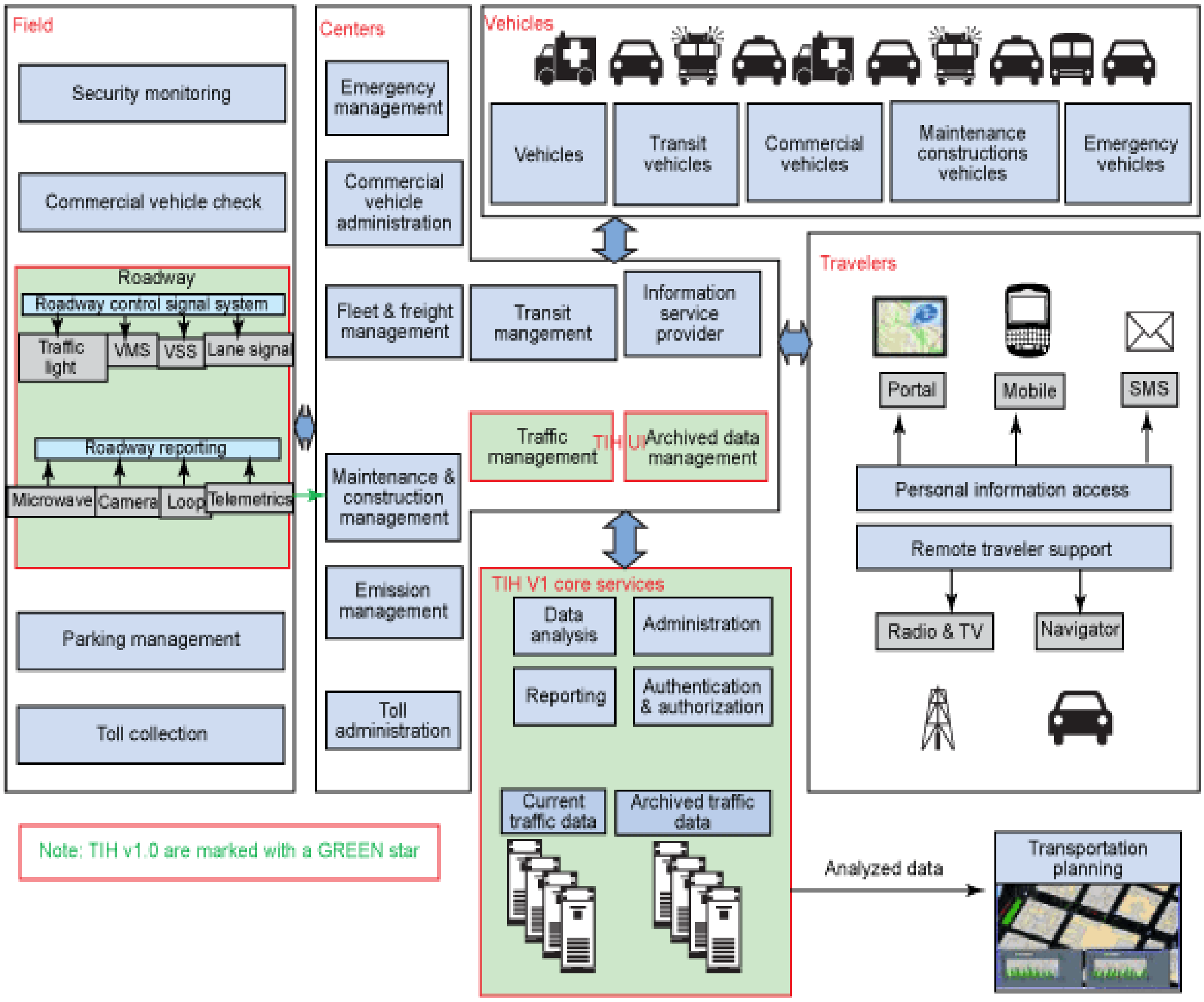

Figure 2-5: IBM Intelligent Transportation high-level architecture

(Source: Lafoon and Mourad, 2011)

The Traffic Management subsystem consists of traffic surveillance and managing events or incidents.

Traffic surveillance*:* Processes traffic data and provides basic traffic and incident management services through the Roadside and other subsystems. All pre-processed data about vehicles passing through the surface street and freeway network is collected by processes. The data is then sent to processes that distribute it to other facilities and load it into the current and long-term data stores. The data in these stores, plus weather and incident data, is used by processes to produce an analysis. (In future releases, a predictive model of future traffic conditions will be produced.) The results of this process, and the data stored by processes, are available for display by traffic operations personnel and the media. The processes that make up the Provide Traffic Surveillance facility within the Manage Traffic function:

i. Store and manage processed traffic data
ii. Display and output traffic data
iii. Exchange data with other traffic centres
iv. Analyze, correlate, and report traffic data

Manage events/incidents: Provides the processes that make up the Manage Incidents facility within the Manage Traffic function. These processes manage the classification of incidents and implement responses when they actually occur. The facility will:

i. Store, manage, and categorize traffic events static data
ii. Provide operator interfaces for events
iii. Provide traffic data analysis for traffic events
iv. Review and manage events data

The events management processes divide events, or incidents, into three types: possible, predicted, and current data. For example, planned events could include special events, sports events, and maintenance and construction activities. Current incidents might include traffic accidents, natural disasters, and incidents caused by the effects of the weather.

Archived Data Management: The Archived Data Management subsystem collects, archives, manages, and distributes data generated from ITS sources for use in: transportation administration, policy evaluation, safety, planning, performance monitoring, program assessment, operations, and research applications. Key services of the Archived Data Management subsystem include: Manage archive data administrator interface, Manage Roadside data collection, get archive data, store and manage archive traffic data, analyse archive and prepare reporting inputs

2.4 Schematic diagram of Nairobi City

It is estimated that out of the approximately 2 million registered motor vehicles in Kenya in 2013, about 60% were located in the Nairobi Metro (Gachanja J. , 2015). According to a study by Ndung'u, (2013) the causes of traffic congestion on Jogoo road included too many low capacity vehicles, poor management by traffic police, roundabouts, indisciplined drivers, inadequate road space among others. The effects of the congestion comprised of time wastage/lateness, usage of too much fuel, air and noise pollution, discomfort while inside the vehicle, risk of accidents, reduced financial returns for businesses and vehicle operators and nuisance in estates and business areas where motorists traversed as they escaped jam on the main roads. According to Gachanja, (2015) “traffic control in the Nairobi Metro has been wanting, and it is now believed that some of the traffic interventions, such as installation of traffic lights in most of the CBD, have not worked despite enormous resources being put into this and even intervention by traffic officers often leads to more confusion and more congestion.” Gonzales E. et al 2009, “argue that for a city of roughly five million inhabitants, Nairobi has few streets to serve traffic demand with only a handful of roads linking the radial arterials outside of the central business district (CBD) as shown below.”

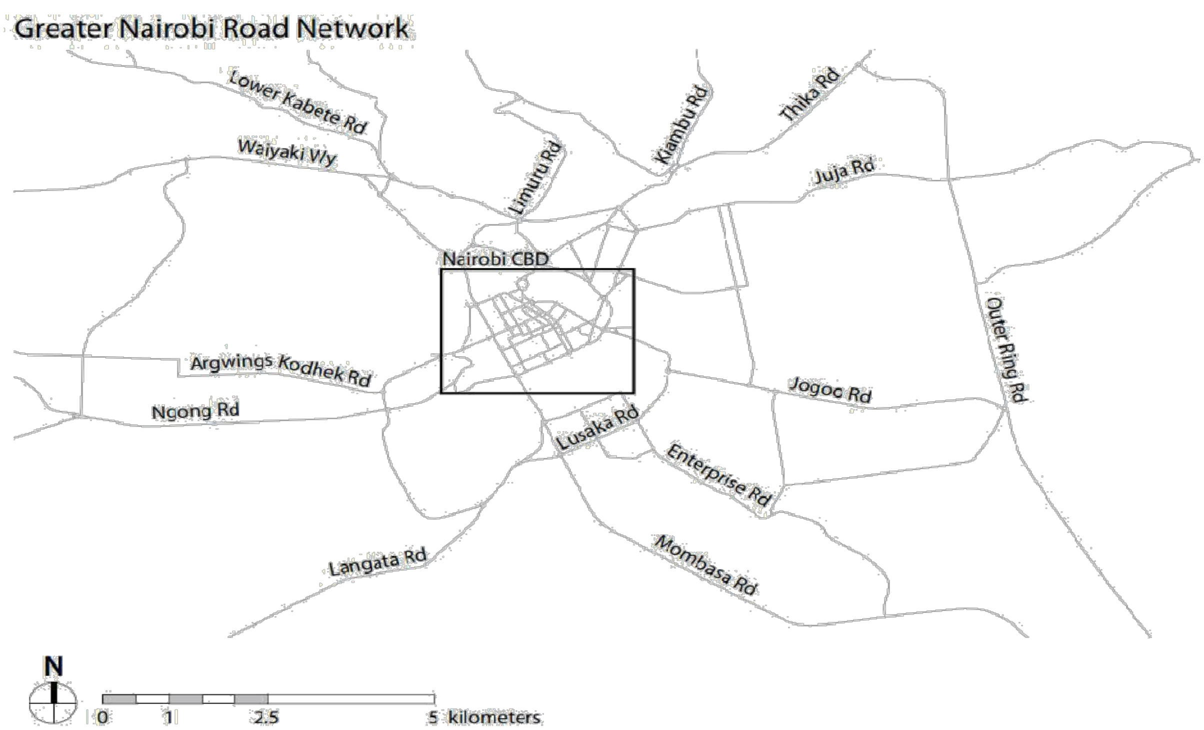

Figure 2-6: The road network in Nairobi

The road network in Nairobi is primarily composed of radial routes connecting surrounding regions to the CBD. The lack of circumferential roads forces many peripheral trips through the centre. Figure 2.7 below illustrates the most suitable locations where the IoT sensors can be put as an initial way of taking care of the Central business district. They can then relay the information to a central data centre which could be cloud based or hosted within the City administration premises.

Figure 2-7: Schematic Diagram with areas suitable for IoT Sensors

2.5 Summary of Review of Literature

Residents of Nairobi spend 62.44 minutes in traffic every day, making Nairobi the world's second worst city on traffic congestion after Kolkata (formerly Calcutta) in India (Wasonga, 2018). This has a spiral effect on various aspects of the Country's economy in terms of time wasted and environmental pollution. Accidents are also a common scenario around the city. One reason for traffic-congestion is that streets are not fully connected to its vicinities. In the central Nairobi, approximately 12 per cent of the land is allocated to streets. A functioning traffic system in a modern capital generally requires around 30 per cent of land allocated to streets. These two major findings lie at the heart of the traffic jam problem in Nairobi: Too many street patterns and too few streets that are adequately connected (Dzikus, 2017). Against this basic analysis, what remains critical is the kind of interventions that will provide the most efficient results, bearing in mind the lack of financial resources available to undertake big transformations. A much smaller investment than the amount lost due to traffic congestion in Nairobi (estimated at Sh37 million) if spent on better street connectivity would solve the congestion problem.

Gachanja (2011) alludes that on the demand side 50% of the traffic congestion in Nairobi could be solved by increasing road capacities and 10.86% by building bypass roads while on the supply side 40.91% could be solved by shifting to public transport and higher vehicle capacity and 10.70% by development of multiple centres in Nairobi metro region. Both of these measures especially increasing road capacities were considered not economically feasible (Gachanja, 2015). Ashe (2015) adds that an intelligent city is a city that can collect data efficiently and bring it in a way that is meaningful to them. It can enhance revenue, or ultimately offer citizens new services that they never before had.

More insight into that comes from Menon (2015) who believes that a smart city is a city that uses digital technologies or information and communication technologies, connected via an intelligent network, to address challenges within city communities and across vertical industries. These challenges may include parking, traffic, transportation, street lighting, water and waste management, safety and security, even the delivery of education and healthcare. A smart city relies on technological solutions that enhance its existing process to better support and optimize the delivery of urban services, to reduce resource consumption and contain costs, and to provide the means and the opportunities to engage actively and effectively with its citizens, with its visitors and with its businesses.

2.6 Research Gap

The literature has revealed that integrating IoT in the traffic management will surely have a great impact in restoring sanity and also help in the management and control of the traffic within Nairobi City County. It has come out clearly that congestion in general is a big problem in most developing countries and that one of the most helpful aspects of a smart city is using technology to ease traffic and parking woes. Sensors in the street can be used to determine if a parking spot is empty, and anyone who accesses an app on a Smartphone can find out in real time the location of the closest parking spot (Madoxx, 2018). Internet of things has not been widely adopted in combating traffic congestion in these Cities. Traffic jams on most roads could reduce drastically if the city authorities would welcome adoptions of IoT technologies to combat traffic (Omollo, 2016).

It is with this background that the research has come up with an endurable IoT design framework that can be applied in any other major city encountering the same problem.

2.7 Current IoT Technologies and Architectures Applicable in Traffic Management

From review of literature, the study adopted the six-layered architecture based on the network hierarchical structure developed by Cheng et al. (2012) involving the coding, perception, network, middleware, application and business layers.

Coding Layer provided the foundation identification to the objects of interest by assigning a unique ID which makes it easy to distinguish the objects where the cars and the parking lots were allocated unique IDs. **Perception Layer** is the device layer of IoT which gives a physical meaning to each object consisting of data sensors in different forms like RFID tags, IR sensors or other sensor networks which could sense the speed and location of the objects and thereby convert the collected information about the devices linked into digital signals which is then passed onto the Network Layer for further action; the cars were fitted with number plates with sensors and sensors were also mounted on parking lots. **Network Layer** receives information and transmits it to the processing systems in the Middleware Layer through the transmission mediums like WiFi, Bluetooth, WiMaX, Zigbee, GSM, 3G, 4G etc with protocols like IPv4, IPv6, MQTT, DDS etc in this case data was transmitted using WiFi. **Middleware Layer** processes the information received from the sensor devices. It includes the technologies like Cloud computing, Ubiquitous computing which ensures a direct access to the database to store all the necessary information in it, in this case ubiquitous computing was adopted to automate information processing. **Application Layer** realizes the applications of IoT for all kinds of industry, based on the processed data where in this case consisted of smart parking. **Business Layer** manages the applications and services of IoT and in this case consisted of back-end management.

CHAPTER THREE

RESEARCH DESIGN AND METHODOLOGY

3.1 Introduction to Research Methodology

Research methodology represents the framework that the research used to illustrate the procedures for collecting data for this study. This chapter presents the research design, the target population, sampling size and the strategy, data collection instruments and procedures and instruments of data analysis.

3.2 Research Design

The function of a research design is to ensure that the evidence obtained enables you to effectively address the research problem as unambiguously as possible (Barbara, 2006). This research has an exploratory character, since IoT is a relatively new and complex field and standardization is still evolving. This approach works quite well since interviews and observations are the most popular primary data collection methods. The research also considered secondary sources of data collection by interrogating the research that has been carried out on the implementation of similar models around the world. An exploratory research is useful since it provides the research with detailed insights that can contribute to theory.

It is not preferable to express the findings of this study in just numerical values, since those would not provide a rich understanding (the why and how). In that case, the research has used qualitative strategy which is also descriptive in nature. A descriptive research intends to present facts concerning the nature and status of a situation, as it exists at the time of the study. It also tries to describe present conditions, events or systems based on the impressions or reactions of the respondents of the research (Omollo, 2016).

A case study enables the research to gain a rich understanding of the context of the research and the processes being enacted (Saunders et al., 2009). Some wireless technologies that enable IoT have been selected as cases within this research. They have been selected by theoretical sampling in order to gain as much information as possible.

3.3 Research Site

According to Kothari (2003), a research site is an area which the researcher designs and tests the sample. This is the location where a given research study is carried out and why the specific locations is chosen. This study was conducted in selected major roads in Nairobi City County which feed the city with the highest amount of traffic on a daily basis. These are Thika road, Northern Bypass, Mombasa road, Eastern Bypass, Kipande Road, University Way, Uhuru Highway and Kenyatta Avenue.

The rationale for this site is that it is the capital city of the country and it's the most densely populated city in the country and it experiences the most challenges to do with traffic congestion. It therefore, makes a very good site for study.

3.4 Target Population

Multiple sources of data were used because the data is more likely to be valid if multiple different data sources support this data and also the probability that data is based on coincidence diminishes (Bryman, 2008; Saunders et al., 2009). Road users, parking attendants, Traffic police officers and officials from the City inspectorate and major road networks listed above formed the target population in this research. These are the groups that are directly involved in this research.

Sampling table as illustrated by Krejcie and Morgan, (1970) indicate that when targeting a population of between 1,000,000 and 10,000,00 which is where Nairobi's population lies, a sample size of 384 was sufficient. Because of low response rate from traffic Police officers and City County enforcement officials and also time and resource constraints the research involved half of the sample, 192 respondents. The sampled respondents were categorised with 162 private car drivers, 9 county parking attendants, 12 enforcement officers and 9 officers from the traffic Police in the study.

$$n = \frac{X^2 * N * P * (1-P)}{(ME^2 * (N-1)) + (X^2 * P * (1-P))}$$

Where:

n = sample size

X^2 = Chi – square for the specified confidence level at 1 degree of freedom

N = Population Size

P = population proportion (.50 in this table)

ME = desired Margin of Error (expressed as a proportion)

Required Sample Size†

Population Size	Confidence = 95%				Confidence = 99%			
	Margin of Error				Margin of Error			
	5.0%	3.5%	2.5%	1.0%	5.0%	3.5%	2.5%	1.0%
10	10	10	10	10	10	10	10	10
20	19	20	20	20	19	20	20	20
30	28	29	29	30	29	29	30	30
50	44	47	48	50	47	48	49	50
75	63	69	72	74	67	71	73	75
100	80	89	94	99	87	93	96	99
150	108	126	137	148	122	135	142	149
200	132	160	177	196	154	174	186	198
250	152	190	215	244	182	211	229	246
300	169	217	251	291	207	246	270	295
400	196	265	318	384	250	309	348	391
500	217	306	377	475	285	365	421	485
600	234	340	432	565	315	416	490	579
700	248	370	481	653	341	462	554	672
800	260	396	526	739	363	503	615	763
1,000	278	440	606	906	399	575	727	943
1,200	291	474	674	1067	427	636	827	1119
1,500	306	515	759	1297	460	712	959	1376
2,000	322	563	869	1655	498	808	1141	1785
2,500	333	597	952	1984	524	879	1288	2173
3,500	346	641	1068	2565	558	977	1510	2890
5,000	357	678	1176	3288	586	1066	1734	3842
7,500	365	710	1275	4211	610	1147	1960	5165
10,000	370	727	1332	4899	622	1193	2098	6239
25,000	378	760	1448	6939	646	1285	2399	9972
50,000	381	772	1491	8056	655	1318	2520	12455
75,000	382	776	1506	8514	658	1330	2563	13583
100,000	383	778	1513	8762	659	1336	2585	14227
250,000	384	782	1527	9248	662	1347	2626	15555
500,000	384	783	1532	9423	663	1350	2640	16055
1,000,000	384	783	1534	9512	663	1352	2647	16317
2,500,000	384	784	1536	9567	663	1353	2651	16478
10,000,000	384	784	1536	9594	663	1354	2653	16560
100,000,000	384	784	1537	9603	663	1354	2654	16584
300,000,000	384	784	1537	9603	663	1354	2654	16586

Figure 3-1: Sample Size Formula and Table

(Source: Krejcie & Morgan, 1970)

3.5 Determination of Study Sample

3.5.1 Sampling Procedures

A sample was drawn from a section of drivers on Nairobi's major roads and also the research also incorporated traffic officers and enforcement officers. Stratified random sampling was employed to select sample size of respondents, where the population was segmented into fractions and thereafter random sampling methods invoked to each fraction to form a test group.

3.5.2 Study Sample Size

Each staff in the population of this study stood a chance of being included in the sample which thus made it immune to sample bias. Mugenda and Mugenda (2004) correctly puts it that sample size of any given population should be representing a specific target of the population. As such, this study adopted target population to enhance more representation.

Estimation of sample size in research using Krejcie and Morgan is a commonly employed method. Krejcie and Morgan (1970) used the following formula to determine sampling size. Due to the challenges that were encountered in trying to sample all the major roads in the city centre, this research focused on eight roads namely, Mombasa Road, Eastern Bypass, Uhuru Highway, Thika road, Kipande Road, Kenyatta Avenue, Northern Bypass and University Way. The research involved a few city inspectorate officials and parking attendants, and officers of the Traffic Police as illustrated in the Table 3-1 below.

Table 3-1: Sampling Table

Sampled Road	Driver Sample Size	Parking Attendant Sample Size	Enforcement Official Sample Size	Traffic Police	Total
Mombasa Road	8	0	1	1	**10**
Eastern Bypass	8	1	0	1	**10**
Uhuru Highway	18	0	1	1	**20**
Thika Road	26	2	2	2	**32**
Kipande Road	7	0	2	1	**10**
Kenyatta Avenue	45	3	2	0	**50**
Northern Bypass	6	0	2	2	**10**
University Way	44	3	2	1	**50**
Grand Total	**162**	**9**	**12**	**9**	**192**

3.6 Data Collection Procedures

3.6.1 Development of Instruments

The instrument used was a questionnaire. The questionnaire was both open-ended and closed ended. In order to cover the whole scope, open and closed ended approach, was employed as proposed by (Orodho, 2005). This further enhanced greater understanding of the research problem. The open ended types of questions gave informants freedom of response to the questions without rehearsal to any question and thus ensure correct “first hand response”. The closed ended type facilitated consistency of certain data across informants (Kothari, 2003) and it was time-efficient. The questionnaire method is free from bias of the interview as answers are in the words of respondents and the respondents will have adequate time to give appropriate answers and save on this (Kothari, 2003).

3.6.2 Pilot Testing of Research Instruments

These are measures taken to ensure that the data collection tools are standardized to collect the intended data for the study without ambiguities and duplicity. This was done through piloting of the study data collection tool. A pilot study was carried out on two non-study roads to gain insights and clarify issues on the system needs study instruments constructs.

3.6.3 Instrument Reliability

This is a measure of the degree to which a research instrument would yield the same results after repeated trials (Mugenda, 2008). The reliability of the questionnaire was be established through split half techniques where the pretest dataset was split into two equal datasets and the Cronbach Alpha evaluated. The results indicated a Cronbach Alpha score of 0.83 greater which was considered to be indicating a good internal consistency that the study results were reliable.

3.6.4 Instrument Validity

Golafshani (2003) opines that the best test of validity of any findings is the extent to which it can be generalized to a wide range of situations and scenarios. This in retrospect reflects how close it is to the reality. Since validity measures the extent to which the tool is likely to show the linking relationships of the variables of the study, a pilot study of 30 respondents to test the validity of the research instrument was conducted. The research tool was then collected in line with the feedback received from selected respondents. The validity content was conducted by asking subject experts and the supervisor on the relevance of the research questions for the research objectives

3.7 Data Processing and Analysis

Analysis of the data collected data was done using Statistical Package for Social Sciences (SPSS) Version 25. First, the data was cleaned, coded and keyed on the software. The data was processed and analysed in form of descriptive statistics was then displayed in frequencies, variances and percentages.

3.8 Ethical Considerations

The research maintained all ethical considerations while doing the study. The participants were well advised of the purpose of the study and their consent sought prior to their participation in the study. Respondents were also informed that the study was voluntary and adequate measures would be taken to protect confidentiality. Accuracy was adhered to in data collection, analysis, interpretation and reporting the findings. The research also maintained ethics in academic writing and publishing

CHAPTER FOUR

RESULTS AND ANALYSIS

4.1 Introduction

This chapter presents the study findings relative to the study objectives. Self-administered questionnaires were used to collect data from the respondents.

4.2 Presentation of findings

The section introduces the results chapter by linking the objectives of the study and purpose the results in a very brief statement.

4.2.1 Socio-Demographic Characteristics

The total sample size for the survey was 192, 171 were private car drivers while 21 were county parking attendants. Male respondents were 84.7% private car drivers and 76.2% county parking attendants. 53.5% of the private car driver respondents had attained university/college education while 66.7% of the county parking attendants had attained secondary level of education. 38% of the private car attendants and 41.7% of the county parking attendants were aged between 30 and 39 years.

Table 4-1: Socio-Demographic Characteristics

Characteristics	Categories	Private car drivers		Enforcement/ Parking attendants	
		Frequency	Percent (N = 171)	Frequency	Percent (N = 21)
Gender	Male	145	84.7%	16	76.2
	Female	26	15.3%	5	23.8%
Education level	University/College	91	53.5%	5	25.0%
	Secondary	74	43.0%	14	66.7%
	Primary	3	2.5%	2	8.3%
	None	2	1.0%	0	0.0%
Age categories	30-39	65	38.0%	9	41.7%
	40-49	48	28.0%	7	33.3%
	20-29	31	18.5%	2	8.3%
	50-59	17	10.0%	3	16.7%
	>59	10	5.5%	0	0.0%

Slightly over half of the respondents identified parking spots by driving around while 70.1% parked their cars on on-street parking. On the other hand, 51.5% of the drivers preferred driving around as a means of identifying a parking space. Few of the remaining ones either use private parking or other means not captured in this research.

Table 4-2: Form of identifying parking lots and Parking place

		Frequency	Percent
Form of identifying parking lots in town	Driving around	87	51.5%
	Parking attendants	42	25.0%
	Booking in-advance	25	14.5%
	Parking boys	17	9.0%
Parking place.	On-street parking	120	70.1%
	Off-street parking	29	16.9%
	Private parking	20	11.6%
	Other	2	1.1%

4.2.2 Benefits from IoT Application in Traffic Management

Most respondents concur that traffic management using IoT when implemented will ultimately help with real time visibility of traffic violations in the city. This will be mostly through the installation of cameras at strategic points around the city and having the information relayed to different enforcement officers. Some people remained neutral about the impact on the visibility of traffic violations at 14.3% for the enforcement officers and 12.9% for the private drivers.

Table 4-3: Traffic management using IoT in real time visibility of traffic violations in the city

Respondents	Traffic management using IoT when implemented will ultimately help with real time visibility of traffic violations in the city.									
	Strong Disagree		Disagree		Neutral		Agree		Strongly Agree	
	Frequency	Percent (%)	Frequency	Percent (%)	Frequency	Percent (%)	Frequency	Percent (%)	Frequency	Percent (%)
Enforcement Officers/ Attendants	0	0.0%	2	9.5%	3	14.3%	9	42.9%	7	33.3%
Private Drivers	9	5.3%	19	11.2%	22	12.9%	47	27.5%	74	43.3%

According to the research, implementation using IoT will definitely lead to the improvement in traffic flow and less congestion will have optimal environmental impact with low carbon emissions translating to better mobility and living conditions. The study captured that 33.3% of the enforcement officers and 36.3% for the private drivers, though not having a lot of knowledge on the IoT, they remain optimistic of this technology to help in resolving traffic congestion.

Table 4-4: Traffic management using IoT in optimal environmental impact with low carbon emissions

Respondents	Improvement in traffic flow and less congestion will have optimal environmental impact with low carbon emissions translating to better mobility and living conditions.									
	Strong Disagree		Disagree		Neutral		Agree		Strongly Agree	
	Frequency	Percent (%)	Frequency	Percent (%)	Frequency	Percent (%)	Frequency	Percent (%)	Frequency	Percent (%)
Enforcement Officers/ Attendants	2	9.5%	4	19.1%	3	14.3%	5	23.8%	7	33.3%
Private Drivers	4	2.3%	24	14.1%	32	18.7%	49	28.6%	62	36.3%

4.2.3 Prototype of sustainable IoT Architecture for parking management in Nairobi

About 28.5% of the enforcement officers sampled and 44.0% of the private drivers were of the opinion that traffic management using IoT will help the county establish the congested routes for the purpose of city planning. However, quite a good number of them remained neutral on that at 23.8% for the enforcement officers and 19.9% for the private drivers.

Table 4-5: IoT help in establishing the congested routes for the purpose of city planning.

Respondents	IoT will help the county establish the congested routes for the purpose of city planning.									
	Strong Disagree		Disagree		Neutral		Agree		Strongly Agree	
	Frequency	Percent (%)	Frequency	Percent (%)	Frequency	Percent (%)	Frequency	Percent (%)	Frequency	Percent (%)
Enforcement Officers/ Attendants	1	4.8%	1	4.8%	5	23.8%	8	38.1%	6	28.5%
Private Drivers	10	5.8%	24	14.0%	34	19.9%	45	26.3%	58	44.0%

4.3 Analysis of Objectives

4.3.1 Causes of traffic congestion in Nairobi

38.7% of the private cars spent between one and two hours in the traffic jam in the morning with an average of 1.6 hours of the morning time spent on traffic jam while an equal number (35.9%) of private car drivers spent 1-2 hours and 2-3 hours in traffic jam in the evening with an average of 2.0 hours of the evening time spent on traffic jam. Cumulatively, drivers spent an average of 3.6(±0.3) hours stack in traffic jam both in the evening and in the morning. This findings were similar to the IBM Commuter Pain Survey where it was found out that 45% of drivers in Nairobi said they had been stuck in traffic for three hours or more (IBM, 2011).

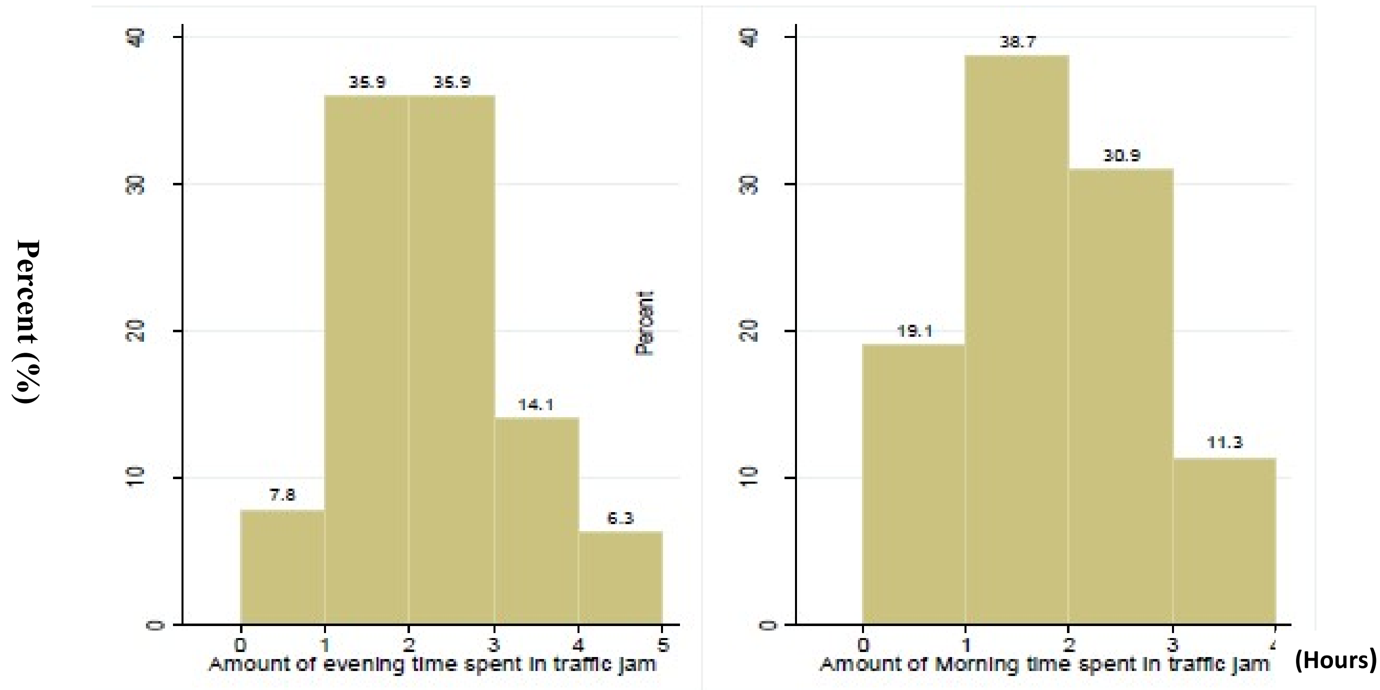

Figure 4 - 1: Time Spent in Traffic Jam

4.3.2 Parking Fee and Traffic Jams

As shown in the scatter plot, most drivers were paying Kshs. 300 irrespective of the amount of time they park their cars.

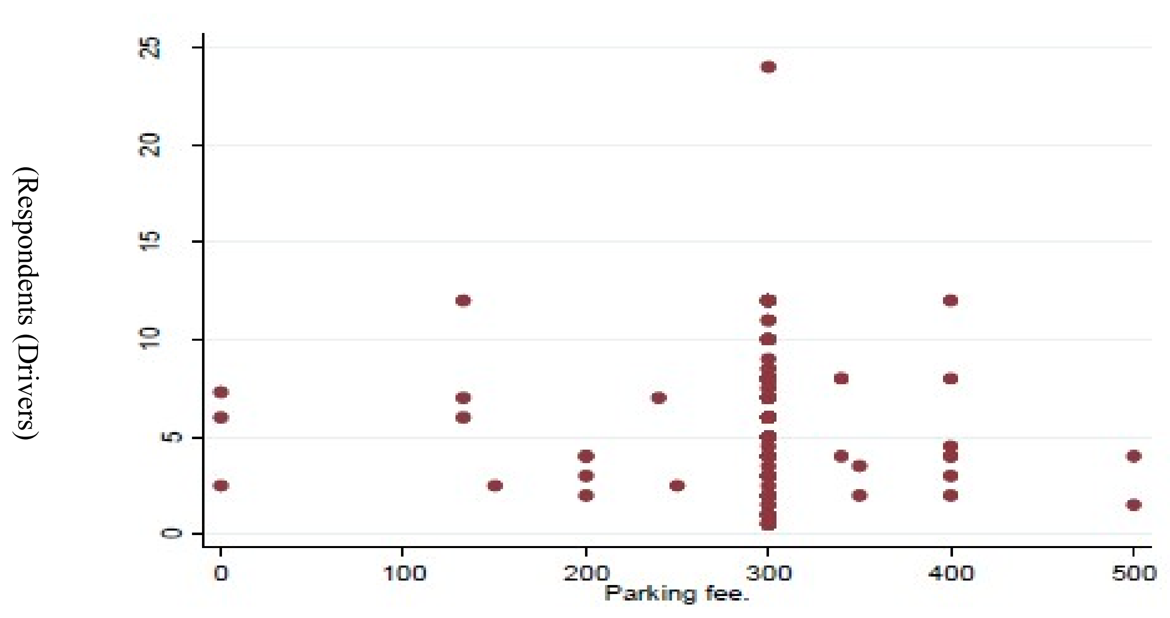

Figure 4 - 2: Parking fee

To determine the major causes of traffic jams in Nairobi both the county parking attendants and private car attendants were asked to rank the causers (individuals) of traffic jam from 1 (most) to 4(least) and the situation that causes traffic jam from 1(most) to 5(least)least. From Figure 4 - 5, both private car drivers and county parking attendants considered matatu car drivers as the most causers of traffic jams in Nairobi, private car drivers were ranked the second causers of traffic jams while traffic police and county council askaris/parking attendants were ranked third and fourth respectively. Similar findings were made in the report by Transport and Urban Decongestion Committee report in which it was reported that in order of bearing greatest responsibility of causing traffic jams matatus (75%), private vehicles(71%), pedestrians (55%), minibuses (48%), heavy commercial vehicles(46%), mkokotenis (45%), and motor bikes(38%) (Nairobi City County, 2014). "This can be explained by the fact that motor cars have increased at a faster rate of 7% than buses and mini-buses (5%), which implies that personal vehicles are becoming more popular as a mode of transport in the country and especially in Nairobi" (Gachanja J. , 2015). This finding was similar to the assertions that private car ownership and absence of a public transport system are the major causes of traffic gridlocks in Nairobi; although the current traffic volume may be managed for a time but with increasing car ownership, it will recur (Kebari, 2015)

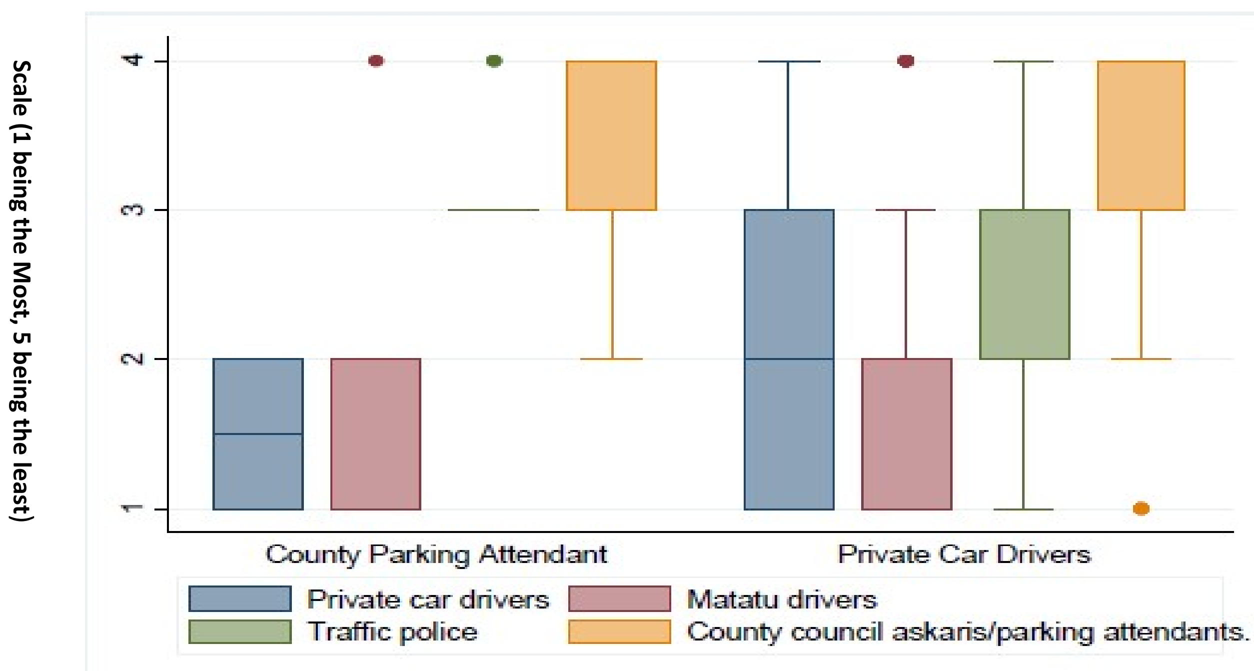

Figure 4 -3: Causes of Traffic Jam from Road Users

Drivers looking for parking spots and insufficient parking lots were consistently ranked the most cause of traffic jams by both the county parking attendants and private car drivers while untimely parking attendance was also consistently rated as the least cause of traffic jams by both groups of respondents as indicated in the medians of the box plots in figure 14. "This findings was similar to the IBM Parking Index survey where it was reported that in addition to the typical traffic congestion caused by daily commutes and gridlock from construction and accidents, over 30 percent of traffic in a city is caused by drivers searching for a parking spot" (IBM, 2011). "Adequate parking arrangements can reduce conflict points within the site and also reduce the accumulation of vehicles at access points" (Hokao & Mohamed, 1999).

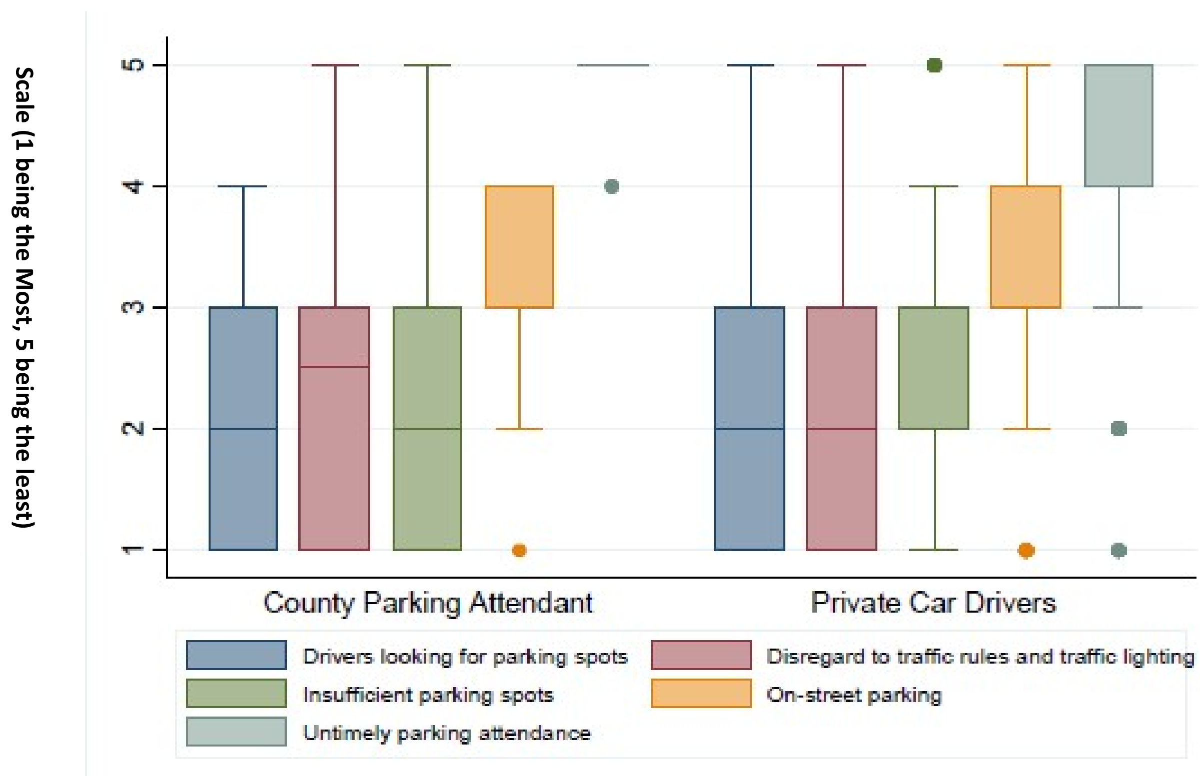

Figure 4 -4: Causes of Traffic Jam from Enforcement Officers

4.3.3 Convenience of current parking identification and parking payment system

Both county parking attendants (80.9%) and private car drivers (71.4%) considered the current system of parking identification as inconvenient and similarly both county parking attendants

(64.9%) and private car drivers (78.9%) considered the current system of parking payment as inconvenient. These findings were contrary to the assertions that the current payment system was convenient as one can have the parking fee paid for by another remotely and saved time to the customer as they do not need to look for the attendant to pay for parking (Ogut, 2015).

Table 4-6: Convenience of current parking identification and parking payment system

Respondent	current system of parking identification				current parking payment system			
	Convenient		Not convenient		Convenient		Not convenient	
	Frequency	Percent	Frequency	Percent	Frequency	Percent	Frequency	Percent
County Parking Attendant	17	80.9%	4	19.1%	15	71.4%	6	28.6%
Private Car Drivers	111	64.9%	60	35.1%	135	78.9%	36	21.1%

79.9% of the private car drivers recommended that the amount of money to be charged should depend on the amount of time one spend in the parking lot.

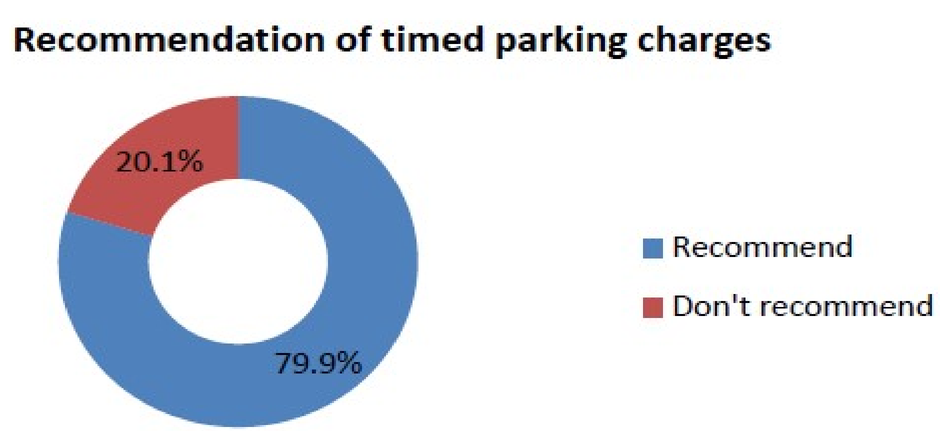

Figure 4 -5: Recommendation of timed parking charges

41.7% of the parking attendants thought that drivers sometimes fail to identify available parking lots and a similar proportion thought that drivers where encountering challenges in identifying parking spots. According to the IBM Parking Index survey in Nairobi 76% of the drivers reported not reaching their intended destination because they gave up looking for parking (IBM, 2011). "And in the IBM's recommendation they suggested parking systems in the city could be automated, alerting commuters to open spaces in the city and minimising time spent searching for traffic" (Mbuvi, 2012).

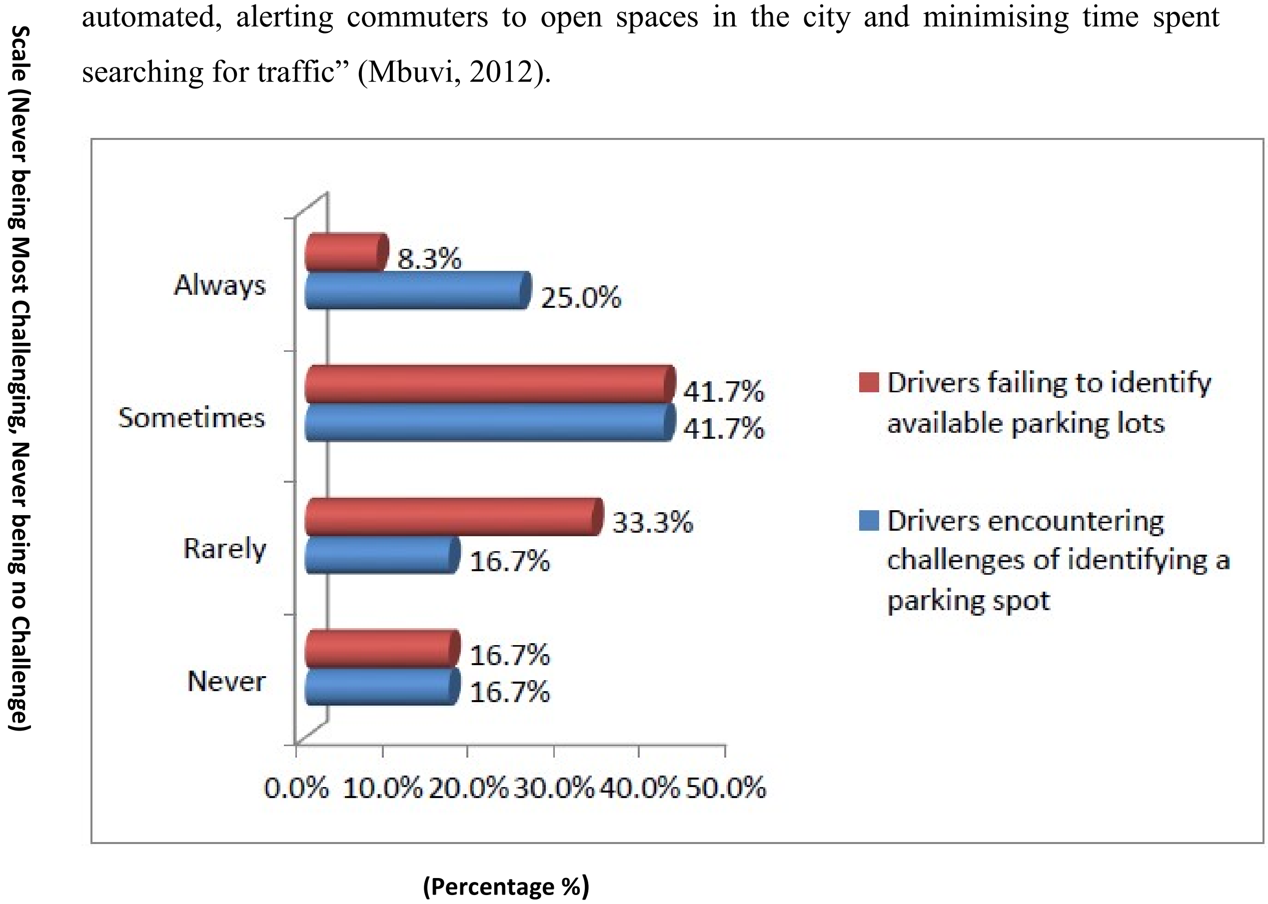

Figure 4 -6: Parking Identification

4.4 Proposed Design Structure for parking management in Nairobi

The research will adopt CISCO's smart traffic management for this study with little modification to the architecture. Previous studies have proven that 40% of traffic in cities is caused by drivers circling looking for a parking space. On this note, the research will include parking sensors in the sensing layer bearing in mind traffic management cannot be separated from parking. This architecture consist of the following independent variables:

Sensing Layer – This layer gathers the useful information of the objects from the sensor devices linked with them and converts the information into digital signals which is then passed onto the Communication Layer for further action. It consists of:

i. Vehicle sensor

ii. Parking sensors

iii. RFID

iv. Cameras

v. License plate reader

vi. CCTV

The Fee Collection variable of the sensing Layer incorporates the modern ways of parking fees payments and different rates payment whereby the county authorities have implemented the use of PDQ (Process Data Quickly machine) in payments and confirmation of payments.

Communication Layer – This layer receive useful information in the form of digital signals from sensing layer and transmit it to the data processing layer through the transmission mediums like Wi-Fi, wired/wireless networks etc.

Data Processing Layer – this Layer receives data from the communication layer and converts it into useful information which is availed to the road users (open architecture). This data is capable of supporting many city services and initiatives across a single common infrastructure.

Open infrastructure – consists of city apps/smart services for road users. It can also serve as open-data to the innovation ecosystem using the open interfaces

The key capabilities of this architecture include:

i. View real-time parking availability, visually displayed on mobile devices or digital signage. Search for parking spaces based on points of preferences.

ii. Track payment and overstay violations using sensors and meter integration.

iii. Monitor, report live, and enforce no-parking and loading zone violations using video analytics.

iv. Deliver live snapshots of violations to mobile devices to aid enforcement officers.

v. Easily configure and manage sensors, video infrastructure, and policies/rules for parking violations.

vi. Report on parking availability, income, administration, etc. Provide useful information to assist with pricing decisions.

Wireless networks, which have been indicated as City Wi-Fi in the proposed diagram can be found in many places these days, they're in our homes, on our mobile phones, in laptops, in games consoles, local cafes, banks and even some airplanes now offer internet access using Wi-Fi. These networks do get stretched to their limits, and this research has tried to sample other alternatives. Suffice to say that Wi-Fi has evolved to become a familiar technology but as a result more and more of us are also becoming familiar with its many shortcomings, such as the limited reach through walls (Jackson, 2016). Naturally there are plenty of ways to mitigate some of these problems, such as by using Wi-Fi extenders, switching to one of the new 802.11ac (**5GHz**) based Gigabit Wi-Fi routers (there's less congestion in the 5GHz band but that will only last so long) or holding out for the first **60GHz** capable WiGig (802.11ad) devices that should run over shorter ranges but offer faster speeds (7Gbps).

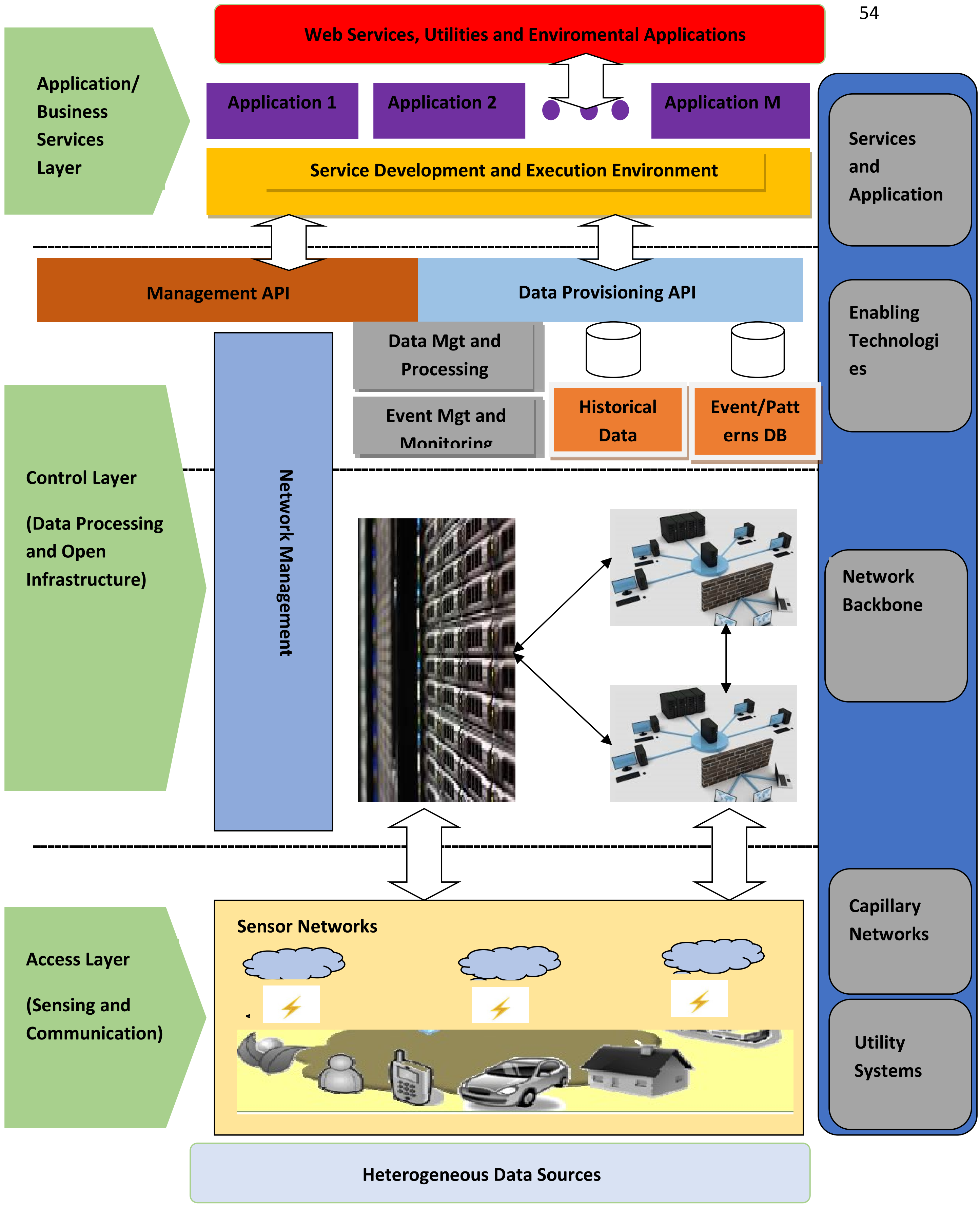

Figure 4 - 7: Proposed Design Structure

CHAPTER FIVE

DISCUSSION, SUMMARY, CONCLUSION AND RECOMMENDATIONS

5.1 Introduction

This chapter summarizes the research findings made in the study in form of study conclusion while also presenting the recommendations made.

5.2 Discussion

5.2.1 Benefits from IoT Application in Traffic Management

According to Koeneman (2017) Smart cities rely heavily on the Internet of Things (IoT). IoT devices can help the public transportation industry reduce costs in significant ways. Traffic management is one of the biggest infrastructure hurdles faced by developing countries today. Developed countries and smart cities are already using IoT and big data to minimize issues related to traffic. In most cities, people prefer driving their own vehicles no matter how good or bad the public transportation is or how much time and money is it going to take for them to reach a particular destination. Thus, increase in use of cars has caused an immense amount of traffic congestion. Several countries are overcoming this traffic bottleneck by fetching information from CCTV feeds and transmitting vehicle-related data to city traffic management centres to help smoothen the traffic run. A better-organized traffic system means the better flow of vehicles on the road and means no idling vehicles in traffic jams. Emission of gases is highest during stop-start driving which happens in traffic-light regulated spots. Hence, smart traffic helps in pollution reduction throughout an entire city. However, smart traffic management also involves other factors like smart parking sensors, smart streetlights, smart highways and smart accident assistance amongst other things. Some of the ways IoT is impacting the transportation industry's bottom line include the following:

Parking Guidance

i. Viewing real-time parking availability, visually displayed on mobile devices or digital signage
ii. Search for parking spaces based on points of preferences
iii. View parking rates and policy information in advance

iv. Receive voice guidance all the way to the parking space
v. Pay using a mobile application

Enforcing Parking

i. Capturing all parking events in metered and non-metered spaces
ii. Tracking payment and overstay violations using sensors and meter integration
iii. Monitor, report live, and enforce no-parking and loading zone violations using video analytics
iv. Deliver live snapshots of violations to mobile devices to aid enforcement officers

Administration & Analytics

i. Easily configure and manage sensors, video infrastructure, and policies/rules for parking violations
ii. Report on parking availability, income, administration, etc.
iii. Provide useful information to assist with pricing decisions

5.2.2 Prototype of sustainable IoT Architecture for parking management in Nairobi

Based on the analysis in the previous sections it was clear that current parking systems was one of the significant causes of traffic congestion in Nairobi. It was in this regard that the research recommended the applicability of IoT in alleviating the situation. Due to time and financial constraints, the research worked on the design framework of IoT and not the entire IoT infrastructure.

Problem: The research established that drivers in Nairobi find it difficult in locating available or nearest parking slots place. This has resulted into increased traffic congestions, increased emissions of CO_2 from the extra fuel consumption, and the inability to park your car at the most convenient location (possible nearest to the intended station of work).

Solution: After analysis of different solutions being used to improve the transportation system of Nairobi, the research established a gap caused by available systems working in isolation making it difficult to share information in real time. The research recommended the use of Internet of Things whereby the transportation systems (parking slots, cars, county traffic management, highways) will be connected using sensors to the internet and as a result are able to share crucial data enabling drivers to make the best decisions.

The smart parking solution (below) will enable drivers reserve the most convenient parking slots before they get to town hence reduce time taken searching for parking slots. Secondly, drivers will be able to pay parking fees only for the duration they spend as opposed to the current flat rate of Kshs. 300. Third, the system will help Nairobi County in law enforcement by making it easy to establish overdue cars and their location. Also, the system will be able to carry out data analytics in order to advise different users on availability of parking slots based on their past preferences. The research proposes the use of Agile development method, where every module is designed, coded and tested with the users before proceeding to the next module. It can assume the following design.

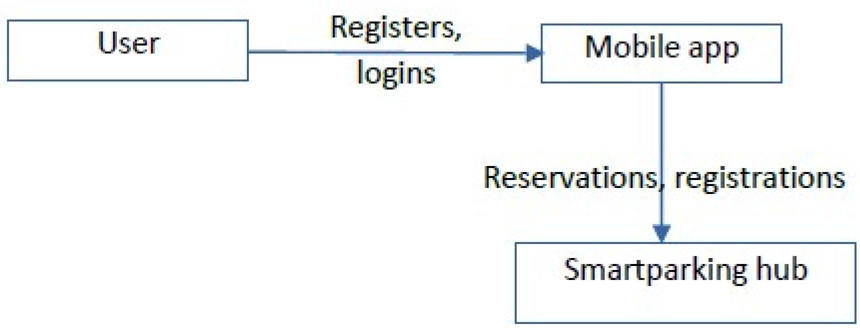

Figure 5 - 1: Design Flow Diagram

5.3 Summary of the Main Findings

Cumulatively, drivers spent an average of 3.6(±0.3) hours stack in traffic jam both in the evening and in the morning. Although private car drivers were ranked second as the cause of traffic jam behind matatu drivers, drivers looking for parking lots was consistently considered to be the most cause of traffic jam in Nairobi. This was further compounded by the fact that drivers sometimes failed to identify existing parking lots in town with drivers spending an average of 30 minutes looking for parking lots in the morning thereby effectively rendering parking identification inconvenient as well as parking payment.

The research in exploring ways of leveraging on Internet of Things (IoT) to combating road traffic in African Cities: a case for Nairobi City, Kenya encountered the following challenges:

i. There was non-existence of sensored car number plates to be used by vehicles, however, there are plans to launch smart number plates within the country.

ii. The research could not verify the adoption IoT because of the prohibitive costs associated with the hardware required.

5.4 Conclusions

From the study, it was evident that traffic congestion is a major problem that affect major cities in Africa. Nairobi, the capital of Kenya experiences traffic congestions as a result of limited road infrastructure, increase rate of urbanization and rising number of cars in the city. From the analysis in the previous sections it is clear that current parking systems is one of the significant causes of traffic congestion in Nairobi that contributed to approximately 40% of the city's traffic congestions. The research developed a prototype based on Internet of Things to help improve parking management in Nairobi by gaining real-time data on available parking slots.

5.5 Recommendations

For the full scale adoption of IoT in parking management, the system requires data sensors (RFID tags) to give location of the cars in the parking lots, WIFI with IPv4 or IPv6 for receiving and transmitting information regarding the cars parked, cloud computing technologies to process the information as well as back-end management for the entire system. As a follow up most of the users interviewed would like these features added into the working system.

i. Integrate Google maps to locate the most convenient parking slot.

ii. Customize parking search based on points of interest and personal preferences.

iii. Get push notifications on town parking patterns especially times of major functions in the city.

iv. Receive voice guidance all the way to the parking space.

v. Track payment and overstay violations using sensors and meter integration.

vi. Observational data should be incorporated in future to take care of non-cooperative participants like police officers.

5.6 Areas of Further Research

Based on the study conclusions the research recommends future studies to areas below:

vii. Risks of using IoT in smart parking.

viii. How IoT can be applied to measure effects of traffic congestion e.g. pollution

ix. The best model of applying IoT in traffic management.

x. Leveraging on IoT to enhance city security/surveillance.

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APPENDIX I: DRIVERS RESEARCH QUESTIONNAIRE

My name is Naftali Mukundi. I am a post graduate student from Africa Nazarene University. As part of my studies, I am required to conduct a research on "Opportunity areas of the internet of things (IoT) implementation in Kenya's traffic management. A case study of vehicle traffic in Nairobi City County". I am interested in your experiences and opinions in regard to the above study. I am therefore appealing to you to fill for me this questionnaire. The information you will provide will be treated with a lot of confidentiality and will be strictly for the purpose of this study. Thank you.

INSTRUCTIONS:

This questionnaire will be filled by Drivers operating within the county in any of the eight different major roads in Nairobi County. The purpose of the study is to assess the opportunity areas of the internet of things (IoT) implementation in Kenya's traffic management.

SECTION A: General Questions and Demographic Characteristics

To select your responses please tick (□) appropriately

Questionnaire Number: ……………… Signature of Respondent: …………………

Which highway or avenue do you use the most?

Mombasa Road [ ] Eastern Bypass [ ] Uhuru Highway [ ]

Thika Road [ ] Norther Bypass [ ] Kenyatta Avenue [ ]

Kipande Road [ ] University Way [ ]

1. Gender:

i. Male [ ] ii. Female [ ]

2. Age:

i. 22 and below [ ] ii. 23-30 [ ] iii. 30-40 [ ] iv. 40 and above [ ]

3. Education level

i. University/College [ ] ii. Secondary [ ] iii. Primary [ ] iv. None [ ]

4. For how many long have you been driving in Nairobi around CBD?

i. Less than 1 year [ ] ii. 1-4 Years [ ] iii. 4 – 8 Years [ ] iv. 8– 12 Years [ ]

iv. 12– 16 Years [ ] vi. 16 – 20 Years [ ] vii Over 20 Years [ ]

5. How many days in a week do you drive and park in town on average?

One [ ] Two [ ] Three [ ] Four [ ] Five [ ] Six [ ] Seven [ ]

SECTION B: Traffic Characteristics.

7. How long in hours do you spend in the traffic as you head towards and out of the CBD?

i. Morning [ ]
ii. Evening [ ]

8. From your own opinion, from, rank the following causes of traffic jams in town from 1 to 5. 1 being the most and 5 being least?

i. Failure to follow laid down traffic rules [ ]
ii. Drivers looking for parking spots [ ]
iii. Picking and dropping of passengers in non- designated spots [ ]
iv. Lack of coordination between different authorities and stage managers [ ]
v. Few Parking slots [ ]

9. Traffic management using IoT will help the county establish the congested routes for the purpose of city planning.

   i. Strongly Disagree [ ] ii. Disagree [ ] iii. Neutral [ ]

   iv. Agree [ ] v. Strongly Agree [ ]

SECTION C: Parking Identification and Payment.

9. Around what time do you normally arrive at the CBD? ……..

10. Do you immediately get parking slot while at that particular time?

   i. Always [ ] ii.Sometimes [ ]

   ii. Rarely [ ] iv. Never [ ]

11. How long, in minutes, do you normally spend looking for a parking spot?

12. Is the current system of parking identification favourable to you?

   i. Yes [ ]

   ii. No [ ]

13. If no, why do you say so? ....

14. Where do you normally park your car?

   i. Private parking [ ]

   ii. street parking [ ]

iii. Designated County Parking Bays [ ]

iv. Other (Specify) …………………………………………………………………………

15. How much in Kenya Shillings do you pay for the parking daily? ....

16. How long, in minutes, do you take to locate a county parking attendant? ....

17. Traffic management using IoT when implemented will ultimately help with real time visibility of traffic violations in the city.

i. Strongly Disagree [ ] ii. Disagree [ ] iii. Neutral [ ]

iv. Agree [ ] v. Strongly Agree [ ]

18. Improvement in traffic flow and less congestion will have optimal environmental impact with low carbon emissions translating to better mobility and living conditions.

i. Strongly Disagree [ ] ii. Disagree [ ] iii. Neutral [ ]

iv. Agree [ ] v. Strongly Agree [ ]

APPENDIX II: PARKING ATTENDANTS/ ENFORCEMENT OFFICERS RESEARCH QUESTIONNAIRE

My name is Naftali Mukundi. I am a post graduate student from Africa Nazarene University. As part of my studies, I am required to conduct a research on "Opportunity areas of the internet of things (IoT) implementation in Kenya's traffic management. A case study of vehicle traffic in

Nairobi City County". I am interested in your experiences and opinions in regard to the above study. I am therefore appealing to you to fill for me this questionnaire. The information you will provide will be treated with a lot of confidentiality and will be strictly for the purpose of this study. Thank you.

INSTRUCTIONS:

This questionnaire will be filled by Parking Attendants and Enforcement officers in any of the eight different major roads in Nairobi County. The purpose of the study is to assess the opportunity areas of the internet of things (IoT) implementation in Kenya's traffic management.

SECTION A: General Questions and Demographic Characteristics

To select your responses please tick (□) appropriately

Questionnaire Number: ……………… Signature of Respondent: …………………

Which highway or avenue do you manage the most?

Mombasa Road [ ] Eastern Bypass [ ] Uhuru Highway [ ]

Thika Road [ ] Norther Bypass [ ] Kenyatta Avenue [ ]

Kipande Road [ ] University Way [ ]

1. Gender:

ii. Male [ ] ii. Female [ ]

2. Age:

ii. 22 and below [ ] ii. 23-30 [ ] iii. 30-40 [ ] iv. 40 and above [ ]

3. Education level

ii. University/College [ ] ii. Secondary [ ] iii. Primary [ ] iv. None [ ]

4. For how many long have you been a Parking Attendant/ Enforcement Officer in Nairobi around CBD?

i. Less than 1 year [ ] ii. 1-4 Years [ ] iii. 4 – 8 Years [ ] iv. 8– 12 Years [ ]

i. 12– 16 Years [ ] vi. 16 – 20 Years [ ] vii Over 20 Years [ ]

5. How many parking slots do you manage? ....

6. Traffic management using IoT will help the county establish the congested routes for the purpose of city planning.

i. Strongly Disagree [ ] ii. Disagree [ ] iii. Neutral [ ]

iv. Agree [ ] v. Strongly Agree [ ]

SECTION B: Parking Identification and Payment.

7. How are you able to know the number of parking slots available at any one given time?

i. Inspecting Physically [ ]

ii. There is a system in Place [ ]

iii. Other (Specify) ……………………………….

8. Do drivers encounter challenges of identifying a parking spot within your area of operation?

i. Always [ ] ii.Sometimes [ ]

ii. Rarely [ ] iv. Never [ ]

9. Is the current parking system is convenient?

i. Yes [ ]

ii. No [ ]

10. If no, Explain? …………………………………………………………………………..

11. How are cars charged parked within your area of operation?

i. Timed parking [ ]

ii. Fixed rate [ ]

iii. Other (specify) ………………………………………………………..

12. From your own opinion, from, rank the following causes of traffic jams in town from 1 to 5.

1 being the most and 5 being least?

i. Failure to follow laid down traffic rules [ ]

ii. Drivers looking for parking spots [ ]

iii. Picking and dropping of passengers in non- designated spots [ ]

iv. Few Parking slots [ ]

v. Lack of coordination between different authorities and stage managers [ ]

13. From your own opinion, from, rank the following causers of traffic jams in town from 1 to 5.

1 being the most and 5 being least?

i. Traffic police [ ]

ii. Matatu drivers [ ]

iii. Enforcement officers/ parking attendants. [ ]

iv. Private car drivers [ ]

v. The Central Government [ ]

14. Traffic management using IoT when implemented will ultimately help with real time visibility of traffic violations in the city.

i. Strongly Disagree [ ] ii. Disagree [ ] iii. Neutral [ ]

iv. Agree [ ] v. Strongly Agree [ ]

15. Improvement in traffic flow and less congestion will have optimal environmental impact with low carbon emissions translating to better mobility and living conditions.

i. Strongly Disagree [ ] ii. Disagree [ ] iii. Neutral [ ]

iv. Agree [ ] v. Strongly Agree [ ]

APPENDIX III: ANU INTRODUCTION LETTER

AFRICA NAZARENE UNIVERSITY

January 22, 2019

To Whom It May Concern

Dear Sir/Madam,

RE: PROPOSAL APPROVAL FOR NAFTALI MUKUNDI (18J03DMIT012)

The above named is a Master of Applied IT student at Africa Nazarene University. This is to confirm that his research proposal titled **"Opportunity areas of the Internet of Things (IoT) implementation in Kenya's traffic management. A case study of vehicle traffic in Nairobi City County"** has been approved for conduct of research, subject to obtaining other permissions and/or clearances that may be required beforehand.

Any support and/or assistance accorded to him will be highly appreciated.

Please feel free to contact me via email on jobuhuma@anu.ac.ke in case of further clarity required.

Yours Sincerely,

AFRICA NAZARENE UNIVERSITY
CHAIRMAN
SIGN:
COMPUTER SCIENCE
P. O. Box 53067, NAIROBI

Obuhuma James
Head of Department, Computer and Information Technology

APPENDIX IV: REASEARCH AUTHORISATION

NATIONAL COMMISSION FOR SCIENCE, TECHNOLOGY AND INNOVATION

Telephone:+254-20-2213471, 2241349,3310571,2219420
Fax:+254-20-318245,318249
Email: dg@nacosti.go.ke
Website : www.nacosti.go.ke
When replying please quote

NACOSTI, Upper Kabete
Off Waiyaki Way
P.O. Box 30623-00100
NAIROBI-KENYA

Ref: No. **NACOSTI/P/19/70472/28008**

Date: **15th February, 2019**

Naftali Kamau Mukundi
Africa Nazarene University
P.O. Box 53067-00200
NAIROBI.

RE: RESEARCH AUTHORIZATION

Following your application for authority to carry out research on ***"Opportunity areas of the Internet of Things (IOT) implementation in Kenya's Traffic Management. A case study of vehicle traffic in Nairobi City County"*** I am pleased to inform you that you have been authorized to undertake research in **Nairobi County** for the period ending **15th February, 2020.**

You are advised to report to **the County Commissioner and the County Director of Education, Nairobi County** before embarking on the research project.

Kindly note that, as an applicant who has been licensed under the Science, Technology and Innovation Act, 2013 to conduct research in Kenya, you shall deposit **a copy** of the final research report to the Commission within **one year** of completion. The soft copy of the same should be submitted through the Online Research Information System.

Kalerwa

GODFREY P. KALERWA MSc., MBA, MKIM
FOR: DIRECTOR-GENERAL/CEO

Copy to:

The County Commissioner
Nairobi County.

The County Director of Education

APPENDIX V: RESEARCH PERMIT

THE SCIENCE, TECHNOLOGY AND INNOVATION ACT, 2013

The Grant of Research Licenses is guided by the Science, Technology and Innovation (Research Licensing) Regulations, 2014.

CONDITIONS

1. **The License is valid for the proposed research, location and specified period.**
2. **The License and any rights thereunder are non-transferable.**
3. **The Licensee shall inform the County Governor before commencement of the research.**
4. **Excavation, filming and collection of specimens are subject to further necessary clearance from relevant Government Agencies.**
5. **The License does not give authority to transfer research materials.**
6. **NACOSTI may monitor and evaluate the licensed research project.**
7. **The Licensee shall submit one hard copy and upload a soft copy of their final report within one year of completion of the research.**
8. **NACOSTI reserves the right to modify the conditions of the License including cancellation without prior notice.**

National Commission for Science, Technology and innovation
P.O. Box 30623 - 00100, Nairobi, Kenya
TEL: 020 400 7000, 0713 788787, 0735 404245
Email: dg@nacosti.go.ke, registry@nacosti.go.ke
Website: www.nacosti.go.ke

REPUBLIC OF KENYA

National Commission for Science, Technology and Innovation

RESEARCH LICENSE

Serial No.A 23184

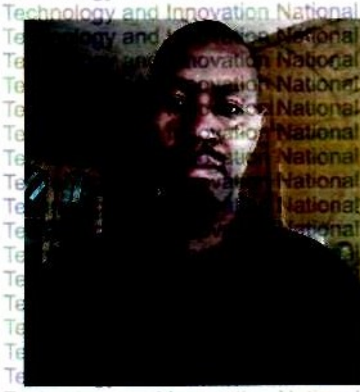
CONDITIONS: see back page

THIS IS TO CERTIFY THAT:
MR. NAFTALI KAMAU MUKUNDI
of AFRICA NAZARENE UNIVERSITY, 98-10111 Gakindu,has been permitted to conduct research in *Nairobi County*

on the topic: *OPPORTUNITY AREAS OF THE INTERNET OF THINGS (IOT) IMPLEMENTATION IN KENYA'S TRAFFIC MANAGEMENT. A CASE STUDY OF VEHICLE TRAFFIC IN NAIROBI CITY COUNTY.*

for the period ending:
15th February,2020

Permit No : NACOSTI/P/19/70472/28008
Date Of Issue : 15th February,2019
Fee Recieved :Ksh 1000



....
Applicant's Signature

....
Director General
National Commission for Science, Technology & Innovation