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Towards the Implementation of Smart Traffic Control in Nairobi City using IoT

By

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DECLARATION

The research project presented in this project report is my original work and has not been presented in any other institution. Reference is hereby made from works of other researchers that may have more insight into this project.

Peter Chege Kariuki: Date: ***August 11, 2020***

(P54/12142/2018)

This project report has been submitted in partial fulfilment of the requirements of the Master of Science Degree in Information Technology Management of the University of Nairobi with my approval as the University supervisor.

Christopher Moturi: Date: ***August 11, 2020***

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ABBREVIATIONS

AI: Artificial Intelligence

ATC: Adaptive traffic control

CCTV: Closed-Circuit Television

GPS: Global positioning system

IBM: International Business Machines

IoT: Internet of Things

ITS: Intelligent Transport Systems

KENHA: Kenya National Highways Authority

NMT: Non-motorized transport

RFID: Radio Frequency Identification

SCOOT: Split Cycle Offset Optimization Technique

SPSS: Statistical Package for Social Sciences

TIS: Traffic Information System

TSP: Transit Signal Priority

WSN: Wireless Sensor Network

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ABSTRACT

The City of Nairobi is experiencing a population explosion, which leads to an increase in traffic congestion. Urban residents are suffering inadequate transport facilities, and meanwhile, the considerable financial loss caused by traffic becomes a significant and growing burden on the nation's economy. The existing traffic control system works based on a constant timing mechanism, which provides equal time slots for each junction. The primary objective of the research was to develop a smart traffic model using IoT. Quantitative data was analyzed using descriptive research analysis which was presented through a measure of central tendency and visual tabulation. The data findings illustrated the relationship of time and traffic where a change in time during peak hours caused an increase in the number of traffic at a road intersection controlled by traffic lights. The research was limited to a sample of streets within Nairobi City, which are controlled by traffic lights. Traffic congestion in Nairobi is crippling the economy through loss of revenue and time during peak hours. Smart traffic control using IoT will enhance the seamless flow of traffic. A traffic simulation model was used to illustrate how the problem of traffic congestion will be solved and how the policymakers and engineers will use the model to actualize a real system.

CHAPTER 1: INTRODUCTION

1.1 Background

1.1.1 Traffic Flow Control

The management of traffic as a result of a high number of vehicles in Nairobi is a constant problem for commuters. The current traffic control system allocates a consistent, equal time stamp for each road junction. The regular timing leads to incorrect green time balancing as a result of individual evaluation errors. The existing system is not efficient for the non-uniform flow of vehicles, and this creates a necessity for a system that is smart and adaptive. Routes should be granted time stamp depending on the queue length experienced in each way.

The number of traffic seen in road intersection profoundly affect both developed and third world countries (Popoola & Adeniji, 2013). People living in urban residents have poor transport infrastructure, which leads to financial loss and eventually affects the nation's economy. Having the idea to improve transport infrastructure will have an impact on the nation's economy since better roads cannot address traffic congestion (EL-Kadi, 2013). Intelligent transportation systems (ITS) is the most efficient solution to the existing problem (EL-Kadi, 2013). The viable solution to the problem is to use IoT to measure real-time traffic flow and try to re-route vehicles in a less congested road (Harriet et al., 2013).

The native traffic control system has significant challenges, such as constant timing intervals per intersection. The modern traffic control system operates on a vast network that has real-time traffic information. The native traffic control technologies are challenged, such as inductive loop, video camera, satellite images, and GPS. Networked sensors that are intelligent are emerging, which are an alternative to the native traffic control system (Budde, 2014). Wireless sensors are distributed and have many benefits such as small size, low cost, and wireless communication.

Management of traffic in a better way will lead to a seamless flow of vehicles, which will eventually reduce traffic congestion. Nairobi City is fetching the traffic information from CCTV cameras present on the roads. The city traffic management board receives all the vehicle-related data. The traffic management group decides on how to divert the traffic and reduce the chances of jam effectively. The use of big data will play a key role when using IoT to analyze route and make a rational decision (Zanella et al., 2014).

1.1.2 Internet of Things (IoT)

The internet of things (IoT) allows integration between the physical world and computer-based systems where objects can be identified and controlled wirelessly within a given network. The embedded computing system allows objects to be identified and operate within the existing internet infrastructure. The method leads to enhanced efficiency, accuracy, which leads to economic benefits. Estimation by experts reveals that IoT devices will consist of 50 billion objects by 2020 (Zanella et al., 2014).

Predictions by UN reveal that by 2050 the global urban population will double to around 6.7 million people (Raje et al., 2018). Significant encounters include new opportunities and challenges as a result of increases in the number of people living in urban areas. To mitigate traffic congestion, Nairobi City should implement the Internet of Things to control traffic flow (Raje et al., 2018). The use of IoT has the advantage of reducing the pressure of urbanization, make lives more comfortable and secure to city residents. Smart traffic systems have different embedded types of sensors, which can determine the number, location, and velocity of vehicles through GPS data (Roy, et al., 2016). Smart traffic lights connected to the cloud server allow monitoring on the current traffic situation and automatically adjust the lights to manage the flow of vehicles. Intelligent solutions can use historical data to predict where the traffic flow should be re-routed and take measures to prevent potential congestion (Omina, 2015).

Predictions by the UN depict that by 2050, the world's urban population will double to around 6.7 million people (Raje et al., 2018). Cities face new opportunities and challenges as a result of the growing number of urban residents. To mitigate traffic congestion, Nairobi City should implement the Internet of Things to control traffic flow (Raje et al., 2018). IoT has a vast potential in reducing urbanization, enhance the experience of city residents by making day-to-day living more secure and comfortable.

Smart traffic solutions use IoT devices to fetch GPS data from driver’s smartphones and use it to estimate the number, speed and location of vehicles (Roy, et al., 2016). Smart traffic lights use cloud computing for data storage which allows monitoring of the road status and automatically change the traffic lights based on the current situation of the road. Intelligent solutions can collect historical data of a given route and use the data to forecast the status of the way at given periods (Omina, 2015).

1.1.3 Traffic Congestion in road transport

Congestion is when vehicles cannot move seamlessly, which occurs when the capacity of the road infrastructure is exceeded (Kiunsi, 2013). The total number of registered cars in Kenya grew by 77% between 2014 and 2019. The highest contributors were motor and auto-cycles, which increased by 368% in 2018. Other types of vehicles, such as earthmovers and farm tractors, had a growth of 70% higher than that in 2014. Buses and minibuses had 51%, while motor cars had 43% with the highest number of registered vehicles. The only category with a decline in registration was trailers -18% (Chow et al., 2013). As a result of the increase in the number of vehicles, the use of social media has been rampant to provide unofficial advice on how to avoid traffic congestion. Some of the online suggestions provided ways of avoiding extensive queues, which include re-routing and not travelling in a given route (Kinai, et al., 2014).

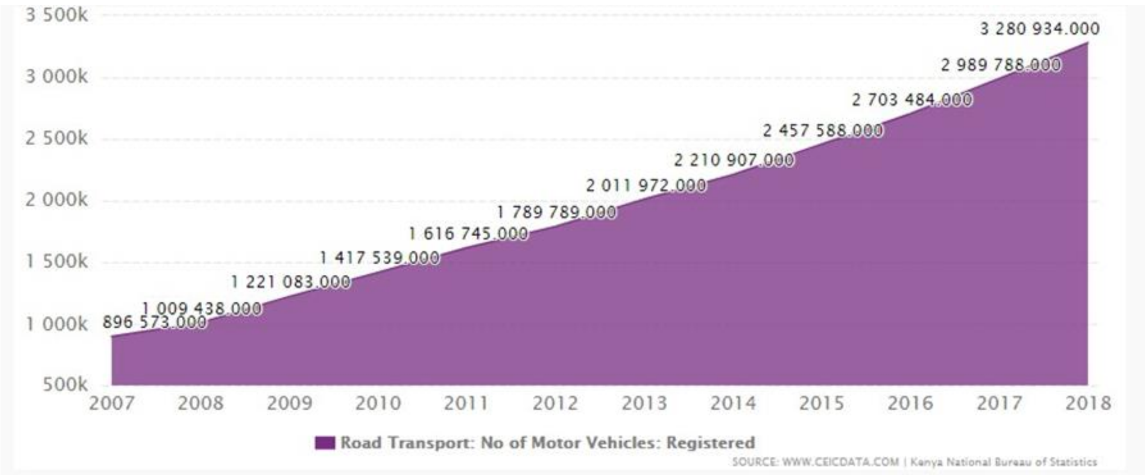

Figure 1 Distribution of registered vehicles in Kenya

Government policies have made significant growth in the rapid increase in motor vehicle registration. In October 2016, TechSci Research, a research-based management consulting firm, gave a report on tax waiver by the government on importation and local assembly of motorcycles. The main aim of the initiative was to improve sales and create jobs which profoundly affected the seamless traffic flow within the city.

Nairobi traffic congestion as a result of poor transport infrastructure is harming the economy (Santani, et al., 2015). In Africa, Nairobi has the longest queue to work due to heavy congestion, high rates of walking, and the spatial distribution of residents and jobs. Nairobi city becomes inaccessible, which leads to low employment and misallocation of labour. During peak hours, there is extensive traffic congestion, which contributes to local air pollution, which leads to economic loss in both fuel and time. This combination of failure will eventually make Nairobi city less attractive, thereby affecting the country's economy (Raje et al., 2018).

1.2 Problem Statement

The number of people residing in urban areas continues to rise faster than road capacity (Ruhiiga, 2013). High traffic at road intersections affects traffic flow, which leads to traffic congestion (Ruhiiga, 2013). Traffic control by police has not proven to be efficient in traffic management. Also, the predefined set time of 60 seconds for the traffic signal has not solved this problem (García-Nieto et al., 2013). IoT assists in addressing constant interval traffic flow control, which leads to congestion by analyzing the traffic density in roads and providing timestamps based on the traffic concentration (Chong & Ng, 2016). A network of sensors is used to track the number of vehicles, and the traffic congestion at the intersections on the road and re-routing is done coupled by the traffic density on the road lanes (Chong & Ng, 2016). A smart traffic management model utilizing sensor data was developed to enhance traffic flow at a road intersection. The aim was to optimally control the duration of green or red light for a specific traffic light at an interrupted road intersection. The traffic signals should depend on the number of cars present on roads to determine the green light balancing.

1.3 Specific objectives

i. To identify the major causes of traffic congestion in Nairobi City.

ii. To develop a smart traffic control model using IoT.

iii. To validate the smart traffic control model using simulation software.

1.4 Research Questions

i. What is the cause of traffic congestion in Nairobi city?

ii. How can IoT be used to solve traffic congestion?

iii. What traffic control models could be used to simulate traffic congestion?

iv. How will the engineers and policymakers actualize the model for its implementation?

1.5 Significance of the study

Nairobi county fetches data from CCTV cameras and conveys traffic-related data to the city traffic management center. A combination of data from IoT enabled sensors is used to record traffic density. Big data analyses information and provide drivers with alternative routes that can improve traffic flow. CCTV feeds, and sensors can assist in identifying accidents, stalled vehicles, and relay their location to the emergency team. The manual traffic control system by the traffic police will be rendered obsolete.

CHAPTER 2: LITERATURE REVIEW

This chapter consists of a presentation of reviews and analyses from various authors with relevance to the topic under research. It includes a detailed discussion of traffic congestion, IoT in traffic control, IoT technologies, smart traffic management techniques, and models.

2.1 Traffic Congestion

Congestion is an excess of vehicles in a given roadway, which leads to speeds that are slower than the regular free flow of cars (Tsekeris & Geroliminis, 2013). Road users have a pre-determined time for completion of a given journey, and this reflects congestion as a physiological phenomenon to commuters (EL-Kadi, 2013).

Congestion falls into three categories, which include: recurring, non-recurring, and pre-congestion (Chow et al., 2013). Recurring congestion is when congestion occurs at a specific time and location, and a motorist is privy and finds ways on how to avoid it. Non-recurring congestion happens at a particular time when the circumstances are not definite. The congestion is not anticipated and makes it worse than recurring congestion as it adds up to the existing congestion without a solution. Pre-congestion occurs where a motorist who uses a given route understands that there is congestion and re-routes to a less congested road (Popoola & Adeniji, 2013). The result is the formation of 'new' congestion on existing road congestion.

Costs of congestion involve increased travel time and reduced speeds, which impose a fee on commuters (Popoola & Adeniji, 2013). The costs of congestion exist in two categories. Direct cost results are easily observable when there are delays when the road network is congested. The vehicles idling longer than usual will increase the running and maintenance costs of the car. Indirect cost occurs when there is increased commodity price due to fuel price or death due to road accidents (Abdul-Wahab, 2013). The purchase of vehicles as a result of a rise in social income leads to less development as a result of traffic build up on the roads.

Efficient traffic management requires quantifiable ways to ascertain the condition and status of the road network (Chaple & Paygude, 2013). Values used in the measurement of traffic congestion exists in two categories: Basic measures and ratio measures. Basic measures estimate the delay time where the delay is the extra time taken for a given route, which is the additional time a commuter takes in a given road network.

This measure shows the effects on the entire transportation system when the delay time is reduced (Takyi et al., 2013). The calculation gives the real-time status of the road. The estimate of total vehicle delay is calculated as follows: -

$$TotalDelay = \left[ActualTravelTime(\min) - AcceptableTime(\min) \right] \times VolumeOnRoad$$

The assumption made is that there is a definite time stamp required to traverse through a given road. The problem with total delay is that there must be a specific measurement for an acceptable time, and the measure will only be known when the delay occurs. Individuals who are stuck in traffic congestion makes it inefficient for them.

The derivation of ratio measures is from two factors of road congestion. The most popular ratio is the buffer index, which is calculated as follows: - The buffer index calculates the extra time in percentage a traveller is allowed to travel to make it on time. The 95th percentile travel rate and average travel rate is used rather than average travel time to mitigate the issue with trips (Francke & Kaniok, 2013). The buffers index is predictive, and it is crucial for people undertaking a journey whose calculation is as follows:

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

Traffic congestion solutions in western countries may not solve the causes of traffic congestion in Africa (EL-Kadi, 2013). Making money is the primary concern among transport operators than transporting the public. Buses and taxis break down as a result of overloading leading to traffic congestion. Implementation of extra charge for congestion systems necessitated the need for people whose preference was to cycle and walk to use a particular road network (Alvanides, 2014). Africa has not implemented such measures which incline pedestrians and cyclists to use the road (Alvanides, 2014). A motorist drives at a lower speed to avoid hitting the cyclist who cycles on the leading road network, eventually leads to congestion.

The African roads are in a dilapidated state due to financial constraints (Popoola & Adeniji, 2013). Motorists drive at a lower velocity, which leads to congestion. The poor road infrastructure makes motorists drive in inappropriate routes when avoiding potholes, which results in accidents and eventually leads to traffic congestion (Gachanja, 2015).

Below are examples of African cities that have addressed Traffic congestion.

Lagos: The former capital city of Nigeria, with a 3.9% annual population growth with the expectation of rising to 24 million in 2020 (Obia, 2016). Lagos is the third most in the list of popular cities in the world (Obia, 2016). 57% of commuters in Lagos spend 30 to 60 minutes stuck in a traffic jam (Popoola & Adeniji, 2013). Research has been done in Lagos to determine the causes of traffic congestion. The findings revealed that traffic congestion was as a result of an increase in the number of vehicles without an upgrade of the existing infrastructure of the road network (EL-Kadi, 2013). The findings also revealed that the use of smart traffic control system to monitor vehicles have a significant impact in reducing traffic congestion. It cautioned that the system should not be used in isolation but should complement the native traffic management system, such as the construction of flyovers and underpass.

Cairo: The government's initiative to subsidize fuel makes the city unique (EL-Kadi, 2013). The result is an increased number of vehicles as people can afford to maintain the cars and fuel them, which leads to an increase in travel time, which leads to traffic congestion (Abdul-Wahab, 2013). Cairo has a 4% GDP level as a result of the cost of congestion (EL-Kadi, 2013). A research conducted in Cairo reveals that the main problem of traffic congestion is an increase in vehicle ownership, mismanagement of traffic, and expansion of cities. A recommendation of the monorail was to replace micro-buses which traverses within the town.

Nairobi: Estimation of the Nairobi population will reach 5 million by the end of 2025. The estimations reveal that Nairobi will end up congested as the infrastructure remains unchanged (Budde, 2014). Over the past five years, the number of vehicles in Nairobi has increased steadily (Kinai et al., 2014). The cheap Japanese models have accelerated the importation of cars into the country. It has led to an increase in city cubs, which have increased the demand for the road network. Traffic congestion is made worse by careless drivers who are not privy to traffic rules and regulations. The existing traffic infrastructure remains the same, but the number of vehicles increases every day. Nairobi is a small city with buildings alongside major roads that make road expansion impossible (Gachanja, 2015). More innovative ways are required to deal with traffic congestion than the construction of road infrastructure (Raje et al., 2018).

The table shows the congestion statistics of African cities

Table 1: Congestion in African Cities.

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

2.2 Smart Traffic Management

Smart traffic lights have made management and monitoring of vehicle a necessity in many countries (Budde, 2014). Two strategies used in the management of traffic include Fixed and real- time. Fixed traffic lights work with a definite time where the duration of the signal does not consider current status. Real-time traffic lights are adaptive to the real-time situation of the road. Specific variables, such as the count of cars, speed, and direction, determine the decision on how to manage traffic lights (Adunya, 2015).

Smart traffic management is a system that uses sensors and traffic signals to monitor and control traffic (Rizwan et al., 2016). Centrally managed sensors and traffic signals exist on the city's major roads. Smart traffic management improves traffic flow by giving priority to traffic according to real-time changes in traffic conditions. The system prioritizes vehicles that enter intersections and uses green split phasing to ensure the efficient flow of cars through the city. Nairobi city employs fixed traffic lights signals that are not responsive to the queue length of traffic (Gachanja, 2015).

Smart traffic control systems use a centralized system with the aid of cameras to determine the number of vehicles. The images captured by the systems inform the intelligent traffic control system of real-time traffic conditions on major highways. The system calculates the timing every two seconds to determine whether to adjust traffic lights activity. The system adapts and changes to improve the arrival time of buses and reduce the number of vehicles in slip lanes (Roy, et al., 2016).

Smart traffic signals reduced the inefficiency of traffic jams or vehicles waiting at an empty intersection. Interconnected intelligent traffic lights can use IoT devices to identify patterns in traffic conditions and thereby update the traffic signals in real-time. Smart traffic lights enhance traffic flow where sensors collect data and communicate with the centralized traffic systems, which generate traffic patterns. The timing of traffic lights is adjusted per real-time traffic conditions and, therefore, not limited to constant timing traffic conditions (Javed & Pandey, 2014). Smart traffic signals assist drivers by providing the required driving speed to arrive at a particular road intersection when the light is green. It assists in traffic regulation and creates a concept of "always green traffic lights" (Javed & Pandey, 2014).

Nairobi city, as part of a smart traffic system, should leverage the use of big data and the internet of things. IoT in traffic management refers to intelligent connected devices that communicate with portable gadgets such as mobile phones which have a connection with either Bluetooth or WIFI (Bull et al., 2016. The transmitted data is via the internet to a central system for analysis. Big data analyses this data and uses it to improve traffic management and flow.

Smart cities embed IoT devices, which include sensors and detectors in their infrastructure throughout the city (Rizwan et al., 2016). IoT and Big data impact traffic management in many ways. IoT devices mounted in major roads collect data and conveys it to a massive data management centre for analysis. The analysis presents optimal lighting patterns to the smart traffic control lights, which adapts to the changing traffic situations. Sensors mounted on the road guide the emergency team to the site of the accident, in the form of alerts (Francke & Kaniok, 2013).

Data collected through sensors ensure the efficiency of public transport. The effectiveness of public transport is slowed down by a variety of factors, which include weather conditions or accidents that occur along the bus route (Popoola & Adeniji, 2013). Real-time traffic data along the given routes assists traffic officials in identifying issues and taking the necessary measures to ensure smooth traffic flow. In the 20th century, the only way of traffic improvement and traffic congestion reduction was through physical infrastructure (Harriet et al., 2016). Improving on the existing road infrastructure is a complex, expensive and only offers a partial solution to the current problem.

Smart traffic systems can have a significant effect on traffic flow than the high cost of building a new road. The root problem of traffic congestion is addressed by analyzing traffic patterns and provide responsive feedback. They enhance the quality of life reduction of pollution and eventually save lives. Real-time information to drivers helps cities regulate traffic on a major road intersection.

One of the most significant infrastructure problems experienced by developing countries is traffic management (Abdul, 2013). Developed countries and smart cities are using IoT and big data to address the issue of traffic congestion (Budde, 2014). The preference for owning a vehicle is rampant in major cities as commuters prefer using their means without taking consideration of the stature of public transportation. Commuters in developed cities overlook the element of money and prefer reaching their destination with the required comfort (Popoola & Adeniji, 2013).

Traffic congestion as a result of the increased number of vehicles is rampant in developing cities. Several countries are addressing this through the extraction of information from CCTV feeds and transmitting data to the city traffic management centres. Efficient traffic management results in a better flow of vehicles with fewer vehicles idling on the roads in the traffic jam. All this eventually leads to lower run time, less pollution, and efficient utilization of natural resources.

2.3 IoT in Traffic Control

Traffic flow is divide into two categories. The first is uninterrupted, which is the flow regulated by vehicle to vehicle interaction between cars in a roadway. Cars on a highway are said to be flowing continuously. The second type of traffic flow is interrupted flow. Interrupted flow is regulated by traffic signals for vehicles heading towards a road intersection. Under intermittent flow, car to traffic signals plays a secondary role in defining traffic flow (Bull et al., 2016).

The existing traffic control strategies include vehicle stop, average delay, travel time, queuing length, traffic volume, and vehicle speed. The traditional traffic signal collects data at predefined locations which are not deployable in a large scale of urban road networks (Santani, et al., 2015). The use of IoT enabled devices enhances traffic control management in significant road intersections controlled by traffic lights. The development of IoT computing systems requires a combination of several technologies. The following relevant technologies will assist in the development of IoT applications.

Radio Frequency Identification (RFID)

RFID is the primary technology for identifying objects uniquely. It makes integration into any purpose easy as a result of reduced size and cost. The transceiver microchip could be either passive or active, depending on its application. Active tags have an inbuilt battery since they have a continuous data signals emission while passive tags get activated when they are triggered (Karakostas, 2013). Active tags are usually costlier than passive tags and have a wide range of applications. An RFID system comprises of readers and associated RFID tags that emit specific identifying information such as location when it gets triggered by a signal. The emitted data signals are transmitted to the readers using radio frequencies, which passes to the processors for analyses.

Wireless Sensor Network (WSN)

A wireless sensor network is a connection of devices that have sensors that can identify the surroundings and use wireless links to convey information (Kumar et al., 2014). Multiple hops forward data to a sink that is available locally or connected to other networks through a gateway. The nodes can either be stationary, movable which are aware of their current location. WSN, combined with other technologies, can be used to alter the environment in which they operate.

Cloud Computing

Cloud computing is an intelligent computing technology that converges several servers into one cloud platform to allow sharing of resources between each other. The resources can be accessed remotely at any time and in any place (Aazamet al., 2014). Cloud computing is the most critical technology in IoT devices, which converges servers and increases the processing power of objects. The cloud computing technology provides adequate storage capacity for collected data. Combining IoT and cloud computing offer a significant advantage when deploying objects to large scale development

Networking Technologies

These technologies are responsible for the connection between different objects; therefore, they require a fast and effective network to handle many potential devices. For a wide range of transmission networks, 3G and 4G networks are the most popular networks. For short-range networks, Bluetooth and WIFI technologies are the most efficient technologies.

Nano Technologies

Nanotechnology is a small improved version of the things that are connected. It enables the development of devices by decreasing the consumption of a system where the nanometer scale is used as a sensor and an actuator just like a standard device. Nano components made from Nanodevices define a new networking paradigm, which is the internet of Nano-things.

Optical Technologies

The development of IoT devices is a result of drastic developments in optical technologies such as Li-Fi and Cisco's Bidi optical technology (Omina, 2015). Li-Fi, an epoch-making Visible Light Communication (VLC) technology, provides excellent connectivity on high bandwidth for IoT connected objects.

2.4 IoT solutions for Smart Traffic control

The Adaptive Traffic Control Systems (ATCSs) is the third generation of urban signal control systems after the fixed time coordinated signal systems (Misbahuddin, et al., 2015). ATCSs use real-time traffic data collected from IoT devices, unlike the centralized signal control system. The significant difference between ATCSs and constant timing of traffic lights is the adaptive nature of ATCSs to the real traffic flow.

Arrival time for vehicles at a road intersection is stochastic. Vehicles arrive one at a time or in batches. Inter arrival time varies between the different times of the day with various traffic conditions and the physical layout of the road and lanes (Kiunsi, 2013). For efficiency of traffic flow, real-time traffic signals must proactively respond to arrival streams to minimize vehicle stops and delays as much as possible. The SCOOT model will be discussed in detail and justify the proposed solution.

SCOOT (Split Cycle Offset Optimization Technique)

It is the most popular adaptive traffic control system with its implementation in over 200 countries worldwide (Sharma & Giddie, 2014). As traffic flows continuously, it responds intelligently to the demand. Networks in a scoot are divided into regions that contain several nodes. On under- saturated intersections at pedestrian crossings, nodes are double cycled with an operation of half of the system cycle length. Coordination which is not feasible regional boundaries occur at long links. The detectors heavily influence scoot performance on traffic flow data which operate with many sensors that exist at the well-defined location. The location of the sensors is the key where they should be located towards the end of the approach link.

Scoot has three optimization procedures: The Split Optimizer, the Offset Optimizer, and the Cycle Time Optimizer (Sharma & Giddie, 2014). These measures are used by the scoot model in the prediction of vehicle delays and stops, which assists in the calculation of the system's performance index. Scoot assists in altering the definite signal plans from the performance index. Changes to the phase splits are first examined by the split optimizer to determine the status of red and green splits on whether to extend, shorten or to remain the same. The operation of the split optimizer is on increments of one to four seconds. The signal timing plans are changed following the fluctuation of traffic flow in given periods. It maintains constant coordination by following traffic flow trends over time.

Traffic data becomes outdated as soon as it is collected for analysis. Scoot kernel assists in controlling the traffic data with less complicated signal plans. The generation of signal plans using this method is not efficient, and it is equally time-consuming. Optimization of road users' experience enhances the smoother flow of vehicles through a network by coordination of traffic signals. Scoot eliminates the dependency of costly and sophisticated signal plans through the intelligent response of traffic flow.

The data from traffic sensors enhances scoot response to traffic signals by adapting to the traffic situation on the road network. Road crossings have "regions," which gathers sensor data that is used to guide timing decisions in each region. The yield in improvement in traffic performance is high by 15% when using scoot than the usually fixed time interval of traffic signals (Popoola & Adeniji, 2013).

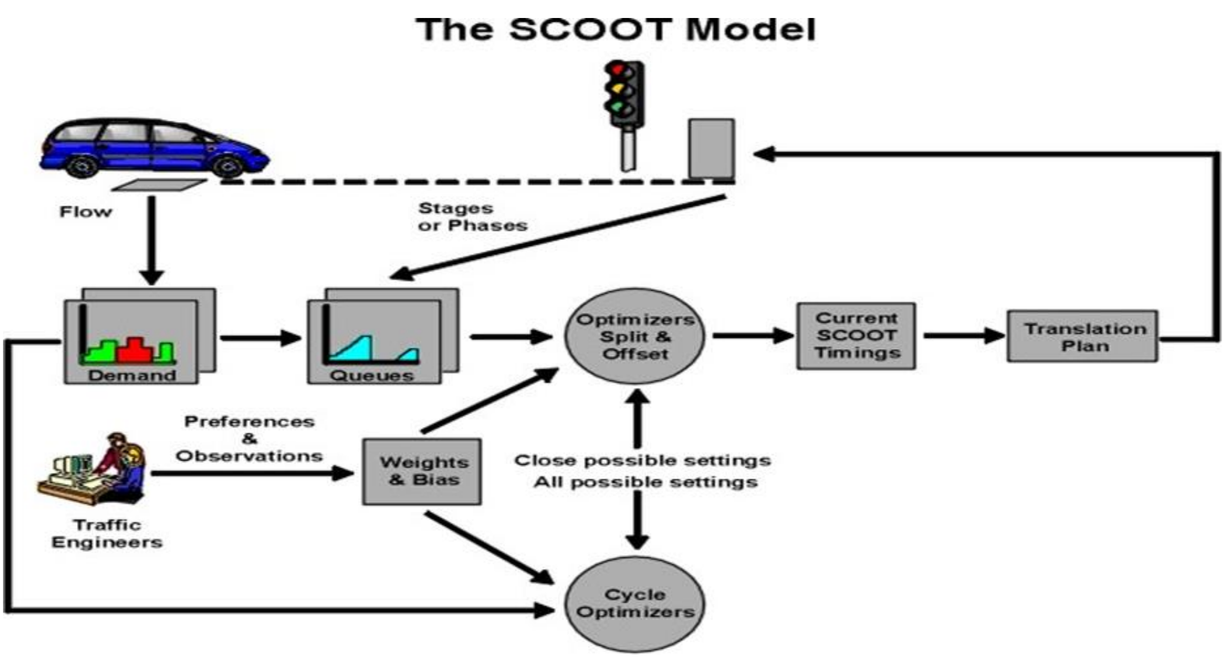

Figure 2: The scoot model

The minimum and maximum phase durations constrain the splits in scoot. To ensure that splits are not limited the phase duration is set to high. Scoot supports road mounted sensors and not sensors on vehicles. Scoot can skip a phase if there is no traffic demand which makes it demand-dependent. In such a scenario, the green splits are controlled by the local controller. The scoot central computer receives feedback from the local controller of change in phase from the one envisaged in the sequence. The demand-dependent phase allows scoot to be flexible and run in a semi-actuated operation.

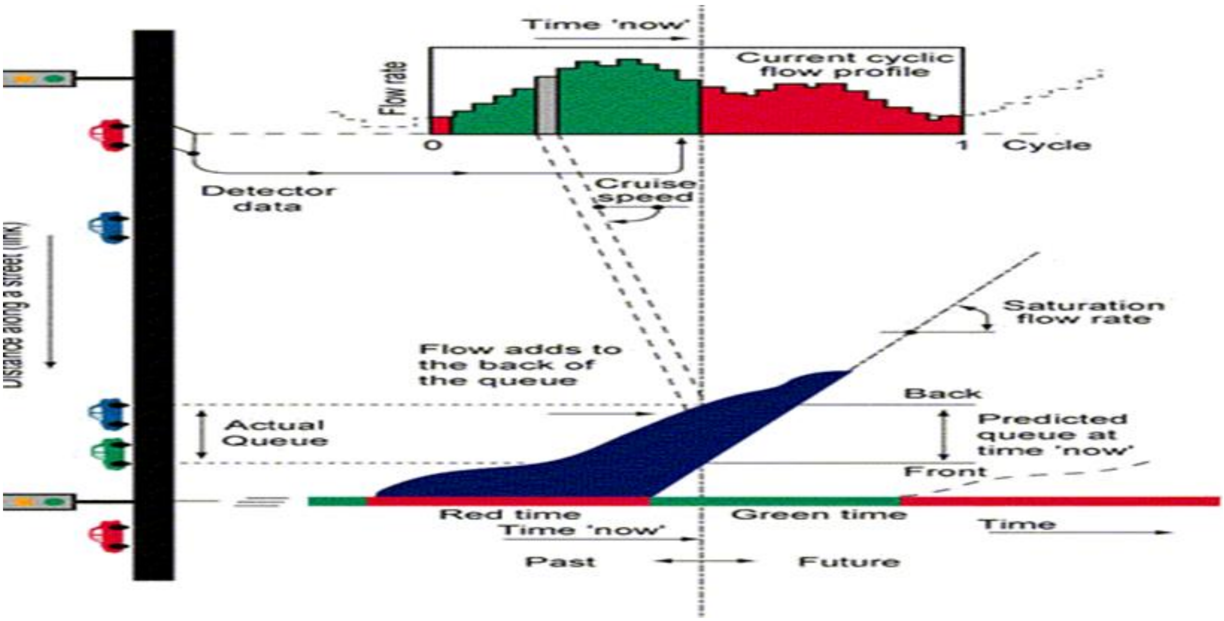

Figure 3: Operational diagram of scoot model

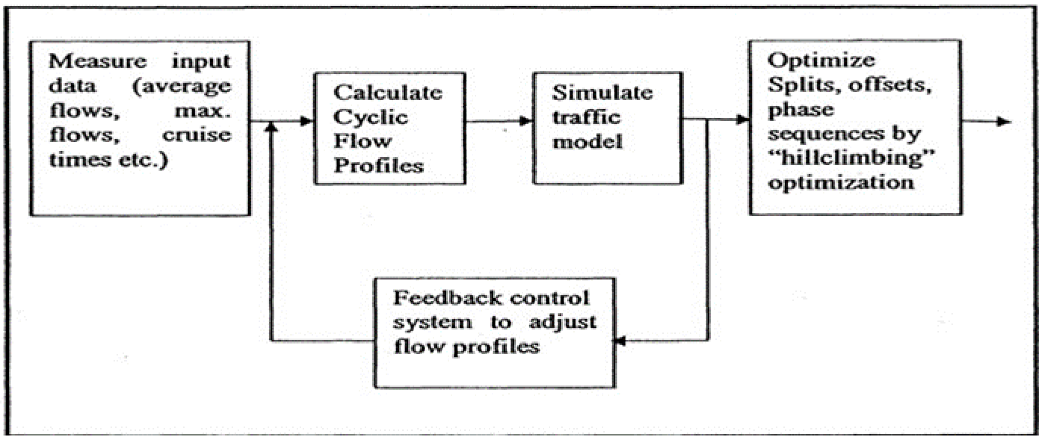

Figure 4: Conceptual Framework representing scoot in a feedback Environment

2.5 Knowledge gap

The traffic police generally control the exiting traffic system. The main drawback of this system controlled by the traffic police is that the system is not smart enough to deal with traffic congestion. The traffic police official can either block a road for more time or let the vehicles on another road pass. The decision making may not be smart enough, and it entirely depends on the official's decision. Moreover, even if traffic lights are used, the time interval for which the vehicles will be shown green or red signal is fixed. Therefore, it may not be able to address the issue of traffic congestion. The scoot model was used and tested using traffic data collected from KENHA and validated using simulation software. This justified policymakers and engineers on ways for its implementation in Nairobi city.

CHAPTER 3: RESEARCH METHODOLOGY

This chapter covers research philosophy, research design, data collection, and analysis methods.

3.1 Research Philosophy

The pragmatic philosophy was used since it presented different technological ideologies for future transportation.

3.2 Research Design

The descriptive research design was used in the study to gather information on the status of the phenomena to describe "what exists" about variables or state of affairs in the current situation and their future implication. It sought to identify characteristics, frequencies, and trends relating to traffic flow in Nairobi. It is justified that the study adopted a descriptive research design to give a better understanding of traffic congestion and identify how smart traffic control using IoT can enhance traffic flow and address traffic congestion.

3.3 Population and sampling

A population is an entire group of individuals, events, or important things that a researcher generalizes to explore findings. Simple random probability sampling was used where participants were considered at random to avoid bias ness. This type of sampling was applied to select the most suitable respondents. The sample size was large to reduce the sampling error but remained manageable. Stratified sampling was implemented on the population. The sample size was equally shared between the stratum. The strata are shown in the table below, where Simple random sampling was employed.

Table 2: Strata Table with the sample population

Stratum	**Sample Population**	**Description and role**	**Sample size**	**Data collected**
Road Users	Vehicle owners	The data was collected from different streets within Nairobi City before the Covid-19 pandemic in Kenya. The roads include: - Mombasa road, Uhuru Highway, University Way, Waiyaki way, Haile Selassie avenue, Kenyatta Avenue, Moi Avenue	80	-Causes of traffic congestion -Effect of traffic congestion

Stratum	Sample Population	Description and role		Data collected
KENHA	Policy documents and records	Provide an archive of data that is collected over a given period for easier access by the public		-Number of traffic per hour -The queue length of traffic

3.4 Data Collection

The data was collected in two phases. Phase 1, a quantitative approach, was used to determine the traffic flow per hour during peak and off-peak hours. Data was collected from policy documents and records which are available in KENHA. The collected data was used to establish the number of vehicles that will reach downstream signals and queue length of cars at different intersections. Phase 2, a qualitative approach, was used to determine the causes of traffic congestion in Kenyan roads. Questionnaires were issued with a rank of 1 to 4 of the causes of traffic congestion, which include: - road intersections, stalled Vehicles, traffic police control, and closed intersection.

3.5 Data Analysis

Quantitative data analysis was done using descriptive statistics. It assisted in depicting the data distribution, including mean, median, and mode representing measures of central tendency, range, variance, and standard deviation representing measures of dispersion. The simple regression model was used to measures the association between traffic congestion and time. Statistical Package for Social Sciences (SPSS) was used. Justification for using regression model was that it enabled us to understand the density of traffic from the relationship between the number of traffic and time factor as shown below:

$$Y = \alpha + \beta X + \mu i$$

Where: Y= Score of the density of traffic; X= Time factor; β = Beta coefficient of the number of traffic; α= Regression constant; μί – an Expected error that is assumed to be associated with the variables.

The coefficient of determination (R-Square) obtained gives the explanatory power of the model. In contrast, the correlation coefficient (Beta factor) gives the nature and extent of the relationship with the dependent variable and independent variable. Test for statistical significance was done using p-values and interpreted at a 0.05 level of significance.

CHAPTER FOUR: DATA ANALYSIS, RESULTS AND DISCUSSION

This chapter presents the data analysis, interpretation, study findings relative to the study objectives.

4.1 Response Rate

The study targeted a total of 100 Respondents in 7 major streets in Nairobi City who constituted Private car drivers. Most of the respondents, 85% were private car drivers and 15% PSV vehicles. The study was conducted during peak hours, which was between 8:00 am – 10 Am and 4:00 Pm – 6:00 pm. The rationale for the peak hours was to collect enough data and take advantage of the concentration of respondents in a small geographical area. Out of the 100 respondents, 80 respondents could be reached and completed the questionnaires while the rest were not willing to fill the questionnaires, hence the response rate of the study was 84.21%. Mugenda and Mugenda (2009) indicate that a response percentage of more than 70% is considered good enough for examination and reporting.

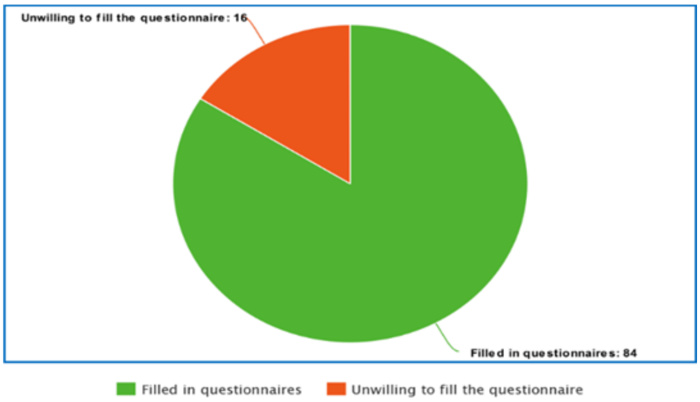

Figure 5: Response Rate

4.2 Demographic Information of the Respondents

This involved a close examination of individual demographic data of each respondent. It facilitated the comprehension of respondent's setting and their ability to provide objective data. The results are illustrated to the research questions and demographic data. The general information sought from the respondents included gender, where the respondents live, whether they use one direct route or they change the route, preferred mode of transport.

4.2.1 Gender of respondents

The study sought to determine the gender distribution of the respondents. The findings were presented in the figure below.

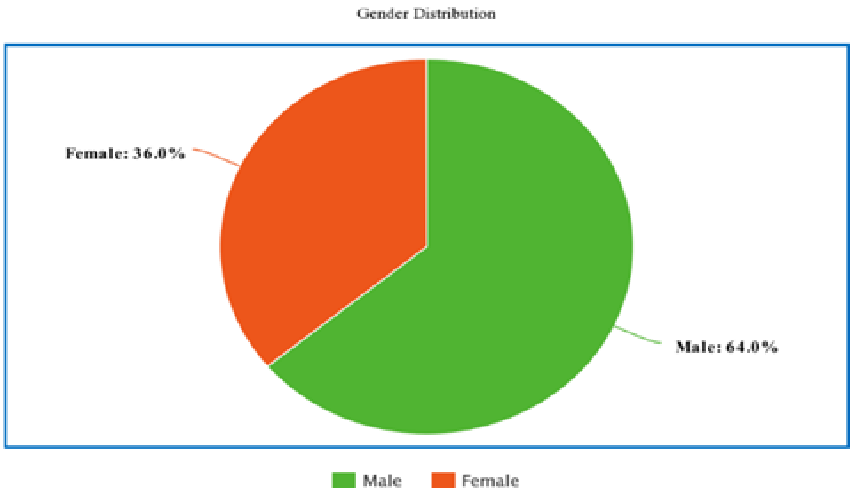

Figure 6: Gender of Respondents

From the findings presented in figure 4.2 above, most of the respondents 64.0% were males, while 36.0 % of the respondents were females. There was gender disparity among the respondents, where males were willing to participate in the study more than the females.

4.2.2 Location Where Respondents Live

The study sought to determine where the respondents live to estimate the distance between the participants' house/work/business/school to Nairobi City. The primary purpose was to evaluate the time respondents depart from home to arrive in town.

Table 3: Distance between House/Work/Business to Nairobi City

Distance between house and Nairobi City	Frequency	Percentage
1-5 km	8	9.5
6-10 km	24	28.5
11-15 km	31	36.9
16-20 km	12	14.2
21-25 km	5	5.9
26-30 km	4	4.7

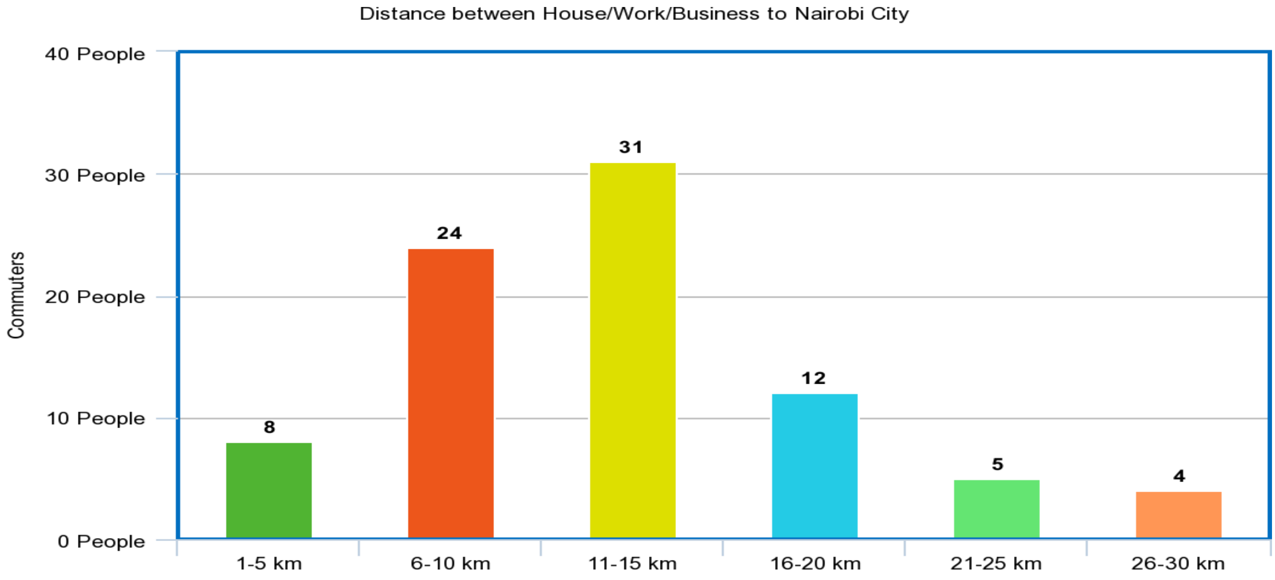

Figure 7: Distance distribution graph

4.2.3 One Direct Route/ Alternative Routes

The study sought to determine whether the private vehicle used one direct route or whether they have an alternative route that they use when traffic is congested. The study findings are presented in the figure below.

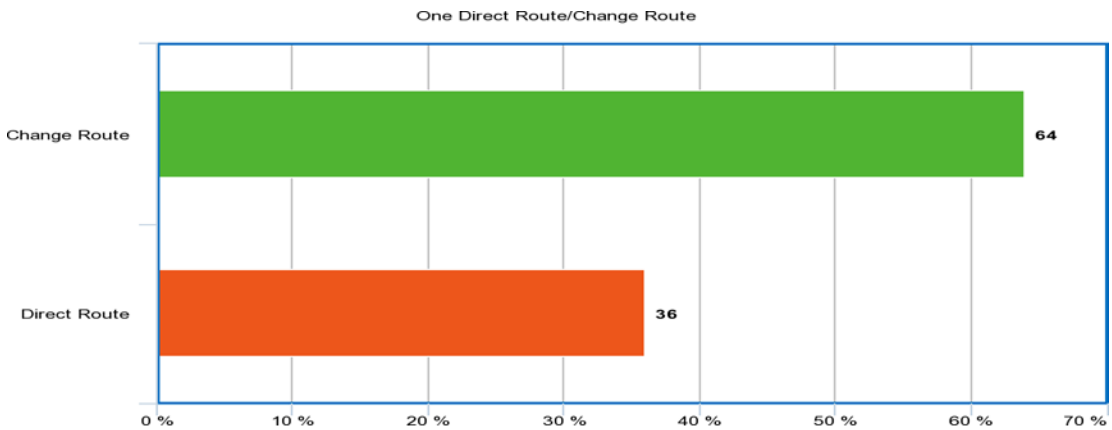

Figure 8: One Direct Route/ Alternative Routes

From the findings in the figure above, most of the respondents, 64% indicated that they change routes, especially when traffic jam is unbearable. However, 36% of the respondents reported that they use one direct route to and from the house. The change of routes depended on the knowledge of the routes that lead in and out of Nairobi city and whether the alternative route has a history of immense traffic jams.

4.2.4 Means of Transport

The study sought to determine the means of transport that the respondents use to their place of work/business/school. The findings were tabulated in the figure below.

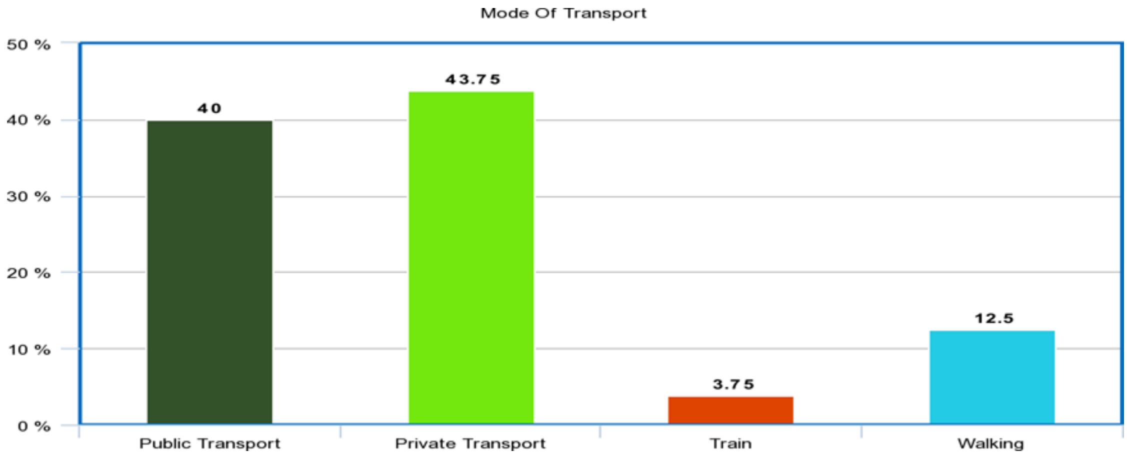

Figure 9: Mode of transport

From the findings in the figure above, most of the respondents, 43.75% indicated that their means of transport to work/business/school is via private car. 40% reported that their means of transportation to work/business/school is via public transport. 12.5% of the respondents indicated that they walk; 3.75% of the respondents indicated that they use the train.

4.3 Causes of traffic congestion in Nairobi

To determine the significant causes of traffic jams in Nairobi, both the private car owners and Psv vehicles were asked to rank the causes of a traffic jam from 1 (most) to 4(least).

From table 4, both private car drivers and Psv vehicles considered road intersections on the road about as the primary cause of traffic jams in Nairobi. Stalled and unattended cars were ranked the second causers. Intersection controlled by traffic police were ranked the third causers of traffic jams while road closed due to construction leading to an intersection were ranked fourth. This can be explained by the fact that motor cars have increased at a faster rate of 7%. This finding had the assertions that private car ownership and the absence of a reliable public transport system are the significant causes of traffic congestion in Nairobi.

Table 4: Causes of Traffic Congestion

Causers Of Traffic	Causes of Traffic congestion in Major streets			
	1	2	3	4
Road intersections	10	13	15	38
Stalled Vehicles	8	30	9	17
Traffic Police control	14	13	15	21
Closed Intersection	13	6	27	23

Causers Of Traffic	Descriptive statistics			
	Minimum	Maximum	Mean	Std Deviation
Road intersections	10	38	19	11.11
Stalled Vehicles	8	30	16	8.80
Traffic Police control	13	21	15.75	3.11
Closed Intersection	6	27	17.25	8.25
Average mean and Std Dev			17	2.92

Data findings

The respondents generally agreed to mean of 17 on various causes of traffic congestion in Nairobi city. Traffic police control had the lowest standard deviation depicting uncertainties on whether it was a real cause of traffic congestion. Road intersections had the highest standard deviation describing that commuters were almost sure that road intersection is the most top contributor to traffic congestion. The highest causer was road intersections with a maximum of 38 while the lowest causer rank was stalled vehicles with a minimum of 8. The average standard deviation depicted that the response rate for the causer was concentrated in certain causers among the given four. One of the objectives of the study was to identify the significant causes of traffic congestion in Nairobi city.

4.4 Major streets traffic characteristics

The data was collected from KENHA on their policy documents and records. The data showed records from 7 key road links controlled by traffic lights in the metropolis with their respective levels of congestion records. The data was for a period of 6 months from July 2019 to December 2019. The data was collected hourly Monday to Friday, 7:00 Am to 7:00 Pm. The traffic volume of the 7-road links understudy for the various months showed some consistency; hence a single month of December was used as the sample.

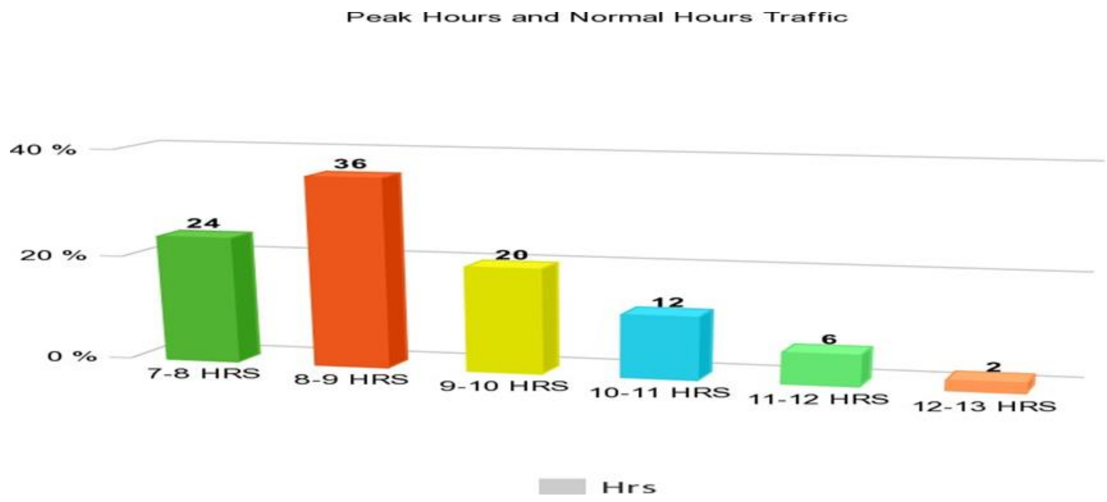

Figure 10: Time Spent in Traffic Jam

Data Finding

36% of the total sampled vehicles during peak hours showed that vehicle owners spent a lot of time due to traffic jams from 8-9. This is displayed with the highest percentage of the sampled vehicle per hour. 2% of the sampled cars during off-peak period 12-13hrs showed the least number of cars illustrating that either car was waiting at an empty intersection or there was a stalled vehicle. The number of sampled vehicles reduce drastically from 9 Am to 1 Pm, illustrating that the time variable influences the traffic congestion. The data from both peak and off-peak periods demonstrate that a lot of time is wasted at both periods based on the number of traffic. This illustrates the problem of vehicles waiting at an empty intersection controlled by traffic lights during off-peak periods or buildup of queue length as a result of the indefinite allocation of timestamp at the intersection by the traffic police.

One of the objectives of the study was to develop a model of smart traffic control using IoT in Nairobi City. The use of IoT devices enhances traffic flow and avert the problem of vehicles waiting at an empty intersection leading to a buildup of traffic. A smart city traffic control using IoT will be the solution to this problem.

4.5 Vehicle Simulation

The simulation of vehicles at a junction was done with an interest in calculating the average junction wait time. Each junction was assigned a different number of cars per minute. The simulation results are illustrated in figure 4.7. The number of vehicles that passed through the four junctions per minute was 188, and the average wait time of the vehicles was 56.17 seconds. This results is an indication of reduced wait times and increased traffic flow at the intersections. This will lead to a reduction in traffic congestion as a result of the minimum average wait time at a road intersection. The benefits of adaptive traffic lights are beneficial as it would reduce the total time taken from home to place of work.

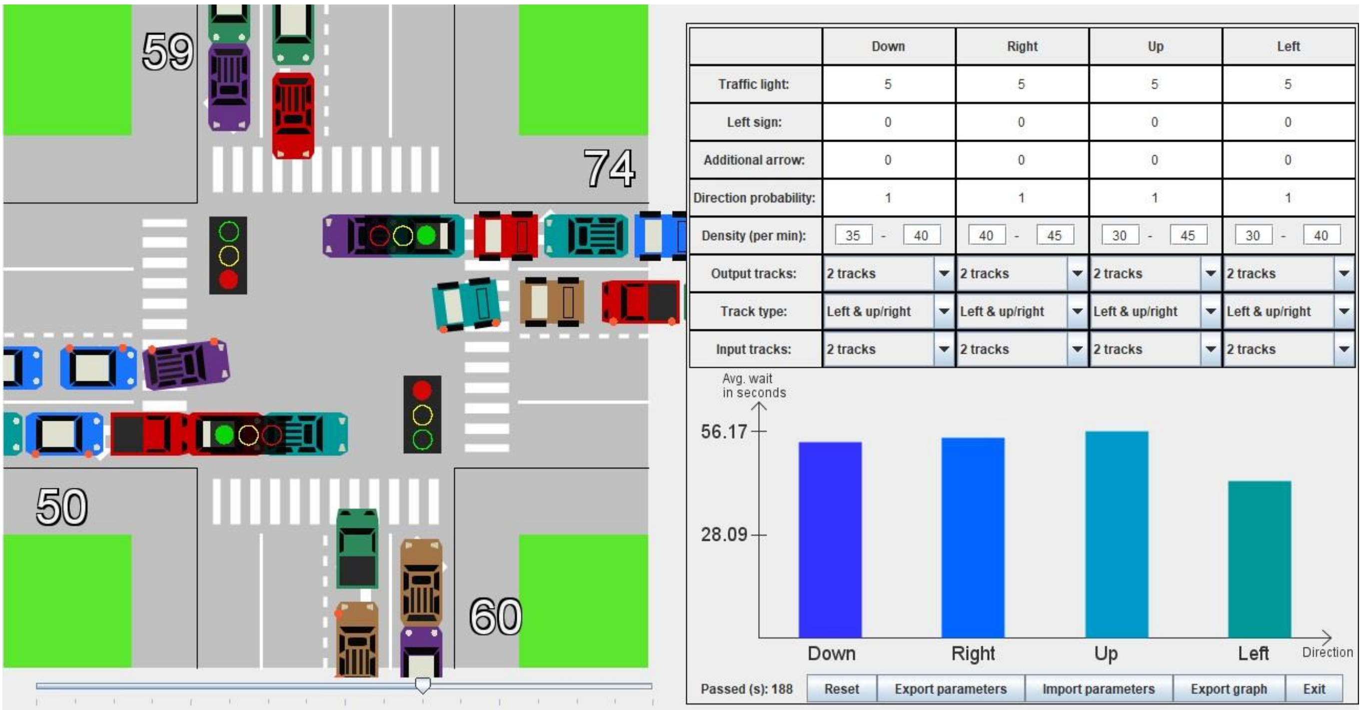

Figure 11: Wait time at a road intersection controlled by smart traffic lights

4.6 Regression Analysis

The study sought to determine the number of traffic in the city with the time factor. Regression analysis was done using Statistical Package for Social Sciences. Adjusted R-squared was used to determine the extent to which the number of traffic was related to the time. The beta factor was used to determine the degree and nature of the correlation between the number of traffic and time. The significance of the beta factors was checked at a 5% level of significance, with p-values less than or equal to 0.05 interpreted for statistical significance; otherwise, it would be statistically insignificant. The results were as shown in the Tables below.

Table 5: Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.889	.790	.736	.22462

The coefficient of determination is the adjusted R square, which illustrates the variation in change of the dependent variable (Traffic) due to the independent variable (Time). Table 5 demonstrates the value of adjusted R square as 0.736, an illustration of the variation of 73.6% in time as a result of changes in traffic numbers at 95% confidence interval. The 73.6% of changes in time is an attribute to the change in traffic number at a given period. Illustration from table 5 reveals a positive correlation between the study variables, as demonstrated by 0.889.

Table 6: Model Coefficient

Model		Unstandardized Coefficients		Standardized Coefficients	T	Sig.
		B	Std. Error	Beta		
1	Constant	1.508	1.131		1.333	.006
	Time	.481	.228	0.203	2.110	.005

As shown in table 6 beta coefficient was significant ($\beta = 0.481$, $t = 2.110$, $P < 0.05$). This implies that for every unit change in time, there was a 48.1% increase in traffic during peak hours.

From the data in the above table, the established regression equation was:

Y = 1.508 + 0.481X

From the above regression equation, it was revealed that if there were no changes in time, the number of traffic would be at 1.508. However, a unit change in the time would lead to an increase in the number of traffic by a factor of 0.481. At a 5% level of significance in time was found to influence the number of traffic significantly.

CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS

This chapter presents a summary of research findings, conclusion, limitations and recommendations for further work.

5.1 Summary of Research Findings

Objective No 1: To identify the major causes of traffic congestion in Nairobi City.

The research established that the leading causes of traffic congestion are intersection controlled by traffic lights. The traditional traffic control system has a fixed timing, which allocates equal time slots for every junction. This system is not efficient for the stochastic non-uniform flow of vehicles, which creates a necessity for a smart traffic management system.

Objective No 2: To develop a smart traffic control model using IoT.

In this research study, a smart traffic control model was developed using a scoot model to illustrate the adaptive nature of traffic lights. The signal timing plans are changed per the fluctuation of traffic flow in given periods. It follows traffic flow trends over time, which enables them to maintain constant coordination. Changes to the phase splits are first examined by the split optimizer to determine the status of red and green splits on whether to extend, shorten, or to remain constant.

Objective No 3: To validate the smart traffic control model

The developed model was validated using PTV Vissim simulation software. The simulation software allowed different input parameters from the collected data, such as the density of vehicles per minute, which was computed to illustrate the average waiting time in seconds. This justified the regression analysis conducted, which showed that changes in the time factor contributed to changes in the number of traffic during peak periods. The graphical analysis developed from the simulation software illustrated an even bar graph as a result of the allocation of vehicle wait time based on traffic density.

5.2 Conclusion

In this research, a smart traffic control model using the Internet of Things was presented. The primary aim of the model was to reduce traffic congestion at a traffic light controlled road intersection. The model relays traffic information to the traffic lights and make them adaptive to reduce vehicles waiting at an empty intersection. The two main variables were the number of cars and the vehicle time, which were classified as either peak or off-peak period. The relationship between time and traffic was established from the findings of the study.

The findings of the study from the parameters obtained were analyzed and validated using simulation software. The simulation software allowed entry of a different number of vehicles at each junction. The results of the simulation showed an uneven average waiting time of the car, which was based on the number of cars presented in the input parameters. This justified that a change in time during peak hours causes a change in the traffic density.

The data findings from the research are useful to the Kenya roads board, which is mandated for infrastructural improvements such as road and rail networks. The Kenya roads board policymakers should adopt the model to a fully functional system to allow easy transport of labour, goods, and services with minimum traffic congestion. This will enhance the economic potential of Nairobi by opening it up for trade and investments when the model will be actualized to a fully functional system.

5.3 Limitations

This study focused on the problem of traffic congestion as a result of road intersection controlled by traffic lights and not traffic congestion on highways with no traffic lights. The research deliverable was a traffic model that required real-life simulation and approval by the Kenya roads board policymakers to actualize the model to fully functional adaptive traffic lights system.

5.4 Recommendations for Further Work

The research is a work presented to limit traffic congestion at a road intersection. However, the model should be explored to develop a fully-fledged smart traffic management system. The developed model was validated through simulation, which illustrated the adaptive nature of traffic lights, which is affected by the number of traffic in a given road intersection. Implementation of the system will require the involvement of the Kenya roads board to take up the model, validate, and implement a smart traffic management system. A strategic plan should be formulated in the implementation process for the smart traffic management system.

The implementation process of the smart traffic system is less costly as it will use the existing road traffic signal infrastructure. The current traffic signals have a central control unit, which will require automation to assign a green time balance based on the traffic flow. The CCTV camera already mounted in the major highway will compliment IoT enabled devices that will be installed in strategic areas. The sensors will allow the collection of real-time traffic data in a given route, which will trigger the central control decision unit.

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APPENDICES

Appendix I: Road Users Questionnaire

UNIVERSITY OF NAIROBI

SCHOOL OF COMPUTING AND INFORMATICS

Master of Science Information Technology Management

Name of student: PETER CHEGE KARIUKI- REG NO: P54/12142/2018

Research Title: Towards the Implementation of Smart Traffic Control in Nairobi City using IoT

Declaration: This questionnaire has been designed for the sole purpose of collecting data of traffic congestion within Nairobi City. The data collected will be treated with a very high degree of confidentiality and it is meant for academic purposes only.

You are kindly asked to fill out this questionnaire by putting an "X" in front of the applicable answer or in the applicable cell or fill the blanks with the appropriate response for each item.

SECTION A: Background Information

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

1. Name of respondent (Optional)…………………………………………………………….

2. Gender of respondent

Male [ ] Female [ ]

3. Where do you live?

………………………………………………………………………………………

4. What is the distance between Nairobi City and your home?

1-5 kms [ ] 6- 10 kms [ ] 11-15kms [ ] 16-20 kms [ ]

21-25 kms [ ] 26-30 kms [ ] Over 30kms [ ]

5. How often do you frequent Nairobi City?

Daily [ ] Weekly [ ] Fortnight [ ] Monthly [ ] Other (Specify)

6. What mode of transport do you use to your place of work/business /school?

Public Transport [ ] Private Transport [ ] Train [ ] Walking [ ] Other [ ] (specify)…………

7. What time do you leave your house for your place of work/school or business place?

A. 5.00 am B. 5.30am C. 6.00 am. D. 6.30am E. Other (specify)…………

8. What time do you arrive at your place of work/school or business place?

A. 6.00 am B. 7.00 am C. 8.00 am D. 9.00 am E. Past 9.00 am

9. Is the means of transport shared with others?

A. YES   B. NO

SECTION B: Routing

1. Do you use one direct route, or do you have to change routes?

A. Direct Route   B. Change Route

2. If you change routes, how time does it take you when changing routes?

10 mins [ ]   20 mins [ ] 30 mins [ ] More [ ]

3. Do you experience any delay in the transport system during your travelling?

A. YES   B. NO

4. Which is the most efficient when travelling in a congested road?

A. Direct Route   B. Change Route

SECTION C: Causers Of Traffic Congestion

Below is a list of major possible causes of traffic congestion in Nairobi City. Kindly indicate your level of agreement with the statements posed using the scale:

Table 6:1 Traffic congestion in Nairobi City

1= Disagree; 2= Neutral; 3 = Agree; 4= Strongly Agree

	1	2	3	4
Road intersections				
Stalled Vehicles				
Traffic Police control				
Closed Intersection				

2. Would you recommend Smart Traffic control system in Kenya?

a. Yes [ ]

b. No [ ]

3. If yes how will it affect your daily commuting schedule?

……………………………………………………………………………………

THANK YOU FOR YOUR PARTICIPATION!!

Appendix II: Research approval letter

UNIVERSITY OF NAIROBI
COLLEGE OF BIOLOGICAL & PHYSICAL SCIENCES
SCHOOL OF COMPUTING AND INFORMATICS

Telephone: 4446543 or 4442014/15/16 Ext. 2007
Telegrams: "Varsity" Nairobi
Email: moturi@uonbi.ac.ke

P. O. Box 30197
Nairobi, Kenya

Date: March 5, 2020

TO WHOM IT CONCERN

PETER CHEGE KARIUKI - P54/12142/2018

The above named is a student in the MSc in Information Technology Management of the University of Nairobi. As part of the requirements of the programme, the student is required to undertake a research project and write a report. The project title for the student is: **Towards Implementation of Smart Traffic Control Using IOT in Nairobi City.** Among the data to be collected for this project is traffic density at major intersections controlled by traffic lights within Nairobi City.

Your institution has been identified as a source of data required for this project. I am therefore requesting that you assist the student, who is under my supervision, to obtain the required information. Your assistance will be highly appreciated

CHRISTOPHER A. MOTURI

SCHOOL OF COMPUTING AND INFORMATICS

Appendix III: Work Plan

The following is a schedule of milestone:

Task	Nov 2019	Dec 2019	Jan 2020	Feb 2020	Mar 2020	April 2020	May 2020	June 2020	July
Proposal Preparation									
M1 Proposal Presentation									
Data collection & Analysis									
M2 Data collection presentation									
Testing and conclusion of final Thesis									
M3 Final Report									