UNIVERSITY OF NAIROBI6

SCHOOL OF COMPUTING & INFORMATICS

Applicability of Internet of Things (IoT) to reduce traffic congestion in Nairobi City, Kenya

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This Project Report submitted in partial fulfillment of the requirement for the award of Masters of Science in Information Technology Management of the University of Nairobi

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Declaration

This project is my original work and to the best of my knowledge this research work has not been submitted for any other award in any University

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This project report has been submitted in partial fulfillment of the requirement of the Master of Science Degree in according of the University of Nairobi with my approval as the University supervisor

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Abstract

Traffic congestion has been a mounting problem in Nairobi, Kenya, that has resulted from rapidly increasing population and the flocking of motorized traffic on the limited street network. Some of traffic concerns are congestions and accidents which have caused a huge waste of time, property damage and environmental pollution within the city. Therefore, this research involved analysis of the current traffic conditions in Nairobi, the expected effects of further growth in demand, and a set of recommendations for how to improve the performance of the street network. From the analysis, the research pursued an intelligent traffic administration system, centered on Internet of Things, that has been characterized by low cost, high scalability, high compatibility and easy to upgrade. After conducting this study, the intelligent traffic administration system could be used by Cities to replace their traditional traffic management systems therefore reduce road traffic tremendously. The IoT is based on the Internet, network wireless, sensing and detection technologies used to comprehend the intelligent recognition on any tagged traffic object by tracking, monitoring, managing and processing data automatically. The study was cross sectional with analytical component and through simple random sampling, 200 private car drivers and 12 county parking attendants were selected for the study. The data collection tools utilized included a structured self-administered questionnaires. Data collected was analyzed using SPSS version 21 and Excel spreadsheet and presented in form of text, tables, graphs and charts. Private cars spent in the morning an average of 1.6 hours while in the evening they spent an average of 2.0 hours stuck in the on traffic jam. Although private car drivers were ranked second as the cause of traffic jam behind matatu drivers, drivers looking for parking lots was consistenty 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.

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Abbreviations

EPC	Electronic Product Code
IoT	Internet of Things
ICT	Information Communication Technology
IT	Information Technology
IP	Internet Protocol
RFID	Radio-Frequency Identification
TMN	Telecommunications Management Network

CHAPTER ONE: INTRODUCTION

1.1 Background

The IoT is a dynamic and global network infrastructure, in which "Things"—subsystems and individual physical and virtual entities—are identifiable, autonomous, and self-configurable. "Things" are expected to communicate among themselves and interact with the environment by exchanging data generated by sensing, while reacting to events and triggering actions to control the physical world.

"IoT realizes a world where billions of objects can sense, communicate and share information, all interconnected over public or private Internet Protocol (IP) networks. These interconnected objects have data regularly collected, analyzed and used to initiate action, providing a wealth of intelligence for planning, management and decision making. The IoT concept was coined by a member of the Radio Frequency Identification (RFID) development community in 1999, and it has recently become more relevant to the practical world largely because of the growth of mobile devices, embedded and ubiquitous communication, cloud computing and data analytics", INRIX 2013..

INRIX (2013). "National Traffic Scorecard – 2013 Annual Report (that provides a comprehensive analysis of the state of traffic congestion across the world) states that traffic congestion bounced back in many countries and cities for the first time in two years. Economic growth and increased employment generally improved in 2013 and the data showed that traffic congestion grew at a 3x the rate of GDP or employment. The report concluded, "Future roads will not be built with concrete as much as they'll be built with software. It's time to apply what we've learned from building the Internet highway to build a smarter transportation networks. Through breakthroughs in crowd-sourcing, connectivity and Big Data, technology is rapidly transforming a world we once measured in miles to one we can measure in minutes".

ABI research, "80 percent of cars on the road in the U.S. and Western Europe will be connected and a source of real-time data by 2017. For the remaining 20 percent, the continued explosion of connected devices in the form of the smartphones and tablets we carry with us everywhere we go will fill the gap. As a result, the coverage and quality of real-time traffic information is growing at a rapid pace. With this new ability, it is possible to gain reliable insight from every vehicle into the traffic speeds, travel times, and volumes on all roads. Constructing an intelligent traffic system based on IoT has a number of benefits such improvement of traffic conditions, reduction the traffic jam and management costs, high reliability, traffic safety and independence of weather conditions".

1.2 Statement of the Problem

Urban traffic faces many challenges which are mainly caused by rapid urbanization and an increase in car ownership which then influence both the flow of traffic and the environment. The main challenges are traffic congestion, pollution and road accidents. Knoflacher (2006), cities in the third world countries face traffic congestion which is mainly caused by the following factors:

a) The urban set-up is not compatible with the traffic demands.
b) Inadequate traffic management measures.
c) Flouting of traffic rules by motorists.
d) Inadequate public transport.

Gachanja 2011, "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 J. , 2015)". "This study aims to develop a sustainable traffic management protoype based on IoT and other technologies to improve traffic conditions and relieve the traffic pressure for the City of Nairobi. Information generated by traffic IoT and collected on all roads can be presented to travelers and other users. Through collected real-time traffic data, the system can recognize current traffic operation, traffic flow conditions and can predict the future traffic flow. By issuing latest real-time traffic information, the system will help drivers in choosing optimal routes."

1.3 Objectives of the Study

The research has the following objectives:

a) To identify the major causes of traffic congestion in Nairobi city and other leading African cities.
b) To review IoT Architectures applicable to traffic congestion management

c) To develop a simple prototype of sustainable IoT Architecture for Nairobi city

1.4 Research Questions

a) What are the major causes traffic congestion in Nairobi city and other leading African cities?
b) What IoT Architectures suite traffic congestion management?
c) How can IoT be applied in managing traffic congestion in Nairobi?

1.5 Significance of the Study

The study provides better understanding about various “Things” in the transport sector that when connected and are able to communicate could drastically reduce traffic congestion in cities in Africa. The study explored the major problems encountered by traffic officials and motorists as a result of traffic congestions in Nairobi then designed an IoT architecture/prototype to reduce Nairobi traffic by approximately 40%.

CHAPTER 2 :LITERATURE REVIEW

2.1 Traffic Congestion in African Cities

“Urban mobility is increasingly becoming one of the planning and development issues for most cities in Africa. These cities are growing fast, outstripping the current transport infrastructure. Despite the population and spatial growth, many of them defined by inadequate planning, rapid urbanization and deteriorating transport infrastructure and services.”

Lagos

“Lagos, the largest city in Nigeria, is fast becoming one of the largest cities in the world — 21 million people are thought to live within its limits and its population is expected to surpass Cairo's by 2015 to becoming the biggest city in Africa.

An estimated 8 million people travel to work via public transportation each day on the 9,100 roads and expressways available in Lagos (Ministry of Economic Planning & Budget, 2013). With more than 1 million registered vehicles in 2011, there are potentially more than one million trips made during the peak travel periods of the day; this is much more during seasonal festivities such as Easter and Christmas when there is an influx from other parts of the country.”

Eniola et al. 2013, “the congestion is caused partly by road users themselves. Lagos road users are known to be very impatient and bad at obeying traffic rules. Indeed many times traffic congestions have been caused by a driver refusing to give way for another motorist. The effects of congestion are many fold; some directly affect the drivers’ sense of wellbeing, be it times wasted sitting in a traffic queue and the changes in the behaviour of drivers.”

Dar es Salaam

Kiunsi 2013, “traffic congestion is one of the problems facing the city and is attributed by a number of factors including rapid population increase, inadequate and poor road infrastructure, city structure, rapid increase in number of cars and lack of physical plan to control city development.” JICA 2008, “established that the traffic is more serious in certain intersections of arterial roads such as Morogoro, Kilwa, Nyerere, Mandela. The study further revealed that the traffic is common during morning and evening peak hours. In the morning peak hours traffic speed is reduced to between 20 to 30km/h at a distance of 25 to 30kms from the city centre for most of main roads.”

Cairo

“The Greater Cairo Metropolitan Area (GCMA), with more than 19 million inhabitants, is host to more than one-fifth of Egypt’s population. The GCMA is also an important contributor to the Egyptian economy in terms of GDP and jobs. The population of the GCMA is expected to further increase to 24 million by 2027, and correspondingly its importance to the economy will also increase”, (Nakat, Herrera, & Cherkaoui, 2014). “The study found that traffic congestion is a serious problem in the GCMA with large and adverse effects on both the quality of life and the economy. In addition to the time wasted standing still in traffic, time that could be put to more productive uses, congestion results ,in unnecessary fuel consumption, causes additional wear and tear on vehicles increases harmful emissions lowering air quality, increases the costs of transport for business, and makes the GCMA an unattractive location for businesses and industry. As the population of the GCMA continues to increase, traffic congestion is becoming worse and the need to address this congestion is becoming more urgent.”

2.2 Causes of Traffic in Nairobi

“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 4 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.”

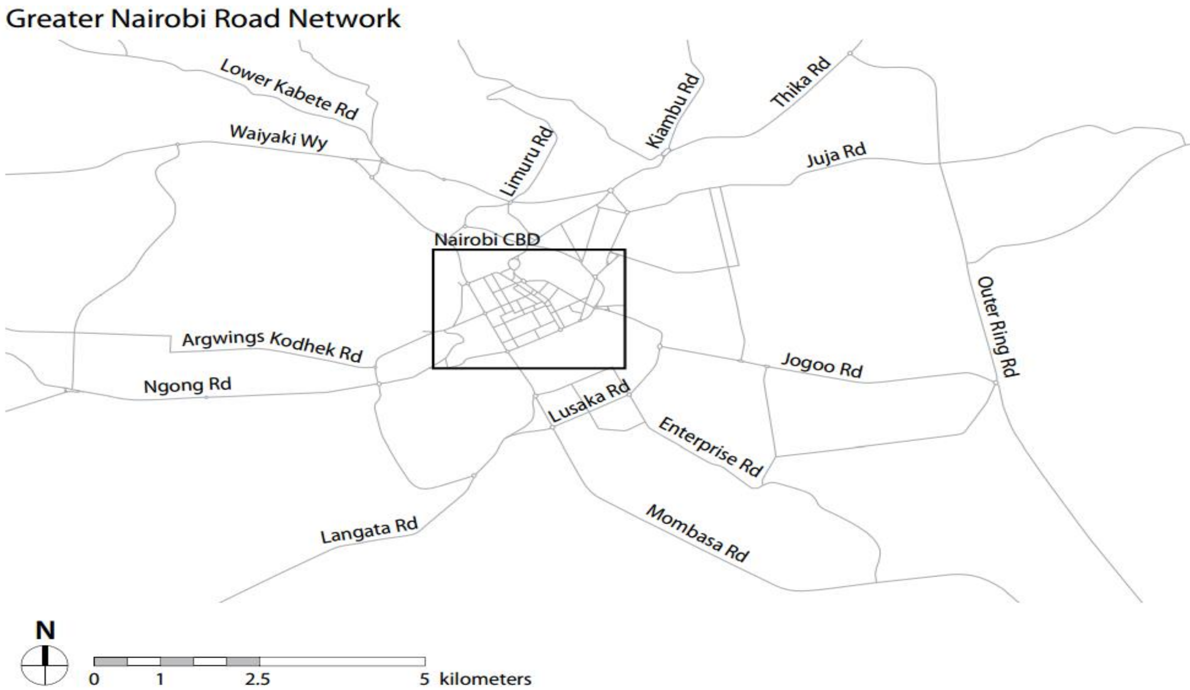

Fig. 6 The road network in Nairobi is primarily composed of radial routes connecting surrounding regions to the CBD. The lack of circumferential roads forces many peripheral trips through the center.

Katahira & Engineers International, 2006 "notes at least 18 intersections are equipped with traffic signals, although phase timing data was only available for 11 signals. The small number of streets for carrying automobile, truck, bus, and matatu traffic in Nairobi results in the following conditions:

- *Concentration of Vehicles on Limited Infrastructure* – Since there are few streets, and most arterials are radial, vehicular trips between different neighborhoods must share limited paved street space, concentrating traffic onto the sparse network of major roads. This is particularly problematic in and around the CBD.
- *Lack of Redundancy* – The connections between the major arterials are few and far between, so there are usually no more than one or two reasonable routes for any origin-destination pair. This means that traffic cannot be redistributed to use street infrastructure more efficiently. Due to the lack of ring roads many peripheral trips must pass through the CBD which compounds traffic congestion in the center."

Proposed Corrective Mechanisms by Nairobi County

"The Traffic Department, under the umbrella of Nairobi Country developed a Traffic Decongestion Program whose aim is to relieve the persistent traffic congestion in Nairobi's central business district. The program has the long term goal of creating a network of monorails and truncated buses. In the short term, the following components are proposed for implementation:

1. Increase Uni-Direction (one-way) traffic movement, including along: Moi Avenue, Koinange Street, Tom Mboya Street, Muindi Mbingu Street, Harambee Avenue, River Road, Kirinyaga Road, City Hall Way and Parliament Road
2. Create dedicated bus routes and lanes in the central business district
3. Remove on-street parking at the following locations: Moi Avenue, Tom Mboya Street, Muindi Mbingu Street, Koinange Street, Harambee Avenue, River Road, Kirinyaga Road, Haile Selassie Avenue
4. Increase the number of multistory car parks, including at the following locations: Sunken car park, Law courts car park, Hakati car park, Central bus station
5. Create Park and Ride stations to service the following highways: Thika Road, Mombasa Road, Ngong Road and Waiyaki Way
6. Designate drop off and pick up points on the following roads: Haile Selassie Avenue, Agip petrol station, Wakulima market area, Railways terminus, St. Peter Clavers – kaka, Moi Avenue, Between Moi Primary and Jevanjee Gardens, Kencom, Kenyatta Avenue, Simmers Hotel and Hughes Building
7. Reinforce road reserves on all by bass and ring roads
8. Restrict heavy transit traffic between 07:00-10:00 and 16:00-20:00 on weekdays
9. Allow vehicles with over 60 passengers and standing passengers to use roads within the NMR
10. Expand the Central Business District to include the following areas:Westlands, Pangani, Eastleigh into Jogoo Road, Lusaka Road into Nairobi West, Langata Road and Mbagathi into Hurlingham.

With respect to the above, traffic management using IoT has not been adopted in Nairobi in an attempt to improve traffic flow in the City."

2.3 IoT Background

"The IoT is a recent communication paradigm that envisions a near future in which the objects of everyday life will be equipped with micro-controllers, transceivers for digital communication, and suitable protocol stacks that will make them able to communicate with one another and with the users, becoming an integral part of the Internet" (Atzori, Iera, & Morabito, 2010).

Evans 2011, "IoT is simply the point in time when more "things or objects" were connected to the Internet than people. The survey notes that in 2003, there were approximately 6.3 billion people living on the planet and 500 million devices connected to the Internet which represented less than one (0.08) device for every person. Based on Cisco IBSG's definition, IoT didn't yet exist in 2003 because the number of connected things was relatively small given that ubiquitous devices such as smartphones were just being introduced."

"The IoT concept, hence, aims at making the Internet even more immersive and pervasive. Furthermore, by enabling easy access and interaction with a wide variety of devices such as, for instance, home appliances, surveillance cameras, monitoring sensors, actuators, displays, vehicles, and so on, the IoT will foster the development of a number of applications that make use of the potentially enormous amount and variety of data generated by such objects to provide new services to citizens, companies, and public administrations. This paradigm indeed finds application in many different domains, such as home automation, industrial automation, medical aids, mobile health care, elderly assistance, intelligent energy management and smart grids, automotive, traffic management and many others", (Zanella & Vangelista, 2013)

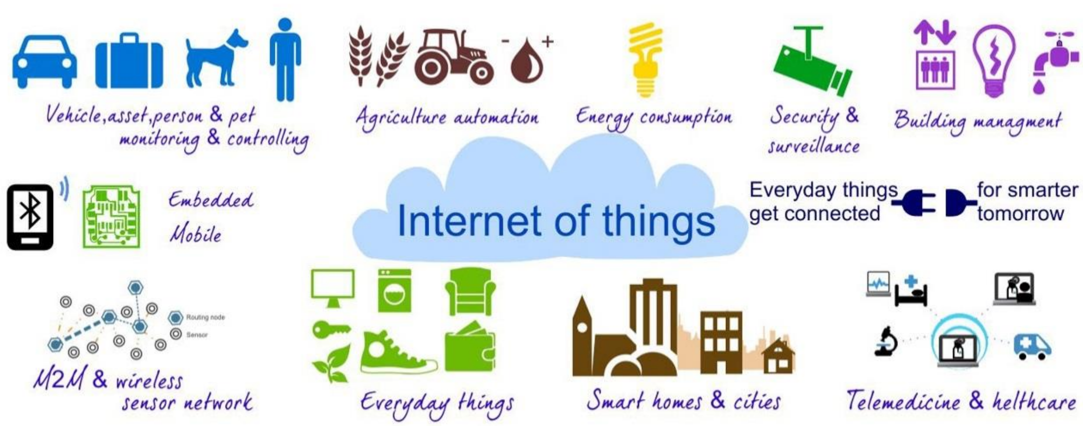

Figure 1: Internet of Things Ecosystem

“Explosive growth of smartphones and tablet PCs brought the number of devices connected to the Internet to 12.5 billion in 2010, while the world’s human population increased to 6.8 billion, making the number of connected devices per person more than 1 (1.84 to be exact) for the first time in history. The Internet doubles in size every 5.32 years”, (Evans, 2011). CISCO 2015, “it has been predicted that by 2015 there will be 25 billion devices, 50 to 100 billion devices by 2020 connected to the Internet.”

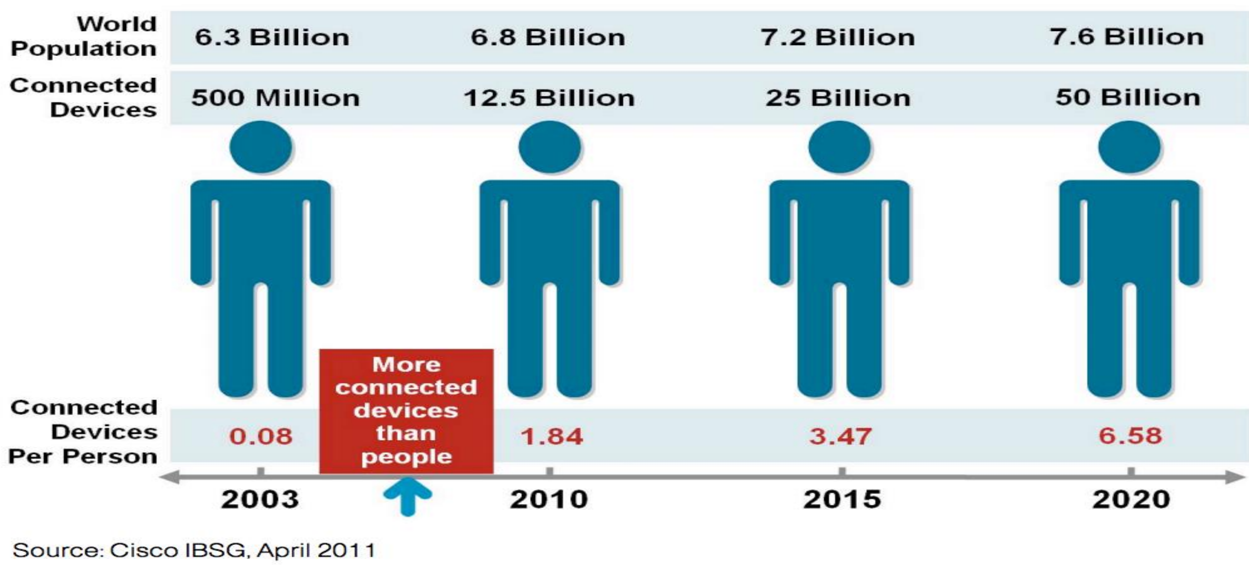

Figure 2: Expected penetration of connected objects by the year 2020

2.4 IoT Architecture

With the envisaged growth in IoT where more than 25 Billion “things” are expected to be connected by 2020, Cisco states that this represents huge numbers that the existing architecture of Internet with TCP/IP protocols will not handle. Cao, Li and Zhang 2011, “notes that with the rapid growth of IoT there is need for new open architecture that can address various security and Quality of Service (QoS) issues as well as support the existing network applications using open protocols.”

Li 2012, “argue that without proper assurance, IoT is not likely to be adopted by many. Therefore protection of data and privacy of users are key challenges for IoT. More importantly, Chen (2012) proposes a number of multi-layered security architectures for further development of IoT.”

Chen and Deng 2009, "described a three key level architecture of IoT while Suo et al. (2012) described a four key level architecture. Wu et al. (2010) proposed a five layered architecture using the best features of the architectures of Internet and Telecommunication management networks based on TCP/IP and TMN models respectively. Similarly, Zhang, Sun and Cheng (2012) states a six-layered architecture based on the network hierarchical structure. So generally it's divided into six layers as shown in the Fig. 3."

The six layers of IoT are described below:

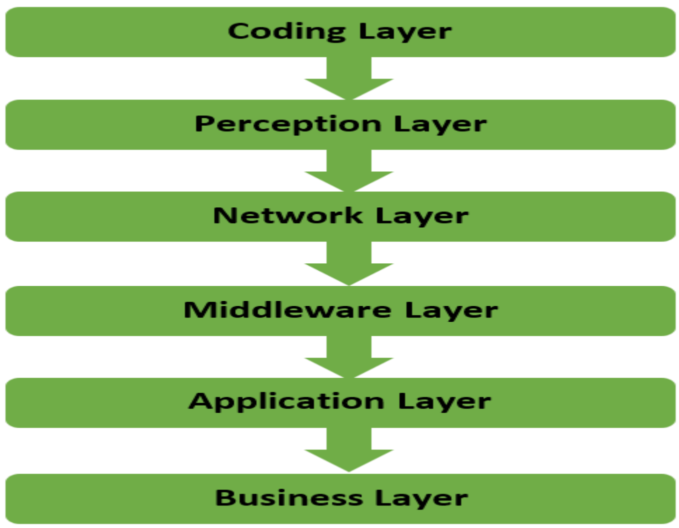

Figure 3: Six-Layered Architecture of IoT

Coding Layer

Zhang, Sun and Cheng, 2012, "describes this layer as the foundation of IoT which provides identification to the objects of interest. They state that it is in this layer where each object is assigned a unique ID which makes it easy to distinguish the objects."

Perception Layer

Bandyopadhyay and Sen, 2011, "states that this is the device layer of IoT which gives a physical meaning to each object. It consists of data sensors in different forms like RFID tags, IR sensors or other sensor networks which could sense the temperature, humidity, speed and location etc of the objects. 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 Network Layer for further action."

Network Layer

Zhang, 2011, "states that the purpose of this layer is to receive the useful information in the form of digital signals from the Perception Layer and transmit 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."

Middleware Layer

Shen and Liu, 2011, "states that this 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. Using some Intelligent Processing Equipment, the information is processed and a fully automated action is taken based on the processed results of the information."

Application Layer

"This layer realizes the applications of IoT for all kinds of industry, based on the processed data. Because applications promote the development of IoT so this layer is very helpful in the large scale development of IoT network (Wu, Lu, Ling, Sun, & Du, 2010). The IoT related applications could be smart homes, smart transportation, smart planet etc."

Business Layer

Khan et al. 2012, "states that this layer manages the applications and services of IoT and is responsible for all the research related to IoT. It generates different business models for effective business strategies."

2.5 IoT Technologies

"The development of IoT computing system where digital objects can be uniquely identified and can be able to think and interact with other objects to collect data for undertaking actions a, requires the need for a combination of new and effective technologies. He argues that this is only possible through an integration of different technologies which can make the objects to be identified and communicate with each other (Khoo, 2011). The following relevant technologies can help large-scale development of IoT applications."

a. Radio Frequency IDentification (RFID)

Chen, 2012, "RFID is the key technology for making the objects uniquely identifiable. It's reduced size and cost makes it integrable into any object. It is a transceiver microchip similar to an adhesives ticker which could be both active and passive, depending on the type of application. Active tags have a battery attached to them due to which they are always active and therefore continuously emit the data signals while Passive tags just get activated when they are triggered." In addition, Shen and Liu, 2011, "argue that Active tags are more costly than the Passive tags however they have a wide range of useful applications. RFID system is composed of readers and associated RFID tags which emit the identification, location or any other specifics about the object, on getting triggered by the generation of any appropriate signal (Zhang, Sun, & Cheng, 2012). The emitted object related data signals are transmitted to the Readers using radio frequencies which are then passed onto the processors to analyze the data."

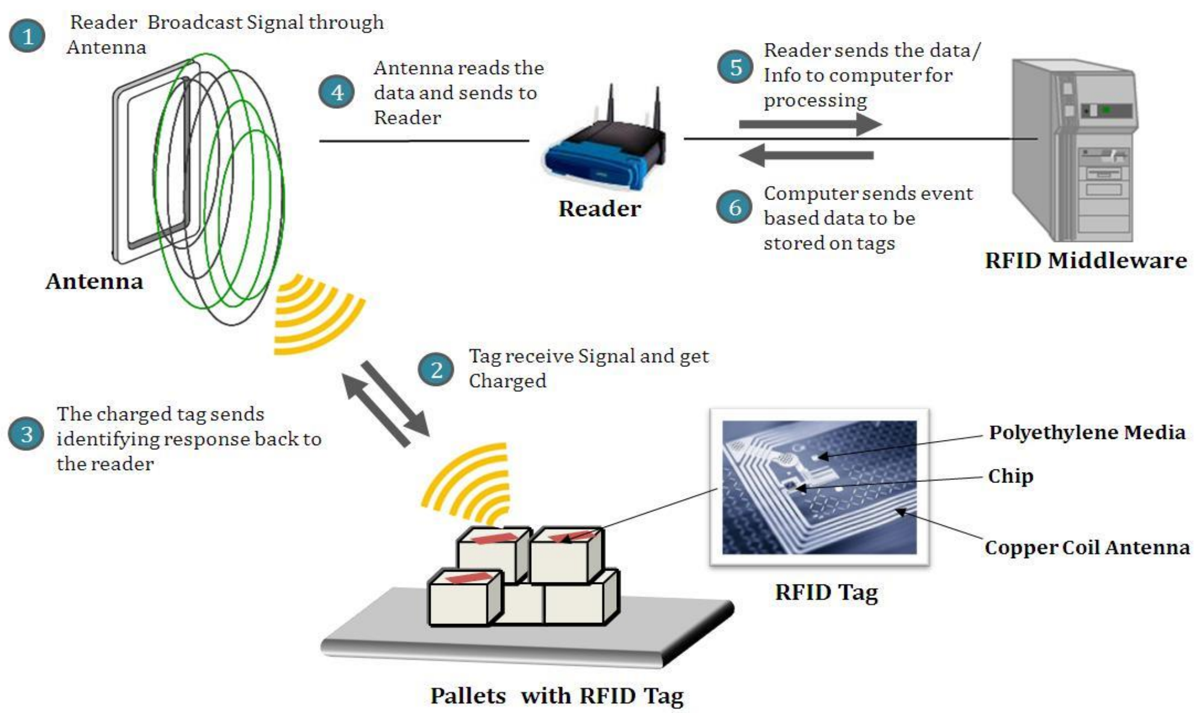

Figure 4: RFID Scenario

b. Wireless Sensor Network (WSN)

Atzori, Iera and Morabito, 2010, " states that WSN is a bi-directional wirelessly connected network of sensors in a multi-hop fashion, built from several nodes scattered in a sensor field each connected to one or several sensors which can collect the object specific data such as temperature, humidity, speed etc and then pass on to the processing equipment. The sensing nodes communicate in multi-hop manner. Each sensor is a transceiver having an antenna, a micro-controller and an interfacing circuit for the sensors as a communic7ation, actuation and sensing unit respectively along with a source of power which could be either battery or any energy harvesting technology." However, Shen and Liu, 2011, "has proposed an additional unit for saving the data, named as Memory Unit which could also be a part of the sensing node. A typical sensing node is shown in the figure below":

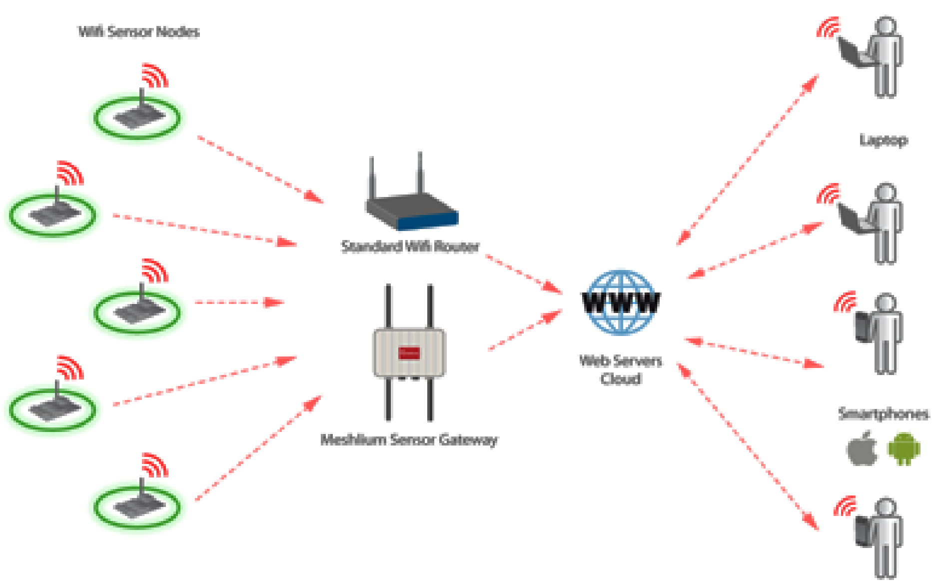

Figure 5: A typical sensing node

Atzori, Iera and Morabito, 2010, "concludes that WSN technology and RFID technology when combined together opens up possibilities for even more smart de-vices, for which a number of solutions have been proposed."

c. Cloud Computing

Rao et al. 2012, "states that Cloud Computing is an intelligent computing technology in which number of servers are converged on one cloud platform to allow sharing of resources between each other which can be accessed at any time and any place." On the other hand, Xiaohui, 2013, "argue that Cloud computing is the most important part of IoT, which not only converges the servers but also processes on an increased processing power and analyzes the useful information obtained from the sensors and even provide good storage capacity. Xiaohui further argues that Cloud computing interfaced with smart objects using potentially millions of sensors can be of enormous benefits and can help IoT for a very large scale development."

Figure 6: A typical Cloud Computing Scenario

d. Networking Technologies

Rao et. Al. 2012, "These technologies are responsible for the connection between the objects, so it calls for a fast and an effective network to handle a large number of potential devices. For wide-range transmission network 3G, 4G etc are commonly used. Similarly for a short-range communication network we use technologies like Bluetooth, WiFi etc."

e. Nano Technologies

Akyildiz and Jornet, 2010, "states that nano technology realizes smaller and improved version of the things that are interconnected. It can decrease the consumption of a system by enabling the development of devices in nano meters scale which can be used as a sensor and an actuator just like a normal device. Such a nano device is made from nano components and the resulting network defines a new networking paradigm which is Internet of Nano-Things."

f. Micro-Electro-Mechanical Systems (MEMS) Technologies

"MEMS are a combination of electric and mechanical components working together to provide several applications including sensing and actuating which are already being commercially used in many field in the form of transducers and accelerometers etc. MEMS combined with Nano technologies are a cost-effective solution for improvising the communication system of IoT and other advantages like size reduction of sensors and actuators, integrated ubiquitous computing devices and higher range of frequencies etc Lubecke" (Lubecke & Chiao, 1999)

g. Optical Technologies

"Rapid developments in the field of Optical technologies in the form of technologies like Li-Fi and Cisco's BiDi optical technology could be a major breakthrough in the development of IoT. Li-Fi, an epoch-making Visible Light Communication (VLC) technology, will provide a great connectivity on a higher bandwidth for the ob-jects interconnected on the concept of IoT. Similarly Bi-Directional (BiDi) technology gives a 40G ethernet for a big data from multi-farious devices of IoT."

2.6 IoT in Transportation Systems

Xiao and Wang, 2011, "argues that the development of Internet of things based on EPC code and RFID reader brings a good opportunity for intelligent traffic monitoring. They state that at first, EPC assigns a unique electronic code for each traffic tool, ensuring the identification uniqueness for them similar to license plate. And then, RFID identifies traffic tools automatically to obtain related data via radio frequency signal. They conclude that the work of the monitoring system based on RIFD recognition is not affected by night or adverse weather. Therefore, intelligent traffic monitoring system based on Internet of things has broad prospects of development and expansion space.

Most of the daily life applications that we normally see are already smart but they are unable to communicate with each other, enabling them to communicate with each other and share useful information with each other will create a wide range of innovative applications. These emerging applications with some autonomous capabilities would certainly improve the quality of our lives.

This section presents some of the possible future applications that can be of great advantage in city transportation ecosystem:"

Smart Traffic System–Cao, Li and Zhang, 2011, "argues that there is a need for a system that can improve the traffic situation based on the traffic information obtained from objects using IoT technologies. For such an intelligent traffic monitoring system, automatic identification of vehicles and other traffic factors is very important for which IoT technologies are needed instead of using common image processing methods. With IoT, the intelligent traffic monitoring system will provide a good transportation experience by easing the congestion. The system could have features for theft-detection, reporting of traffic accidents among others."

Smart Parking –In a Smart city field study on "intelligent parking lot application using wireless sensor networks" (Lee, Yoon, & Ghosh, 2008). "Smart parking service is based on road sensors and intelligent displays that direct motorists along the best path for parking in the city. The benefits deriving from this service are manifold: faster time to locate a parking slot means fewer CO emission from the car, less traffic congestion, and happier citizens.

The smart parking service can be directly integrated in the city IoT infrastructure by using the IoT technologies."

2.7 Past Technologies related to IoT in Traffic Monitoring

Google 2015, "Google Car which is an initiative to provide a self-driving car experience with real-time traffic, road conditions, weather and other information exchanges (Google Official Blog), all due to the concept of IoT."

Fernandez-Caballero, Gomez and Lopez-Lopez ,2008, "presented a visual application which allows a study and analysis of traffic behavior on major roads (more specifically freeways and highways), using as the main surveillance artefact a video camera mounted on a relatively high place (such as a bridge) with a significant image analysis field."

Tai et al. 2004, “presented an image tracking system and its applications for traffic monitoring and accident detection at road intersections. Locations of motorcycles as well as automobiles are obtained in real time using the active contour model approach. Image measurement is further incorporated with Kalman filtering techniques to track individual vehicle motion.”

Hong, Kwon and Kim, 1999, “presented the design and implementation of a portable, Web-based network traffic monitoring and analysis system called WebTrafMon, which provides monitoring and analysis capabilities not only for traffic loads but also for traffic types, sources and destinations.”

Zhu et al. 1996, “presented a novel approach to automatic traffic monitoring using 2D spatio-temporal images. A TV camera is mounted above a highway to monitor the traffic through two slice windows, and a panoramic view image and an epipolar plane image are formed for each lane.”

2.8 IoT Versus Current traffic conditions in Nairobi

According to Gachanja, (2011), “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 J. , 2015).

Nairobi, the commercial hub of the second-fastest growing regional economy in Africa, accounts for about two-thirds of Kenya’s $41 billion annual economic output, which the government predicts will grow 5.8 percent this year. The crowd is only growing. Kenya’s projected 4.3 percent annual rate of urbanization from 2010 to 2015, when 12 million of its people will live in urban areas, is more than double the global average of 2 percent and above the African average of 3.6 percent, United Nations.”

IBM, 2011, “the city’s roads were the world’s fourth-most congested. The World Health Organization estimates road accidents kill as many as 13,000 Kenyans a year. The government estimates that traffic jams cost 50 million shillings ($578,000) a day in lost productivity in the city, a base for General Electric Co. and Google Inc. and home to the UN’s headquarters in Africa.”

2.9 Gap Analysis

From the above analysis, traffic congestion is a major problem in most cities in the developing world where road infrastructure is inadequate. The problem is compounded by lack of real time information on traffic flows and lack of facilities for optimizing this flow. This paper seeks to address the problem of gaining real-time data on congestion levels around a heavily congested African cities using Internet of Things. Nairobi, the capital of Kenya is picked as a case for this study.

Additionally, it has emerged that 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. In conclusion of the study, a sustainable intelligent IoT Architecture for traffic management will be proposed for the City of Nairobi which could subsequently be used by any other African Country.

2.10 IoT architectures for traffic management

2.10.1 IBM Intelligent Traffic Management

“A critical integration point of IBM Intelligent Transportation is the gathering of traffic and event data from other traffic center systems and field devices based on the increasingly popular Traffic Management Data Dictionary (TMDD) standard. "Center" subsystems deal with the functions which include roadway information and reporting, traffic management, archived data management, and core services (such as administration, authentication, and authorization).”

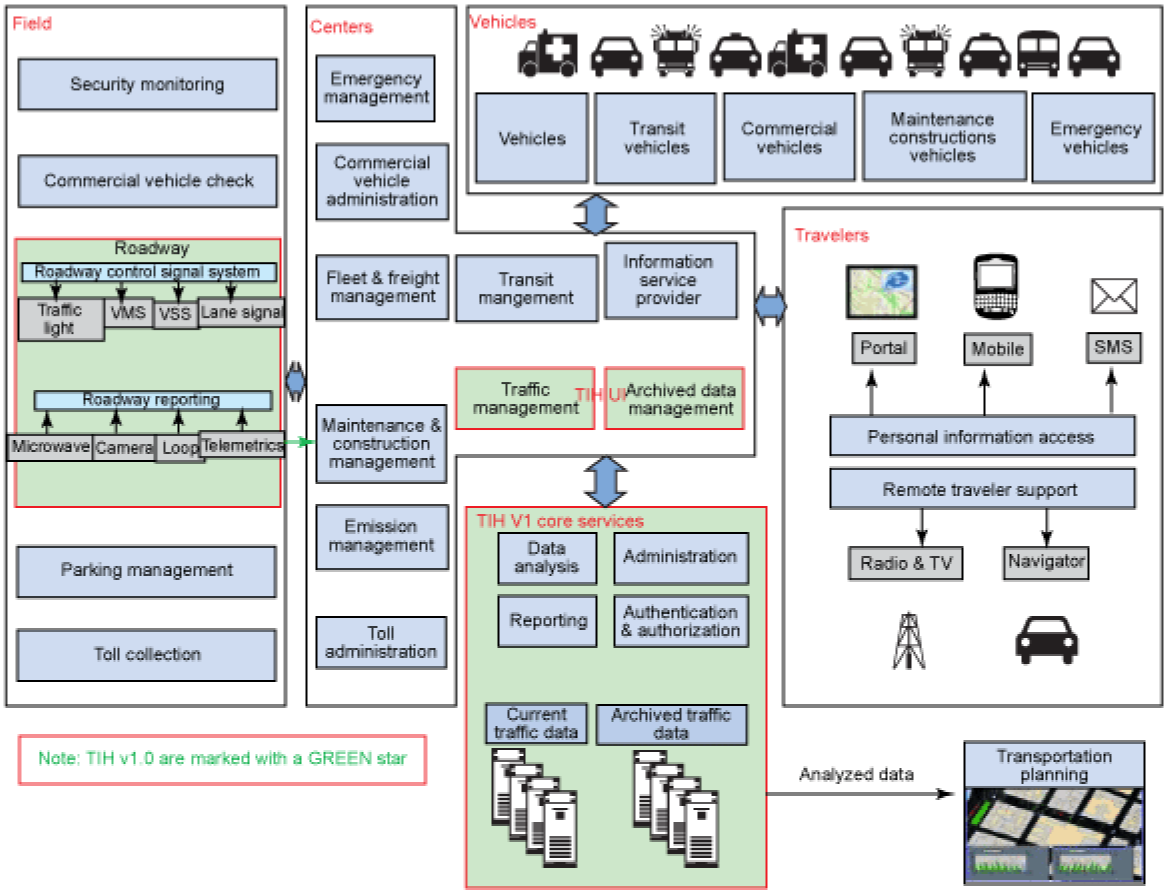

Figure 7: IBM Intelligent Transportation high-level architecture

2.10.2 Intelligent Transportation System with the IoT 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."

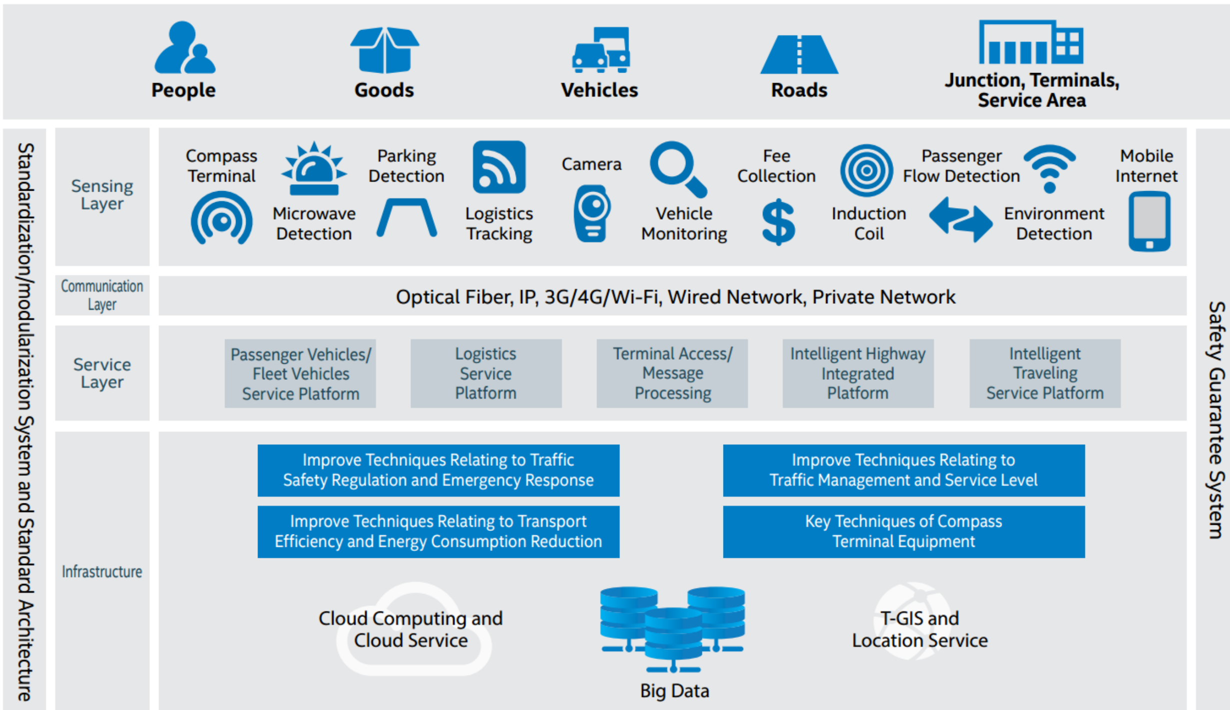

Figure 8: Intelligent Transportation System with the IoT by Intel

2.10.3 AGT and Cisco Traffic Incident Management Solution Architecture

The AGT and Cisco® Traffic Incident Management Solution, "addresses the two most important traffic challenges facing cities today: road safety and congestion. It helps accurately detect more incidents, early on, before they become more serious, and enables quicker response by monitoring and analyzing traffic flow data. The solution stands out with two important innovations: the fusing of data from multiple sources to identify real incidents and reduce false alarms, and the integration of multiple applications into one comprehensive solution.

The AGT and Cisco Traffic Incident Management Solution:

- Collects data from a variety of sensors and stores it for processing
- Fuses, filters, and applies advanced analytics to the collected data to identify the most relevant information
- Visualizes the relevant information using layers to increase situational awareness
- Supports a wide variety of other integrated partner applications and analytics"

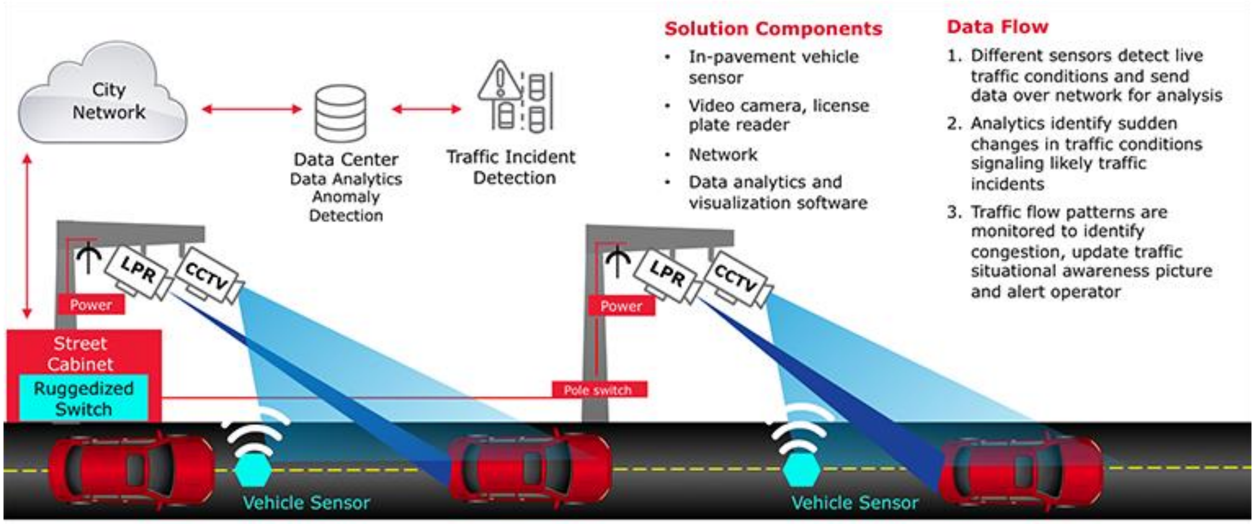

Figure 9: AGT and Cisco Traffic Incident Management Solution Architecture

2.10.4 Cisco Smart Connected City Parking Architecture

Street-line sensors detect the real-time availability of parking spots, while also integrating with digital meters to identify meter violations. Video cameras enabled with analytics monitor parking spots and no-parking zones. The system can also track specific vehicle types and report on loading zone violations. Street-line's suite of applications for consumers, city officials, and enforcement officers ensure that the correct information is delivered, at the right time, to the right people for decisions.

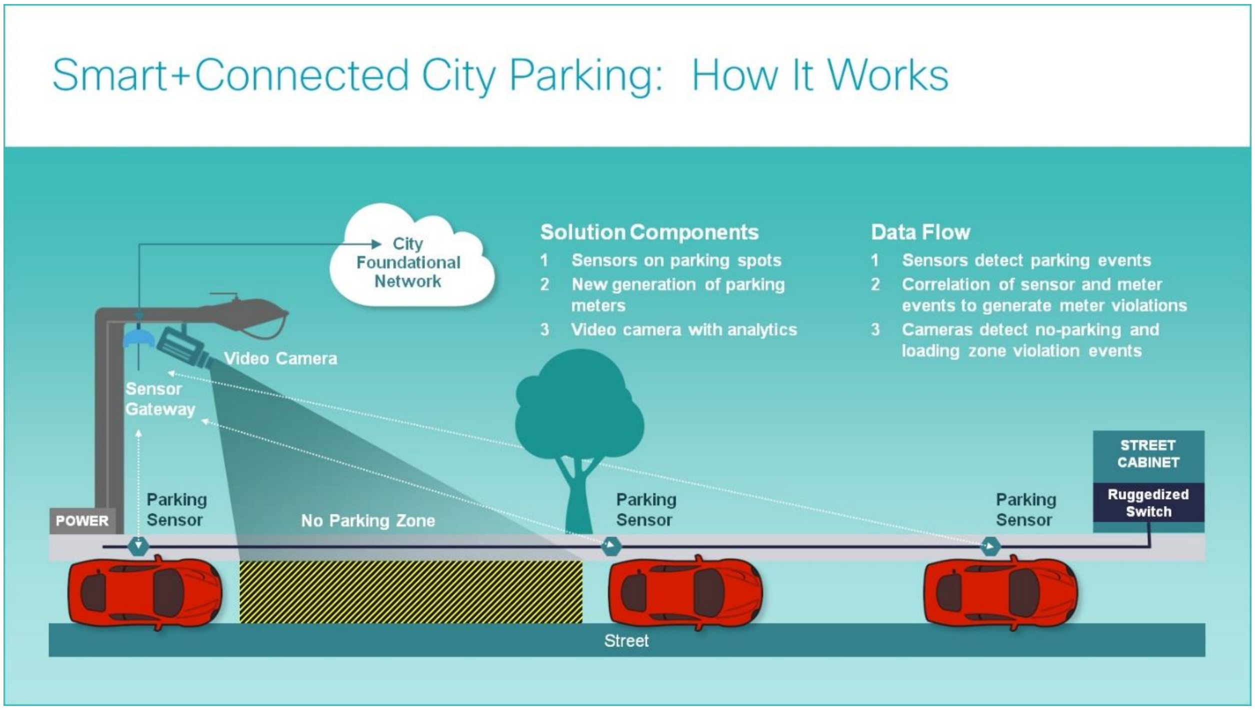

Figure 10: Cisco Smart+Connected City Parking

2.11 Proposed IoT Architecture for Nairobi City

I 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, I 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:

- Vehicle sensor
- Parking sensors
- RFID
- Cameras
- License plate reader
- CCTV

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

Table 1: Conceptual framework

Data sources (people, vehicles, roads, parking slots, junctions/service areas)		
Sensing Layer		
Vehicle sensor	Video camera	Fee collection
Parking sensor	CCTV	License plate reader
RFID		
Communication layer		
City Wi-fi	Wired/wireless access	
Data processing layer		
Data centers	Cloud computing platform	
Open infrastructure		
Apps/services for city residents		
Traffic Reduction		
• Reduced congestion • Better mobility • Savings in time and fuel • Decrease travel times • Road safety • Environmental impact – reduced CO_2 • Enhance economic productivity from reduced travel times		

The key capabilities of this architecture:

Table 2: Key Capabililties of IoT Architecture for Nairobi

Parking Guidance • View real-time parking availability, visually displayed on mobile devices or digital signage • Search for parking spaces based on points of preferences • View parking rates and policy information in advance • Receive voice guidance all the way to the parking space • Pay using a mobile application
Enforcing Parking • Capture all parking events in metered and non-metered spaces • Track payment and overstay violations using sensors and meter integration • Monitor, report live, and enforce no-parking and loading zone violations using video analytics • Deliver live snapshots of violations to mobile devices to aid enforcement officers
Administration & Analytics • Easily configure and manage sensors, video infrastructure, and policies/rules for parking violations • Report on parking availability, income, administration, etc. • Provide useful information to assist with pricing decisions

CHAPTER 3: METHODOLOGY

Research methodology represents the framework that the researcher used to illustrate the procedures for collecting data for this study. The methodology for this study involved reseach design, examining the types of data required and their sources, methods of data collection, data analysis and presentation techniques.

3.1 Research Design

This study adopted an interpretivist approach in research in order to integrate human interest into the study. "Moreover, interpretivism studies usually focus on meaning and may employ multiple methods in order to reflect different aspects of the issue. This approach suited this study because Interviews and observations which are the most popular primary data collection methods in interpretivism studies, are crucial to the type of data that will be collected."

The research strategy used was the descriptive approach since the aim of the study was to develop a sustainable traffic management architecture based on IoT and other technologies to improve traffic conditions and relieve the traffic pressure for the City of Nairobi. "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 is also concerned with the relationships and practices that exist, beliefs and processes that are ongoing, effects that are being felt, or trends that are developing. Also, such approach tries to describe present conditions, events or systems based on the impressions or reactions of the respondents of the research."

3.2 The Study Population, Sample size and sampling techniques

3.3.1 Population

The study pollution involved the following groups that have been purposively targeted with the view that they could provide relevant information in relation to the research questions.

a. ***Road users*** – this group comprised private cars drivers.
b. ***Road Network*** – comprised Mombasa road, Uhuru Highway, Langata Road, Ronald Ngala Street, University Way, Waiyaki way, Thika Highway, Kenyatta Avenue, River Road, Moi Avenue, Tom Mboya Street among others

3.3.2 Sample Size and Sampling Procedure

According to McGregor & Doya, (2014) the number of vehicle on Nairobi's roads have more than doubling since 2012 to 700,000. According to sampling tables drawn by Krejcie & Morgan, (1970), while carrying out a research whose target population lies between 75,000 and 1,000,000, a sample size of 384 is considered sufficient, hence 384 road users were targeted in this study. Because of time and resources constraints the researcher involved half of the minimal sample, that is 192 private car drivers and 12 county parking attendants in the study. Using all road that connect to the CBD for the study would present practical challenges. In the light of this, the following 8 key road links serving the CDB will be surveyed. And within each road 24 road users (drivers) were randomly sampled.

Table 3: Road Sample size

Road	**Sample size**
Uhuru Highway	24
Mombasa Road	24
University Avenue	24
Haile Selassie Avenue	24
City Hall Way	24
Kenyatta Avenue	24
Tom Mboya Street	24
Moi Avenue	24

3.3 Data collection tools and nature of data

This research utilized both primary and secondary data. Primary data were collected via self-administered questionnaires while secondary data will be obtained via document reviews. Accurate data on Nairobi traffic congestion was important to define the existing problem hence assis desing appropriate solution that would address the problem.

3.4.1. Questionnaires

This study was used to obtain important tafffic information from the major road users in Nairobi. The questionnaires were self-administered. This allowed for responses from the respondents with varying characteristics, some of whom required further assistance in providing responses.

Additionally, closed and open-ended questions were used to determine various individual's perception of the traffic congestion in Nairobi.

3.4.2. Document Review

This entailed identifying relevant policy documents from deparments responsible for managing traffic in Nairobi. They include Kenya Urban Roads Authority, Trafffic Department (Nairobi County) and Kenya National Highways Authority (KeNHA).

3.4 Pilot study

A pilot study was carried out on two non-study roads to gain insights and clarify issues on the system needs study instruments constructs.

3.5.1 Validity

According to Mugenda (2008), validity is the degree to which an instrument measures what it purports to measure. The research concentrated on content validity by performing a pre-test so as to adjust the research tool to meet the required standards. The results of the study were validated by reviewing it with other similar researches done.

3.5.2 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 will be established through split half techniques where the pretest dataset will be split into two equal datasets and the Cronbach Alpha evaluated. The results indicated a Cronbach Alpha score of 0.73 greater than 0.70 which was considered to be indicating that the study results were reliable.

3.5 Data Analysis

The study generated both quantitative and qualitative. The researcher went through the questionnaires carefully and systematically to check for inconsistensies and incompleteness. The responses obtained were coded, entered and analysed using SPSS version 2.1. Quantitative data were analysed by use of descriptive statistics involving the mean/median, frequencies and percentages and results presented in graphs and charts. Qualitative data were analysed using content and thematic analysis and themes developed.

3.6 Ethical Considerations

Prior to data collection exercise, the respondents were informed of what the research was about, its tentative research goals and objectives. Additionally, all respondents were guaranteed confidentiality during this process. Data collected was kept confidentail and be used only for purposes of this research. Approval to conduct data among parking attendant was sought from the Nairobi County government.

CHAPTER FOUR: RESULTS AND DISCUSSION

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

4.1 Socio-demographic characteristics

The total sample size for the survey was 212, 200 were private car drivers while 12 were county parking attendants. Male composed majority of the respondents 85% private car drivers and 75% county parking attendants. Majority (53.5%) of the private car driver respondents had attained university/college education while majority (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: Socio-Demographic Characteristics

Characteristics	Categories	Private car drivers		County Parking attendants	
		Frequency	Percent (N = 200)	Frequency	Percent (N = 12)
Gender	Male	170	85.0	9	75.0
	Female	30	15.0	3	25.0
Education level	University/College	107	53.5	3	25.0
	Secondary	86	43.0	8	66.7
	Primary	5	2.5	1	8.3
	None	2	1.0	0	.0
Age categories	30-39	76	38.0	5	41.7
	40-49	56	28.0	4	33.3
	20-29	37	18.5	1	8.3
	50-59	20	10.0	2	16.7
	>59	11	5.5	-	-

Slightly over half of the respondents identified parking spots by driving around while majority (70.1%) parked their cars on on-street parking.

Table 5: Form of identifying parking lots and Parking place

		Frequency	Percent
Form of identifying parking lots in town	Driving around	103	51.5%
	Parking attendants	50	25.0%
	Booking in-advance	29	14.5%
	Parking boys	18	9.0%

Parking place.	On-street parking	138	70.1%
	Off-street parking	33	16.8%
	Private parking	24	12.2%
	Other	2	1.0%

4.2 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. Cummulatively, 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).

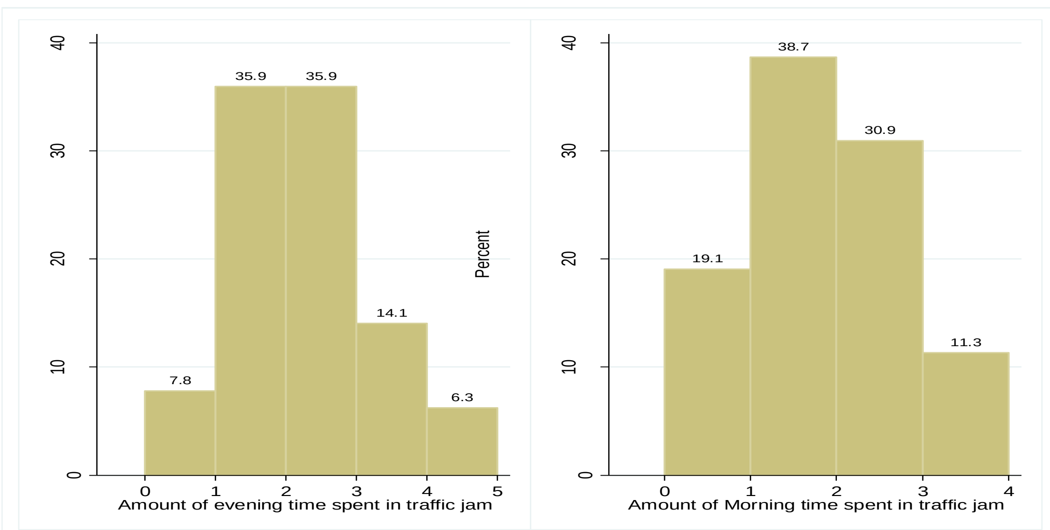

Figure 11: Time Spent in Traffic Jam

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

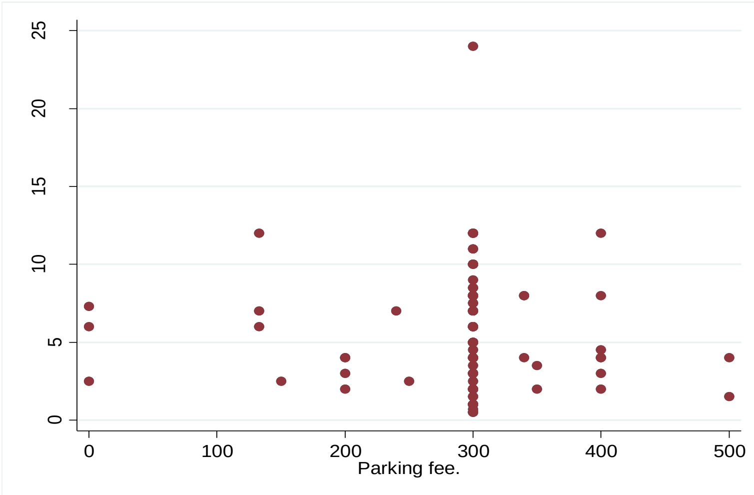

Figure 12: Parking fee

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 13, 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 polic and county council askaris/parking attendants were ranked third and forth 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)

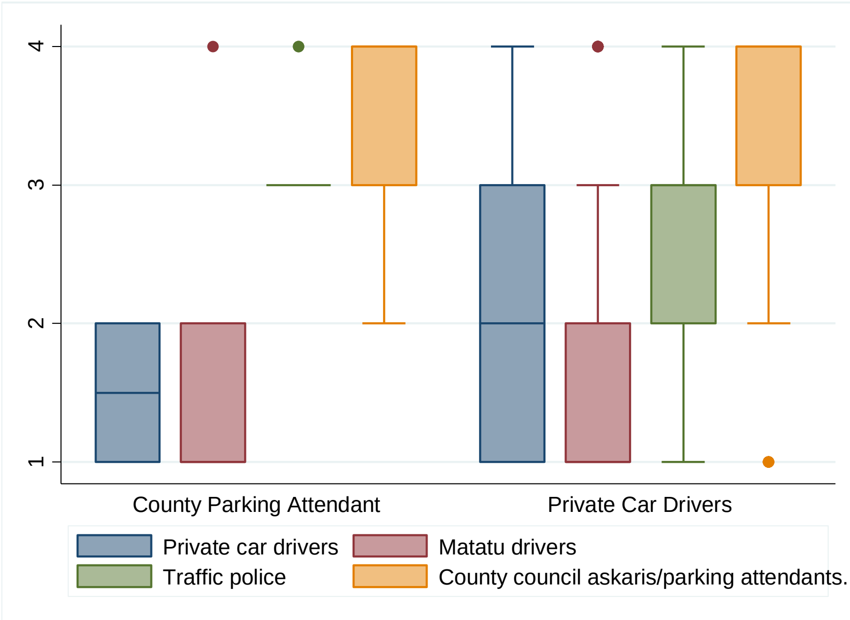

Figure 13: Causes of Traffic Jam from Road Users

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 respodents 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 repored 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).

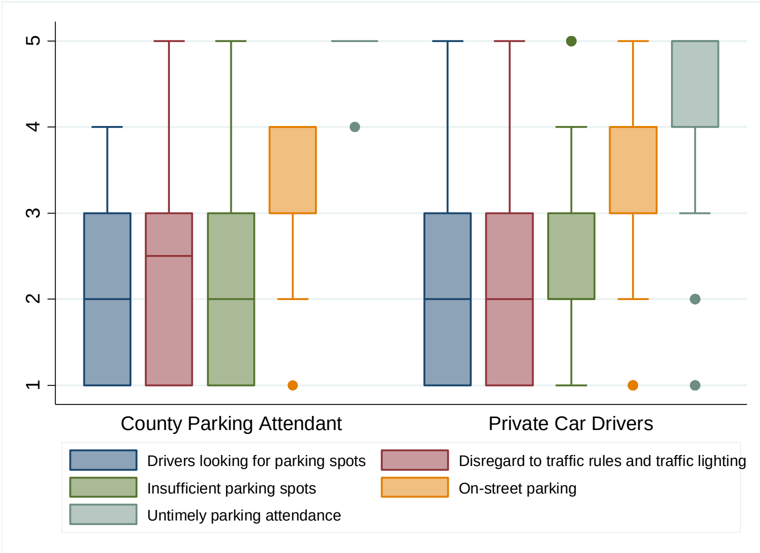

Figure 14: Causes of Traffic jam

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).

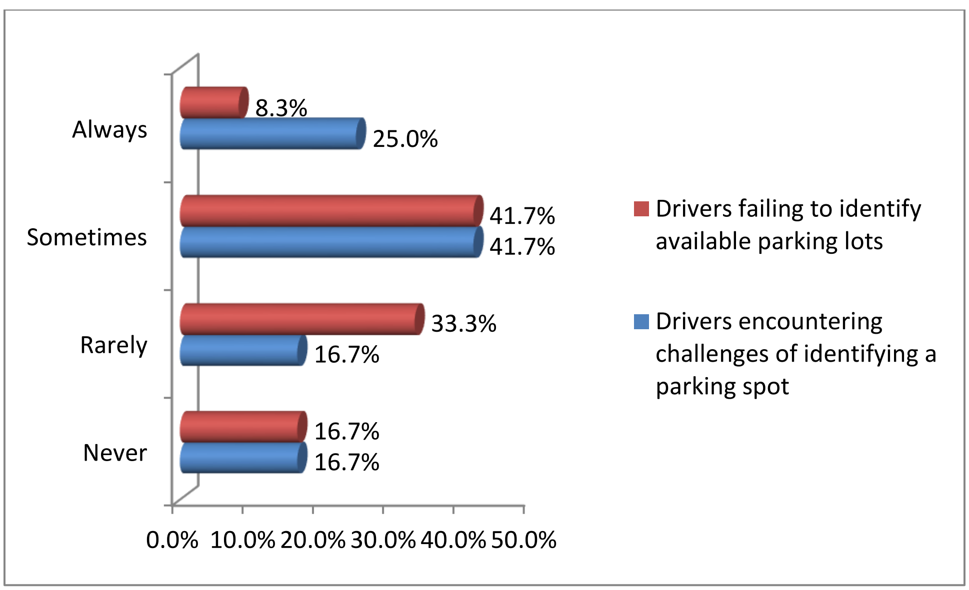

Figure 15: Parking Identification

Drivers in the mid morning spent 30 minutes looking for parking spots in town while drivers in the early morning spent 12 minutes to walk from the parking spot to their workplaces. Kruskal wallis test (p-value = 105 and .831) indicated that drivers spent similar amount of time looking for parking spots and similar amount of time walking from parking spot to place of work irrespective of the time a driver drives to town. Drivers averagely spent 10 minutes to look for parking attendant to pay for the parking lots. “These findings were similar to the IBM Parking survey in which they found out that on average drivers in Nairobi spent 31.7 minutes in their longest search for a parking spot where 13% reported driving around for more than one hour for a parking spot within the last year”, (IBM, 2011). This could be attributed to the fact that most commuters try to access jobs and socio-economic opportunities at the same time on an 8:00 a.m.–5:00 p.m. daily schedule therefore spend similar times irrespective of the time of the day (Gachanja J. , 2015). Similar assertions were made by Kinyanjui and Kahonge (2013) in which they reported that sometimes, the time spent looking for the attendant is significant and most drivers dread leaving their cars before they pay the parking fee due to the consequences which include having your vehicle locked or even towed which in turn attracts heavy penalties. Parking space need to be provided close to the motorist’s place of work to avoid walking a longer distance which will prompt driving hence the increase in traffic in the Central Business District (CBD) (Mudzengerere & Madiro, 2013).

Table 6: Time spent looking for parking lot and parking attendant

Time of driving to town	Time spent looking for parking spot	Walking time from parking to work place.	Time spent looking for parking attendant
Early morning	15	12	10
Morning	20	10	10
Mid morning	30	10	10
Afternoon	20	10	8

Drivers driving to town in the early in the morning always/sometimes got parking spots immediately they arrived in town, drivers in the morning sometimes got parking spots immediately, drivers in the mid morning rarely got parking spots immediately while drivers in the afternoon sometimes got parking spots immediately.

Table 7: Time of Immediate getting of parking slots

Time of driving to town	Immediately time of get parking slots							
	Always		Sometimes		Rarely		Never	
	Frequency	Percent	Frequency	Percent	Frequency	Percent	Frequency	Percent
Early morning	14	42.4%	14	42.4%	4	12.1%	1	3.0%
Morning	23	22.3%	58	56.3%	20	19.4%	2	1.9%
Mid morning	3	13.6%	9	40.9%	10	45.5%	0	0.0%
Afternoon	5	12.2%	19	46.3%	16	39.0%	1	2.4%

Both county parking attendants (83.3%) and private car drivers (62%) majorly considered the current system of parking identification as inconvenient and similarly both county parking attendants (75%) and private car drivers (77.4%) majorly 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). This could be attributed to the fact that the current system did not provide real time parking information but only provided for payments, which was considered to be the most desirable feature parking management system according to 83.3% of employees Lulu East Africa, a company providing parking services in Nairobi, this was followed by mobile payment with 71.7% (Muema, Kyambo, Kyambo, Kirichu, & Senagi, 2014).

Table 8: Convinience of current parking identification and parking payement 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	10	83.3%	2	16.7%	9	75.0%	3	25.0%
Private Car Drivers	124	62.0%	76	38.0%	154	77.4%	45	22.6%

Majority (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.

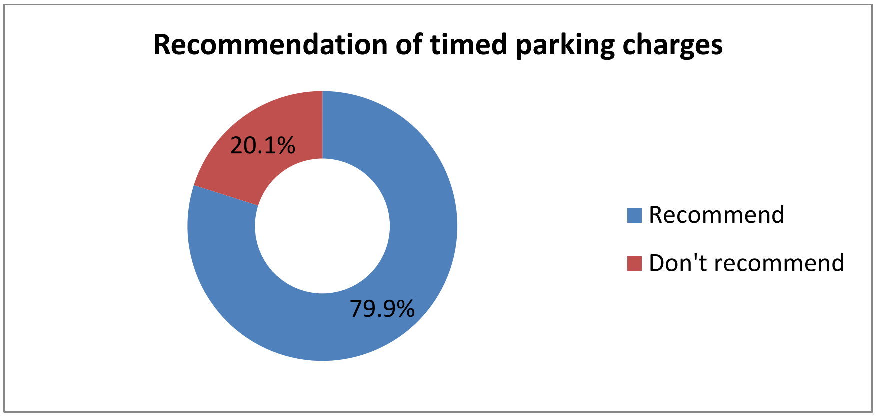

Figure 16: Recommendation of timed parking charges

4.3 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** receive information and transmit 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."

4.4 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 researcher recommended the applicability of IoT in alleviating the situation. Due to time and financial constraints, the researcher demonstrated the application of smart parkig using IoT and not the the entire IoT infrastructure.

4.4.1 Smartparking Application

4.4.1.1. 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 CO2 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).

4.4.1.2. Solution

After analysis of different solutions being used to improve the transportation system of Nairobi, thte 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 inorder to advise different users on availability of parking slots based on their past preferences.

4.4.1.3. Development Language

The central hub was developed on PHP using CodeIgnitor framework while the mobile phone was developed in Android programming language to target Android mobile phones due to their mass coverage in the city.

4.4.1.4. Development Methodology

The researcher used the Agile development method, where every module is designed, coded and tested with the users before proceeding to the next module.

4.4.1.5. Design Structure Diagram

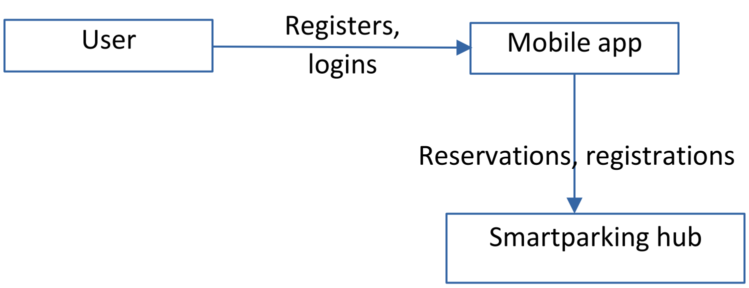

Figure 17: Design Structure Diagram

4.4.2 Mobile – Android Interface

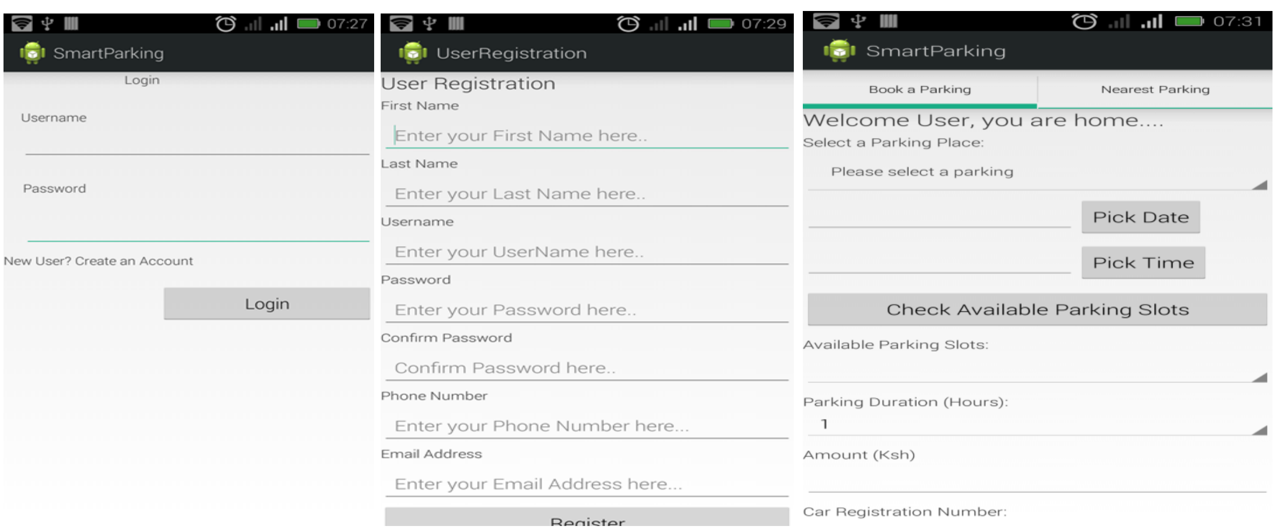

Figure 18: Login, user self –registration, user dashboard

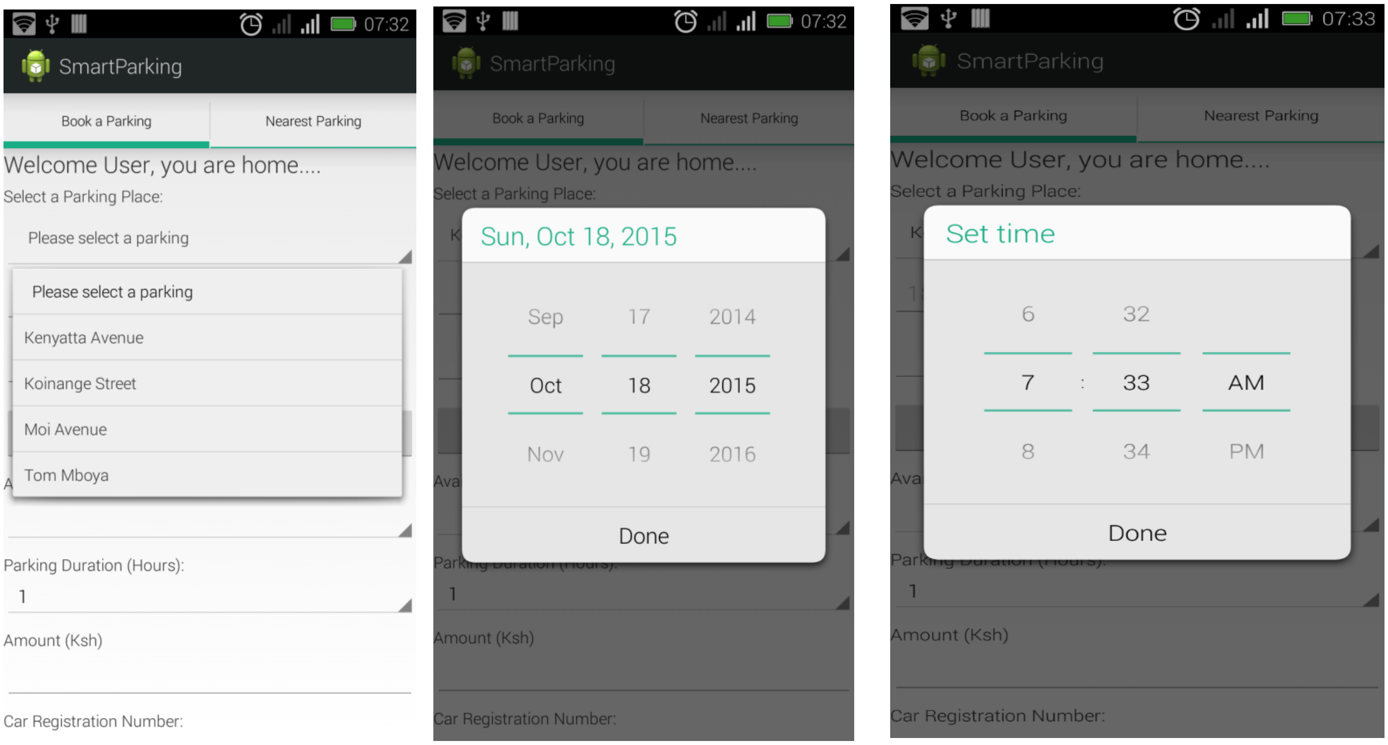

Figure 19: Select a parking place, choose the date, choose time

Check the available parking slots within the selected parking place above, System checks and produces a drop down list of the parking slots. The first two prefix stands for the place and the numbering of the slots are A, B, C onwards as below, Pick the duration of parking:

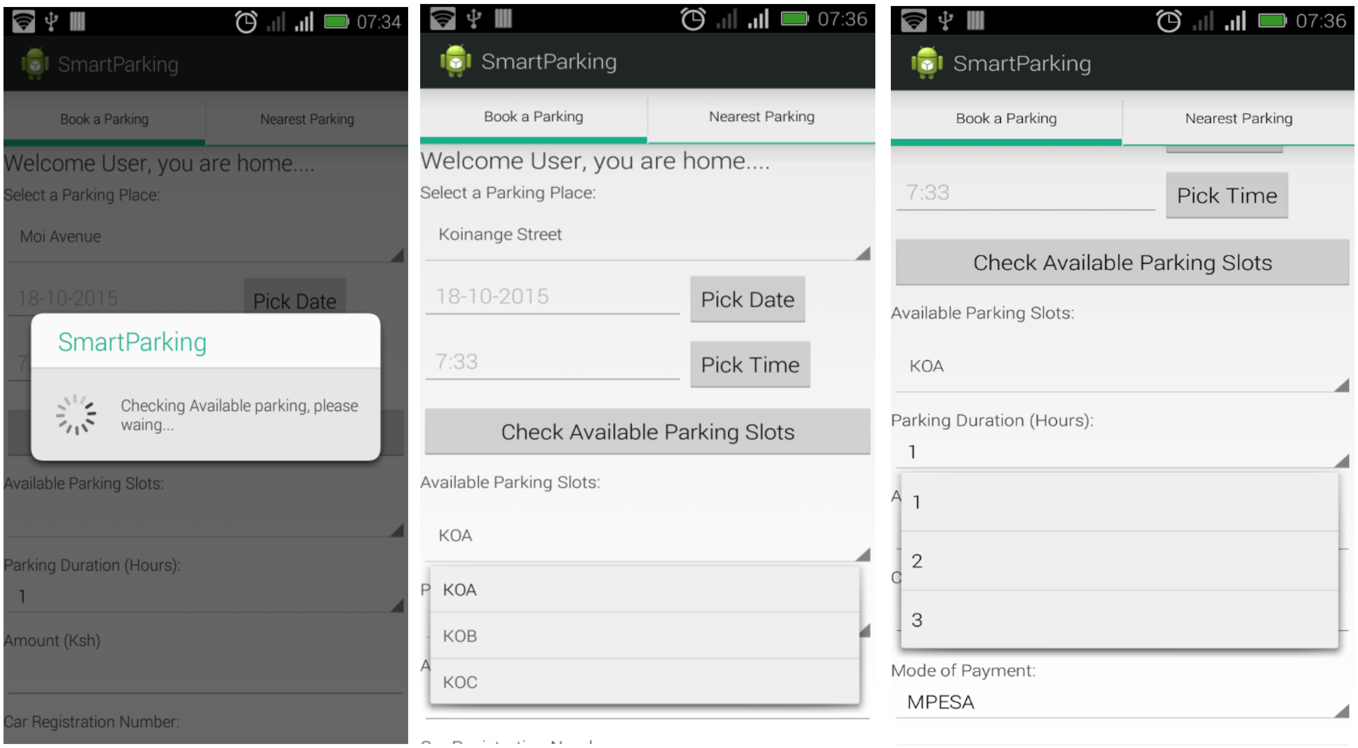

Figure 20: Check the available parking slots

The amount is automatically generated, and then enter your vehicle registration number, before selecting the mode of payment, book and when successful, it will respond with a success message.

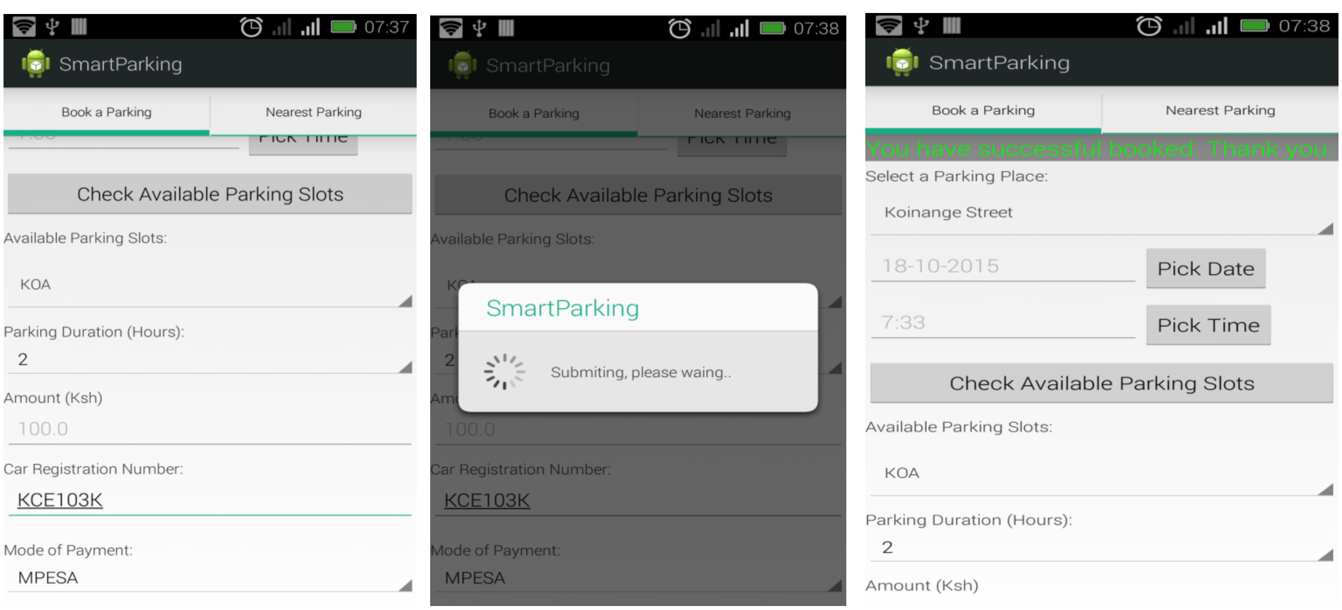

Figure 21: Booking parking slots

4.4.3 Web Interface

This is used for the administration purposes, for adding, updating, deleting parking places, parking slots and their various charges.

Login, should you forget your password you will be able to reset it and manage users of the system.

Figure 23: Login

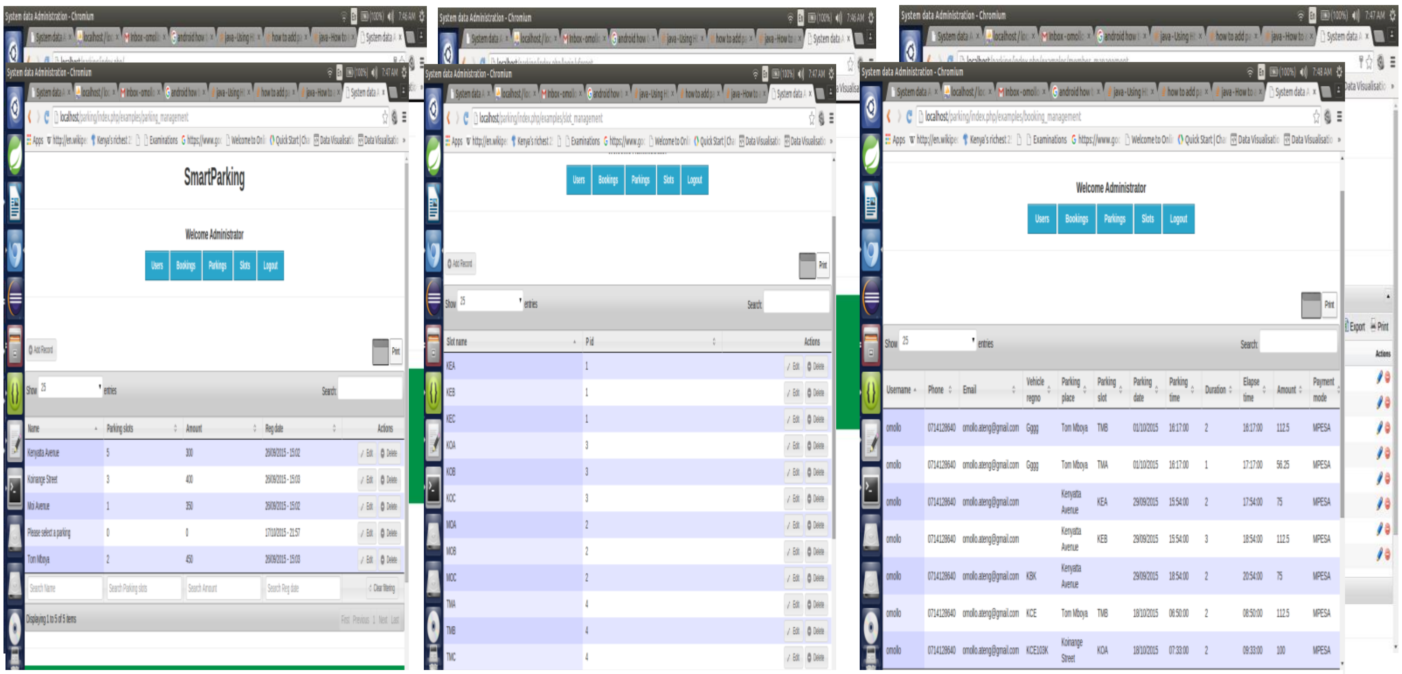

Figure 22: Manage Parking Places, Parking Slots and Check real-time bookings Online

CHAPTER FIVE: CONCLUSIONS & RECOMMENDATIONS

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

5.0 Achievements

Based on the study findings the researcher concludes as follows:

1. Cummulatively, 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 consistenty 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.

2. Although IoT has not been adopted in solving traffic jams in Nairobi, the reseach designed an IoT prototype to help in parking management.
3. For the full scale adoption of IoT in parking management, the system required 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.
4. The prototype was presented to a sample of road users through which the researcher got these comments:
    a. Integrate Google maps to locate the most convenient parking slot
    b. Customize parking search based on points of interest and personal preferences
    c. Get push notifications on town parking patterns especially times of major functions in the city
    d. Receive voice guidance all the way to the parking space
    e. Track payment and overstay violations using sensors and meter integration

5.1 Challenges

The researcher 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:

1. There was non-existance of sensored car number plates to be used by vehicles, however, there are plans to launch smart number plates within the country.
2. The researcher could not verify the adoption IoT because of the prohibitive costs associated with the hardwares required.

5.2 Conclusions and Recommendation

From the study, it was evident that traffic congestion was a major problem that affect major cities in Africa. Nairobi, the capital of Kenya has experienced 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 was clear that current parking systems was 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.

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

1. Risks of using IoT in smart parking
2. How IoT can be applied to measure effects of traffic congestion e.g. pollution
3. The best model of applying IoT in traffic management
4. Leveraging on IoT to enhance city security/surveillance

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APPENDICES

Appendix 1: Consent Form

APPENDIX I: INFORMED CONSENT FORM

I am Lucas, a Masters of Science in Information Technology Management of the University of Nairobi. I am conducting a research on Leveraging Internet of Things (IoT) in combating road traffic in African Cities: a case for Nairobi City, Kenya. You have been randomly selected to assist in this research by responding to the questionnaire intended for this research. Note that you are not supposed to indicate your name anywhere and the information you provide will be treated with utmost confidentiality and will be used for the purpose of this research only.

It is anticipated that the research will take one hour of your time and the research questions includes those related causes of traffic jam, parking identification and parking payment. The questionnaire is divided into four sections which address the above factors and socio demographic characteristics.

Note that it is expected of you to complete all the questions to enhance validity and reliability of the findings however you may skip any questions you are not comfortable with. It is your right to stop your participation in the research at any time. There are no risks associated with participation and no financial benefits. Findings from the study will help in designing and testing a parking system with the aim of reducing time spent looking for parking and therefore reduce traffic jams in Nairobi.

Respondent Agreement

The research has been explained to me and I voluntarily consent to participate. I have had an opportunity for my questions to be answered.

________________________________ ____________________

Interviewer signature Date

Appendix 2: Private Car Drivers Questionnaire
Section A: Socio-demographic characteristics

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

Street: Uhuru Highway { } Mombasa Road { } University Avenue { } Haile Selassie { } City Hall Way { } Kenyatta Avenue { } Tom Mboya Street { } Moi Avenue { }

1. Age in complete years…………….

2. Gender
   a. Male [ ]
   b. Female [ ]
3. Education level
   a. University/College [ ]
   b. Secondary [ ]
   c. Primary [ ]
   d. None [ ]
4. How many years have you been driving frequently to Nairobi CBD? …..

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

Section B: Identification of Parking

6. How do you normally identify parking lots in town?
   a. Parking attendants [ ]
   b. Parking boys [ ]
   c. Booking in-advance [ ]
   d. Driving around [ ]
7. At what time do you normal drive to town? ……..

8. At this time how often do you immediately get parking slots while at your place of choice?
   a. Always [ ]
   b. Sometimes [ ]
   c. Rarely [ ]
   d. Never [ ]
9. How long on average do you normally spend looking for a parking spot? (in minutes) ……..

10. How much do you normally walk from the parking spot to your work place? (in minutes) …………
11. Do you find your current system of parking identification convenient?
    a. Yes [ ]
    b. No [ ]
12. If no, why do you say so?
    ……………………………………………………………………………………………....
    ....
13. At what time of the day do you find it easy to find easy to locate a parking spot during the week day?
    a. Morning [ ]
    b. Mid-day [ ]
    c. Evening [ ]
    d. Night [ ]

Section c: Payment of parking

14. Where do you normally park your car?
    a. On-street parking [ ]
    b. Off-street parking [ ]
    c. Private parking [ ]
    d. Other (Specify) ……………………………………………………………………
15. On average how long do you park your car? ....

16. How much do you pay for the parking in a day? KShs............................

17. How long do you take to locate a parking attendant (County Parking attendants)? ....
18. Do you find the current parking payment system convenient?
    a. Yes [ ]
    b. No [ ]
19. If no, why do you say so?
    ………………………………………………………………………………………………
    ………………………………………………………………………………………………
20. Would you recommend parking charges to be based on amount of time spent on the parking lot?
    a. Yes [ ]
    b. No [ ]

Section D: Causes of Traffic

21. Typically in a week day how long do you spend stuck in a traffic jam in the:
    a. Morning …………….

    b. Evening ……………..

22. In an order of ranking from 1 (most) to 4(least), who according to you are the main causers of traffic snarl ups in town?
    a. Private car drivers [ ]
    b. Matatu drivers [ ]
    c. Traffic police [ ]
    d. County council askaris/parking atttendants. [ ]
23. In a ranked order from 1 (most) to 5(least) rank the following causes of traffic jams in town?
    a. Drivers looking for parking spots [ ]
    b. Disregard to traffic rules and traffic lighting [ ]
    c. Insufficient parking spots [ ]
    d. On-street parking [ ]
    e. Untimely parking attendance [ ]

Appendix 3: County Parking Attendants Questionnaire
Section A: Socio-demographic characteristics

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

Street: Uhuru Highway { } Mombasa Road { } University Avenue { } Haile Selassie { } City Hall Way { } Kenyatta Avenue { } Tom Mboya Street { } Moi Avenue { }

1. Age in complete years…………….

2. Gender
   a. Male [ ]
   b. Female [ ]
3. Education level
   a. University/College [ ]
   b. Secondary [ ]
   c. Primary [ ]
   d. None [ ]
4. How many years have you been a parking attendant in Nairobi? …………..

5. How many parking slots are you in charge of?.........................

6. On average in a day how many cars are parked in these parking lots in a week day? …………………..

   Section B: Identification of Parking
7. How frequent do drivers encounter challenges of identifying a parking spot within your jurisdiction?
   a. Always [ ]
   b. Sometimes [ ]
   c. Rarely [ ]
   d. Never [ ]
8. On average how frequent do you think parking slots are available but drivers fail to identify them?
   a. Always [ ]
   b. Sometimes [ ]
   c. Rarely [ ]
   d. Never [ ]
9. How do you know the number of parking slots available at any given time?
   a. Physical inspection [ ]
   b. Counting number of receipts [ ]
   c. Other (specify)………………

10. Do you think the above system is convenient to you?
    a. Yes [ ]
    b. No [ ]
11. If no, why say so?
    ....
    ....

Section c: Payment of parking

12. How do you charge cars parked within your jurisdiction?
    a. Fixed rate [ ]
    b. Timed parking [ ]
    c. Other (specify) …………………………………………………………..
13. During the last one week, how many cars have defaulted on paying parking within your area of jurisdiction?...

14. Do you think the current system of paying for parking is convenient to you?
    a. Yes [ ]
    b. No [ ]
15. If no, why do you say so?
    ....
    ....

Section D: Causes of Traffic

16. In an order of ranking from 1 (most) to 4(least), who according to you are the main causers of traffic snarl ups in town?
    a. Private car drivers [ ]
    b. Matatu drivers [ ]
    c. Traffic police [ ]
    d. County council askaris/parking attendants. [ ]
17. In a ranked order from 1 (most) to 5(least) rank the following causes of traffic jams in town?
    a. Drivers looking for parking spots [ ]
    b. Disregard to traffic rules and traffic lighting[ ]
    c. Insufficient parking spots [ ]
    d. On-street parking [ ]
    e. Untimely parking attendance [ ]