# DEVELOPMENT OF CLOUD-BASED VEHICULAR AD-HOC NETWORK AND TRAFFIC CONTROL STRATEGY IN REDUCING TRAFFIC CONGESTION

BY

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JANUARY, 2017

# DEVELOPMENT OF CLOUD-BASED VEHICULAR AD-HOC NETWORK AND TRAFFIC CONTROL STRATEGIES IN REDUCING TRAFFIC CONGESTION

BY

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A THESIS SUBMITTED TO THE SCHOOL OF POSTGRADUATE STUDIES, AHMADU BELLO UNIVERSITY, ZARIA IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF DOCTOR OF PHILOSOPHY (Ph.D) DEGREE IN COMPUTER SCIENCE

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JANUARY, 2017

# DECLARATION

I declare that the work in this thesis entitled "**Development of Cloud-Based Vehicular Ad-Hoc Network and Traffic Control Strategies in Reducing Traffic Congestion**" has been carried out by me in the Department of Computer Science. The information derived from the literature has been duly acknowledged in the text and a list of references provided. No part of this thesis was previously presented for another degree or diploma at this or any other institution.

Hakeem Adewale SULAIMON
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Name of Student Signature Date

# CERTIFICATION

This thesis entitled "**Development of Cloud-Based Vehicular Ad-Hoc Network And Traffic Control Strategies in Reducing Traffic Congestion"** by Hakeem Adewale SULAIMON (Ph.D./Scien?03396/2010-2011) meets the regulations governing the award of the degree of Doctor of Philosophy of the Ahmadu Bello University, Zaria and is approved for its contribution to knowledge and literary presentation.

Professor A. A. Obiniyi Signature ______________Date___________
Chairman, Supervisory Committee

Prof. O. S. Adewale Signature ______________Date___________
Member, Supervisory Committee

Prof. S. B. Junaidu Signature ______________ Date___________
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# DEDICATION

This thesis is dedicated to Almighty Allah (SWT) and Prophet Muhammed (SAW).

## ACKNOWLEDGEMENT

My profound gratitude goes to Almighty Allah for His infinite mercy I have enjoyed in the course of this study and in other issues that relates to my welfare. I wish to express my sincere appreciation and special thanks to my supervisors Prof. A. A. Obiniyi, who sacrificed a lot of his time, patience and commitment towards the actualization and completion of this work, despite his tight schedules. I equally thank my other supervisors Prof. O.S. Adewale's contribution to this research and Prof. S.B. Junaidu's tremendous assistance in this research work.

I wish to appreciate the Head, Computer Science department, Prof. Sahalu B. Junaidu, Seminar and Postgraduate Coordinator, Dr. Barroon I. Ahmed and other lecturers such as Dr. A.F. Donfack Kana, Prof. Ajibade, Dr. B.K. Ayeni, Dr. Salisu Aliyu who have contributed by one way or the other to the success of this work. My appreciation also goes to the Provost and entire management team of Federal College of Education, Zaria, Dean of Sciences and entire staff members of Computer Science department for the support given me towards the successful completion of this research.

More so, I am grateful to my mother Alhaja Chief R. M. Sulaimon, my loving and caring wife Hajia Risikatu Sulaimon-Bello, My son Abdulbasit Abdulhakeem who always shown so much concern about the completion of this programme, Rahmat, Radiya, Abdulrahman, Abdulhameed, Abdulsalam and all my younger brothers and sisters for their concern and prayers. A special acknowledge goes to my Administrative Officers past and present, Barrister Kona Sani I. Muhammed and Sarki Muhammed who gave me full support especially when I am away to attend to the research in the campus. I will not forget to appreciate Dr. Ahmed Omodara, Dr. Adedayo Opadeyi, Dr. (Mrs) G. Egwu, Abubakar Abba, Anas Ibrahim, Yussuf Yakubu, Samson Udezi, Abubakar A. Abubakar, Abubabar Yunisa

Kwama and other staff of Federal College of Education, Zaria which I could not mention their names here.

Lastly, my gratitude goes to my colleagues and well-wishers who contributed in one way or the other towards the completion of this thesis just to mention but a few, Jerry Emmanuel, Aminu Abdullahi Muhammed, my Personal Assistant Idris Umar, Abdulkareem Bashir Suleiman, Fadele Ayotunde, Abudu Bimbo, Nubunga Ishaya, Najeem Owamoyo, Maryam class representative and other Master's students who actually contributed in improving the work in our seminar classes. Above all, I specially thank my colleagues that are running Doctorate degree programme in the department; Ogala Joseph Charles, Mrs. Oyenike Olanrewaju, Odonwodo Christian Uchenna and Oyelade Olaide Nathaniel.

# ABSTRACT

Road traffic congestion occurs when the volume of traffic is too close to the maximum capacity of a road network. Traffic congestion always has negative effects on lives and environment such as fuel consumption and air pollution. More so, travel time increases as a result of traffic congestion and the situation will continue to deteriorate unless better traffic control strategies are implemented. Researches revealed that information systems need traffic flow model to provide prediction, such as, travel time prediction, route choice and flow rate. Existing traffic flow models are inadequate in handling mixed traffic stream. This research develops a conceptual framework for traffic control strategy to deliver an improved traffic congestion reduction system is developed. It also looks at route guiding scheme that can make routing decisions easy for drivers and also looks at how much expansion of road capacity could reduce traffic congestion. The developed traffic control strategies are implemented with VISSIM traffic simulation tool, CloudSim cloud simulator and JAVA programming Language. Percentage of Improvement (PoI) is used to evaluate the simulation framework. Root Mean Square Error (RMSE) and Root Mean Square Normalized Error (RMSNE) are used to validate the simulation model. Route Information System is developed for drivers to make routing decision. Evaluation results revealed that the proposed road expansion capacity could reduce traffic congestion in an urban area by approximately 11 and 47% when expanded by one lane and two lanes respectively. Also, a free flow is achieved by approximately 54% and 34.5% when drivers are guided with route information over traffic in non-signalized traffic stream and traffic control with traffic signal respectively.

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## ABBREVIATIONS AND ACRONYMS

| | |
|---|---|
| AIMSUN | Advance Interactive Microscopic Simulator for Urban and Non-Urban Network |
| AODV | Ad-hoc on-Demand Distance Vector |
| API | Application Programming Interface |
| ATMS | Advanced Traffic Management Systems |
| ATIS | Advanced Traveler Information System |
| ATM | Active Traffic Management |
| AVL | Automatic Vehicle Location |
| AVI | Automatic Vehicle identification |
| AWS | Amazon Web Services |
| CC | Cloud Controller |
| CMU | Cracks Me Up |
| CORSIM | CORidor SIMulation |
| DDOS | Distributed Denial of Service |
| DOT | Department of Transportation |
| DSL | Dynamic Speed Limit |
| DSS | Decision Support System |
| DSRC | Dedicated Short Range Communication |
| FHWA | Federal Highway Administration |
| FRESIM | FREeway SIMulation |
| GPS | Global Positioning System |
| I2V | Infrastructure -to-vehicle |
| IaaS | Infrastructure as a Service |
| ILD | Inductive Loop Detector |
| ITSs | Intelligent Transportation Systems |
| IVC | Inter-Vehicle Communication |
| MANETs | Mobile Ad-hoc NET works |

| | |
|---|---|
| MAPE | Mean Absolute Percentage Error |
| MITSIM | Microscopic Traffic Simulator |
| MOVE | Mobility model generator for Vehicular network |
| MRS | Microwave Radar Sensors |
| NCTUns | National Chiao Tung University Network Simulation |
| NETSIM | NETwork SIMulation |
| NS-2 | Network Simulator-2 |
| OBU | On-Board Unit |
| OD | Origin to Destination |
| PARAMICS | PARAllel MICroscopic Simulation |
| PCS | Probabilistic Choice set |
| POI | Percentage of Improvement |
| PTV | Planung Transport Verkehr |
| RMSNE | Root Mean Square Normalized Error |
| RSUs | Road Side Units |
| SaaS | Software as a Service |
| SCs | Segment Controllers |
| SIMLAB | Simulation Laboratory |
| SUMO | Simulation of Urban Mobility |
| SSG | Signal State Generator |
| SSH | Secure Shell |
| SSL | Secure Sockets Layer |
| SSSP | Single Source Shortest Path |
| TraNS | Traffic and Network Simulation |
| TraCL | Traffic Control Interface |
| TMS | Traffic Management Simulator |
| TRARR | Traffic on Rural Roads |

| | |
|---|---|
| TWOPAS | Two Lane Passing |
| TCC | Traffic Control Center |
| TCCs | Traffic Control Centers |
| TCL | Tool Command Language |
| TCP | Transmission Control Protocol |
| TCSs | Traffic Control Strategies |
| UDP | User Datagram Protocol |
| V2V | Vehicle to Vehicle |
| V21/V2R | Vehicle-to-Infrastructure/Roadside |
| VANET | Vehicular Ad-hoc Network |
| VEINS | Vehicles in Network Simulation |
| VISSIM | VerkehrInStädten–SIMulations model |
| WLT | Wireless Location Technology |

# CHAPTER ONE

# INTRODUCTION

## 1.1 Background to the Study

A Vehicular Ad-Hoc Network (VANET) is an emerging technology that uses moving cars for communication in a network to create a mobile linkage. The main objective of VANET research is to develop a vehicular communication system that will result in fast, cost efficient and easy distribution of data for the benefit of the passengers' comfort and their safety (Karnadi *et al.*, 2007). VANET combines Vehicle-to-Vehicle (V2V) also known as Inter-Vehicle Communication (IVC) with Vehicle-to-Infrastructure/Roadside (V2I/V2R) and Infrastructure-to-Vehicle (I2V) communication as shown in Figure 1.1.

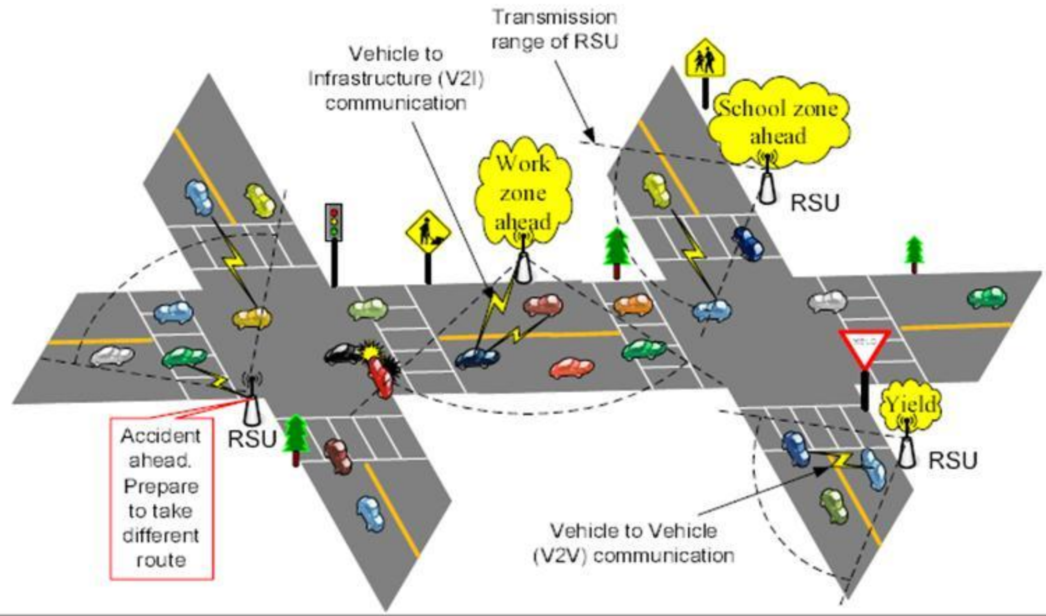



Figure 1.1: V2V, V2I/V2R and I2V Communications (Caballero-Gill, 2010)

Intelligent Vehicular Ad-hoc Networks (InVANETs) are kind of artificial intelligence that helps vehicles to behave in intelligent manners during vehicle-to-vehicle collisions or accident. Intelligent Transportation Systems (ITSs) is the communication technologies and management strategies in an integrated manner to provide traffic information to improve safety and efficiency of the road transportation systems (Obiniyi and Sulaimon, 2011; Mathew, 2014). The ITSs will allow vehicles to form vehicular networks allowing communication among them, other vehicles, and RSUs to improve driver safety, provide enhanced monitoring to Traffic Control Centers (TCCs), and reduce traffic congestion by delivering real-time traffic conditions to drivers. The RSUs are the infrastructure that can communicate with each other and with other networks (Deshmukh *et al.*, 2015). The On-Board Unit (OBU) in a vehicle will consist of a wireless transceiver that can communicate with nearby road-side units. VANETs' applications involve incident management, collision warning, vehicle tracking, improved driving and resource awareness (Schoch *et al.*, 2008).

VANET is also a technology that can be used to reduce congestion by enabling the traffic management to obtain traffic information that will reduce the intensity of congestion. Outright elimination of traffic congestion may not be a realistic goal, but traffic management that is based on available traffic information that will reduce the intensity of congestion may be achievable (Olusina and Samson, 2014). In this thesis, Segment Controllers (SCs) are introduced as the Road Side Units (RSUs) to communicate with equipped vehicles and Cloud Controller (CC). These SCs are programmed to collect traffic data from the equipped vehicle and transmit them to the Cloud Controller. In addition to reporting traffic measurements to a Traffic Control Center (TCC), the TCC analyzes the data and inform the vehicles about the latest traffic conditions and other useful information from the TCC.

Route choice guiding scheme for drivers' route alternations are also introduced as means of reducing traffic congestion. The research also captured the impact of road capacity expansion on traffic congestion in an urban area. RSUs with internet facilities are used to relate with cloud computing. Cloud computing is an emerging technology that can enable the storage and preservation of road information and used when needed. It is the use of computing resources (hardware and software) that are delivered as a service over a network (typically the Internet).

## 1.2 Problem Statement

The growth of urban automobile traffic has led to serious and worsening traffic congestion problems in most cities around the world. Since travel demand increases at a rate often greater than the addition of road capacity, the situation will continue to deteriorate unless better traffic management strategies are implemented. More so, travel time increases as a result of traffic congestion and waiting time at the roundabout also increases. According to World Bank estimation on the ratio of passenger car to 1000 people of Nigeria in four selected years; 2002, 2003, 2004 and 2007 are 14.0, 16.0, 17.0 and 30.8 respectively. The rate has been increasing as there is visible evidence that more vehicles are being imported to the country till today which are relatively cheap and affordable. The overall effect is the high volume of vehicular traffic on Nigerian road (Federal Road Safety Corps, 2010).

Efficient road management by the authorities concerned to reduce traffic congestion has become a challenge. Assigning routes to all routing requests in the way that the overall travel time and traffic volume on each road are minimized is also a problem. Drivers are expected to get a better awareness of their driving environment so that in case of an abnormal situation they will be able to take early action in order to avoid any possible damage or to follow a better route (Obiniyi and Sulaimon, 2013). Information systems need traffic flow model to provide prediction, such as, travel time prediction, route choice and flow rate. Traffic authorities need timely and quality traffic data to analyze, predict and improve traffic flow condition for a better traffic control strategies. More so, to implement this idea, there is a need for a more unified model, architecture and generic framework of a traffic control strategies using Cloud computing technology. The transport infrastructures and traffic management put in place in the city have not been able to ameliorate traffic congestion.

This inadequacy called for additional traffic management techniques to the existing traditional method which could be found in cloud computing. So far, the conventional approaches to traffic management have not been able to make the desired impact, judging from the traffic congestion patterns in Nigerian cities (Obiniyi and Sulaimon, 2014). With the capability of the existing modern cars, there is a need to explore the features such as on-board sensor, storage and Internet facilities using cloud computing to reduce the traffic congestion on our roads. With the emergence of new technologies (such as wireless network communication and cloud computing), it is possible to develop more sophisticated traffic control strategies that will result in an improved performance.

## 1.3 Research Motivation

During the last decades the road traffic has increased tremendously leading to congestion, safety issues and increased environmental impacts. Road congestion results in a huge waste of time and productivity for millions of people. According to Washington State Department of Transportation (2006), between 1980 and 2003, Washington's population grew by 45%, the number of workers grew by 55%, and the number of vehicles increased by 77%. Three major urban areas experienced 92% of the total hours of congestion delay in their Country. The US mobility report in 2011, states the present data is consistent with the past research. Vehicular congestion caused urban Americans to travel 5.5 billion hours more and to purchase an extra 2.9 billion gallons of fuel for a congestion cost of $121 billion (Schrank *et al.*, 2015).

In ancient Rome for example, Julius Caesar once prohibited the movement of cars during day light to relieve traffic congestion on roads (Bruton, 1975). As a result, many countries are continuously trying to find improvements and new solutions to solve these issues. One way of improving the traffic conditions is by the use of intelligent transport systems, where information and communication technologies are being used for traffic management and control. Attempts made by the Nigeria government to ensure that the congestions are managed through the various traffic management techniques have not yielded the desired results. Dealing with traffic congestion has been made a high priority and deemed necessary for further social and economic development of any nation (Arnott *et al.*, 1991; Onasanya and Akanmu, 2002).

If road traffic is not properly control, there may be traffic congestion which may lead to collision between the vehicles or accident and it may also increase the temperature of the vehicle engine which may lead to overheating. A possible way to deal with this problem is to have transportation authority to distribute traffic information to drivers, which in turn can decide (or be aided by a navigator) to route around congested areas (Leontiadis *et al.*, 2011). Numerous measures are taken to address problems arising from traffic flow, its transition and congestion. An essential step in this direction is the creation of a traffic monitoring system with capabilities to estimate traffic data with significant accuracy and reliability.

Historically, dedicated infrastructure has been used for monitoring traffic data, however, the corresponding sensors have limited coverage, high installation and maintenance costs, and their fixed position does not enable optimized and adaptive sampling as traffic conditions change. Therefore, there is a need for a mechanism which can augment these monitoring systems or even replace them. This could prove very helpful to traffic control researchers in the transport industries and road safety management authorities as they will have access to large amounts of archived and live traffic data which can be used in different forms. The emergence of Cloud computing technologies provide access to inexpensive use of mass quantities storage, bandwidth and computing resources as a service or using the pay-per-use model on which it thrives (Cloud computing, 2009). Hence, in this research, better traffic control strategies are developed to reduce the traffic congestion.

## 1.4 Aim and Objectives

The aim of this research is to develop cloud-based vehicular ad-hoc network and traffic control strategies to reduce traffic congestion on Nigerian roads, while the specific objectives are to:

a. Design a framework for traffic control strategies using road infrastructure and cloud computing technology
b. Develop vehicular behavioral models for vehicular movement on the road network
c. Incorporate route choice guiding scheme for drivers' route alternation
d. Evaluate the impact of road capacity expansion on the traffic congestion
e. Simulate and evaluate the developed simulation framework at different scenarios by varying traffic parameters.

## 1.5 Contributions of the thesis to Knowledge:

This research has been able to:

a. Establish an availability of periodic road quality and reliable information for traffic agency through Cloud computing technology to assist them in planning and decision making process.
b. Provide route alternation guiding scheme that can make routing decisions easy for drivers to reduce road traffic congestion.

c. Establish an innovative coordinated road infrastructure and cloud service usage to provide an improved traffic control strategies.
d. Demonstrate how much expansion of road capacity could reduce traffic congestion
e. Demonstrate the effect of homogenous and heterogeneous traffic stream on the reduction of road traffic congestion.

## 1.6 Organization of the rest of the thesis

The rest of the thesis is organized as follows;

Chapter two discusses the concept of traffic congestion and its causes. It also looks at the existing hardware and software solution to traffic control strategies. Common traffic and route choice models are also reviewed. Concept of Cloud computing technology and Cloud simulation toolkits are discussed. Traffic and network simulators are identified with a focus on their operations and how they can be used. Finally, statistical indicators for evaluation of traffic simulation model are also discussed.

In chapter three, the conceptual framework of the proposed Traffic Control Strategies (TCSs) are discussed by looking at its main components such as Segment Controller (SC) as road side unit, equipped vehicles, and Cloud Controller. The TCSs System Model is also developed and its components are discussed in details. The message transmission algorithm is designed for the framework and vehicular behavioral models are also developed.

In chapter four, the developed traffic control strategies are implemented with VISSIM traffic simulation tool and JAVA programming Language. Percentage of Improvement (PoI) is used to evaluate the model. Root Mean Squared Error (RMSE) and Root Mean Square Normalized Error (RMSNE) are used to validate the simulation model. Route Information System is developed for Drivers to make routing decision.

Chapter five contains the summary, conclusion and recommendation.

# CHAPTER TWO

# LITERATURE REVIEW

## 2.1 Introduction

In this chapter, the concept of traffic congestion, causes and its remedies are discussed. Some existing hardware and software solutions to traffic control strategies are reviewed. Common microscopic traffic simulation tools in the literature are reviewed in which some car following models used in developing these tools are discussed. Some common route choice models and routing algorithms are looked into. Finally, Cloud computing technology concept and cloud simulation model are also discussed.

## 2.2 Concept of Traffic Congestion

Traffic congestion is a condition on transport networks that occurs as use increases, and is characterized by slower speeds, longer trip times, and increased vehicular queuing. The most common example is the physical use of roads by vehicles. Road traffic congestion is a situation when the volume of traffic is too close to the maximum capacity of a road or network. To quantify these negative effects is complex and multi varied. Traffic congestion always has negative effects on lives and environment (Olusina and Samson, 2014). For congestion to be mitigated or eliminated, gathering of information on traffic incidents such as state of the road, congestion spots and volume of traffic on each road is essential. Traffic congestion appears when too many vehicles attempt to use a common transportation infrastructure with limited capacity (Papageorgio *et al*., 2003).

Traffic congestion results in excess delays, reduced safety, and increased environmental pollution. The problem is no longer limited to traditional cities such as Lagos, Ibadan, Benin-City, Port Harcourt, Kano, Zaria and Kaduna (Ogunsanya, 2002). Virtually every state capital city in Nigeria today faces the problem of traffic congestion (Moses, 2011). One of the major cities in Northern Nigeria is Zaria which was not previously associated with traffic congestion is now facing considerable traffic congestion on many of its roads, especially when the schools are in session or when the market people are coming back from their places of work as displayed in Figure 2.1;

Figure 2.1: A Typical Picture of Traffic Congestion in Tudun Wada, Zaria
(Captured at 6.12p.m on 16/10/2016)

### 2.2.1 Causes of Traffic Congestion

Jain *et al.* (2012) explained the following as causes of traffic congestion and poor traffic management:

a. Unplanned Cities: No provision is made towards scaling road capacities
b. Poor discipline: Drivers frequently jump red lights and block the intersection, causing further traffic congestion
c. No alternate traffic means: Increase in road capacity call for alternative means
d. Archaic management: Traffic junctions are often unmanned, thereby allowing drivers to drive in a chaotic manner
e. Tighter budget: Significant amount of investment is required to set up a traffic management infrastructure.

Popoola *et al*. (2013) carried out a study on causes and remedies of traffic congestion from the road user' perception and come out with the fact that inadequate road capacity is the most significant causes of traffic congestion on Lagos-Ibadan expressway. Structured questionnaires were employed in carrying out their survey. The causes and suggested remedies of traffic congestion in Popoola *et al.* (2013) as shown in the Table 2.1 tend to agree with earlier findings from a number of studies (Aderamo and Atomode, 2011; Aworemi *et al.*, 2009; Bashiru and Waziri, 2008) that the major causes of traffic congestion include: inadequate road capacity, poor road pavement, accidents on the road and poor traffic control management which addresses other causes of traffic congestion by one way or the other.

Table 2.1: Causes and Remedies of Traffic Congestion with their Ranking (Popoola e*t al.*, 2013)

| Causes and Remedies of Traffic Congestion | | | |
|---|---|---|---|
| Causes identified | | Suggested Remedies | |
| Ranking | Causes | Ranking | Remedies |
| 1 | Inadequate road capacity | 1 | Enlarging the width of the road |
| 2 | Poor road pavement | 2 | Construction of proper drainage |
| 3 | Accidents on the road | 3 | Provision of parking space |
| 4 | Poor traffic control management | 4 | Rehabilitate all roads needing attention |
| 5 | Poor drainage system | | |
| 6 | Poor driving habit | 5 | Public enlightenment /traffic education |
| 7 | Poor road network | | |
| 8 | Poor parking habit | 6 | Hack down all illegal buildings/shops built on the Right of Way (ROW) |
| 9 | Lack of overhead bridges/fly-over | 7 | Provision of road furniture |
| 10 | Religious/special event along the | 8 | Create a separate/ alternative root for |

| | | | |
|---|---|---|---|
| | road | | trucks and heavy vehicles |
| 11 | Poor design junctions/round-about | 9 | Provision of pedestrian facilities |
| | | 10 | In-depth training of transport/ traffic personnel |
| 12 | Presence of heavy trucks | | |
| 13 | Presence of heavy trucks Lack of pedestrian facilities | 11 | Introduction of ferry services |
| | | 12 | Construction of railway |
| 14 | Lack of road furniture | 13 | Create special commercial transport coordinator |
| 15 | Lack of parking facilities | | |
| 16 | On-going construction activities | 14 | Ban all form of road side trading/hawking |
| 17 | Malfunctioning vehicle | | |
| 18 | Excessive speeding | 15 | Reduce the number of bus-stop where necessary |
| 19 | Too many taxis/buses | | |
| 20 | Lack of effective mass transit | 16 | Launch more commercial vehicles |
| 21 | Work zone | 17 | Removal of motorcycles and tricycles on the road |
| 22 | Poor weather | | |
| 23 | Slow driving | 18 | Parking fees |
| 24 | Frequent use of sirens | | |

**2.3 Traffic Control Strategies**

2.3.1 Existing Hardware Solution to Traffic Control Strategies

*a. Video Detection System:* Video detection systems utilize cameras and image processing software to collect data on traffic flow. A camera is pointed at a roadway, and image processing software analyzes changes in pixels between successive frames. The processing software identifies when a vehicle has entered the frame, and then translates the movement of the vehicle on the video into traffic flow parameters (Klein, 2001; Klein *et al.*, 2006).

Advantages of Video detection system over other Loop Detectors are;

i. It is nonintrusive detector that can collect all the traffic flow parameters as inductive loops.

ii. A single controller and camera combination can be used to detect multiple lanes on an approach.

iii. Wide-area detection can be provided when information gathered from multiple camera locations are linked together.

iv. Video detection system is sometimes more cost effective solution for traffic signal detection over the lifecycle of the equipment.

The limitation of video detection systems are stated below:

i. Some periodic maintenance, such as cleaning camera lenses, requires shutting down lanes.

ii. Video detection systems have issues in inclement weather (such as heavy rainfall, fog, snow) which can create problems with the video processing software because they reduce the contrast in the image between vehicles and the background.

iii. High winds can affect the camera when it is within the field of view

iv. Reliable signal can actually be realistic during the night when there is street lighting.

v. Occlusion is a major potential problem with video detection systems (Figure 2.2) (Fontaine, 2009; Olariu and Weigle, 2009; Arbabi, 2011).

With this technology, when vehicle obstructs or blocks the view of part of another vehicle within the camera's field of view there can be undercounting of traffic volumes or poor speed estimation.

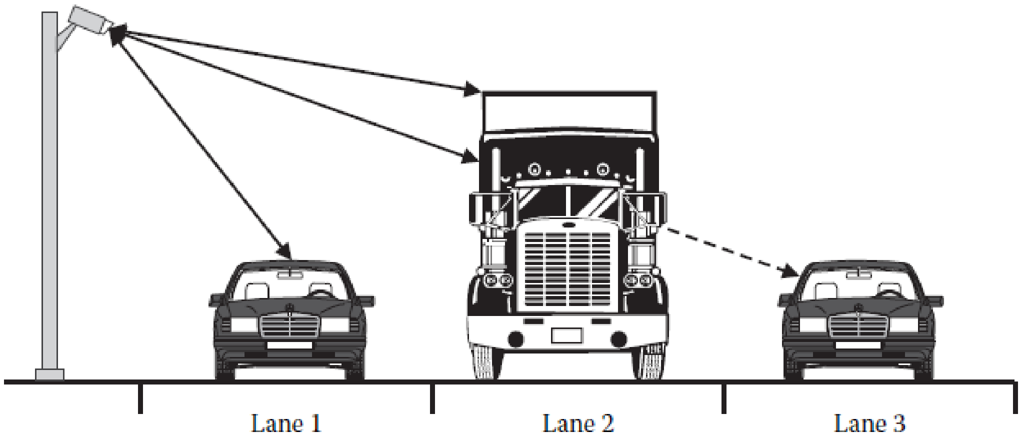



Figure 2.2: Occlusion and its impact on video detection (Fontaine, 2009)

*b.* *Inductive Loop Detectors:* An inductive loop is an electromagnetic communication or detection system which uses a moving magnet to induce an electrical current in a nearby wire. Induction loops are used for transmission and reception of communication signals, or for detection of metal objects in metal detectors or vehicle presence indicators. A common modern use for induction loops is to provide hearing assistance to hearing-aid users. Vehicle detection loops, called *inductive-loop traffic detectors*, can detect vehicles passing or arriving at a certain point, for instance approaching a traffic light or in motorway traffic. An insulated, electrically conducting loop is installed in the pavement.

The electronics unit transmits energy into the wire loops at frequencies between 10 KHz to 200 KHz depending on the model. The inductive-loop system behaves as a tuned electrical circuit in which the loop wire and lead-in cable are the inductive elements. When a vehicle passes over the loop or is stopped within the loop, the vehicle induces eddy currents in the wire loops, which decrease their inductance. The decreased inductance actuates the electronics unit output relay or solid-state optically isolated output, which sends a pulse to the traffic signal controller signifying the passage or presence of a vehicle. Parking structures for automobiles may use inductive loops to track traffic (occupancy) in and out or may be used by access gates or ticketing systems to detect vehicles while others use Parking guidance and information systems. There are also several advantages to using Inductive Loop Detectors (ILDs):

i. Flexible design to satisfy large variety of applications.
ii. Mature, well understood technology.
iii. Large experience base.
iv. Provides basic traffic parameters (e.g., volume, presence, occupancy, speed, headway, and gap).
v. Insensitive to inclement weather such as rain, fog, and snow.
vi. Provides best accuracy for count data as compared with other commonly used techniques.
vii. Common standard for obtaining accurate occupancy measurements.
viii. High frequency excitation models provide classification data.

*Disadvantages of* Inductive Loop Detectors (*ILDs) are as follows:*

i. ILDs require regular tuning to ensure that speeds and vehicle classification data are of high quality.
ii. Maintenance, installation, and replacement of ILDs can be problematic, particularly in congested urban areas.
iii. Multiple loops are usually required to monitor a location.
iv. Detection accuracy may decrease when design requires detection of a large variety of vehicle classes.
v. They are prone to failure, and large portions of an ILD network may not be returning quality data at any given time because of ILD failure rates and maintenance difficulties. For example, in 2005 the Virginia Department of Transportation Traffic Management Center in Hampton Roads estimated that about

40% of their ILDs were not returning quality data (Hanshaw, 2006). The difficulties in maintaining ILDs have called for the researches on alternative detection technologies.

*c. Microwave Radar Sensors:* Microwave Radar Sensors (MRSs) are devices for transmitting high frequency electromagnetic signals and receiving echoes from objects of interest within their volume of coverage. MRS has flexibility in where they can be placed. The sensors are typically mounted on existing structures that pass over the highway (such as sign structures or bridges) or on posts adjacent to the roadway as shown in Figure 2.3, therefore MRS are another alternative option to ILDs, and have the following advantages:

i. MRS is nonintrusive.
ii. They can directly measure speed.
iii. They can provide volume, occupancy and vehicle classification data.
iv. They can be mounted to collect data for a single lane or to collect data across multiple lanes.
v. They are typically insensitive to inclement weather at relatively short ranges.

MRS has disadvantages:

i. The accuracy of MRS is not as good as well-functioning ILDs.
ii. MRS suffers from many of the same occlusion problems as video detection.
iii. They cannot detect stopped vehicles and vehicles with low speed.

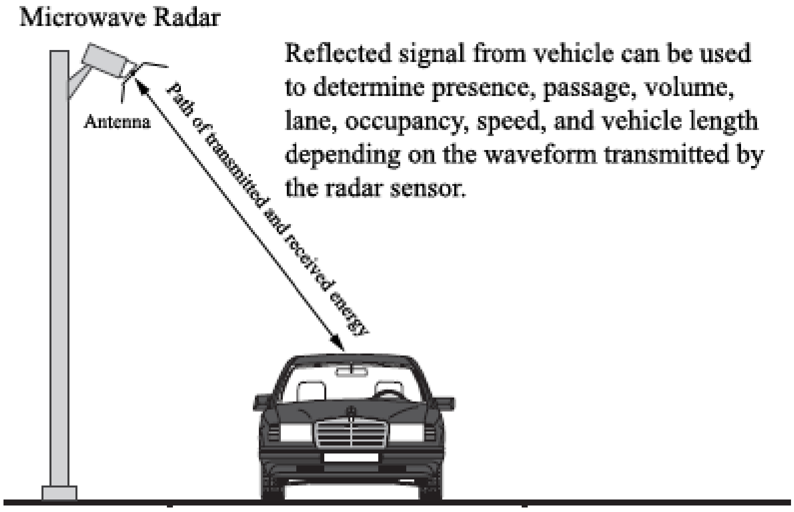



Figure 2.3: Microwave radar operation (Arbabi, 2011)

The most common application of microwave sensors is to supplement data collected from ILDs on major freeway facilities. Infrared, ultrasonic, and acoustic radars are fairly similar technologies that are used for detection of vehicles, but these technologies do not perform as accurately as MRS in various conditions and are not used as widely as ILDs, cameras, and MRS for monitoring traffic data.

*d. Automatic Vehicle Identification* (AVI)*:* These systems are probed vehicle-based systems that usually rely on tags which reflect encoded radio signals transmitted from roadside antennas or readers. The reflected signals are modified by the tag identification code so that the tag's information can be read by the system. This type of system has also been adapted to collect traffic monitoring data. In a monitoring application, roadside antennas are installed along major highways where the Departments of Transportation (DOT) wants to collect information on travel times or speeds. The unique tag identification numbers are logged each time a vehicle passes by an antenna. The travel time of the vehicle can then be explicitly calculated by examining when a vehicle passes known antenna locations on the highway.

This provides true point-to-point travel times for all vehicles with tags. An example for this method is the system of toll transponders and vehicles' smart tags.

There are several issues related to the deployment of AVI-based monitoring systems:

i. The ability of AVI-based systems to provide useful data is directly linked to the number of potential probes on the road. A sufficient number of probe vehicles must travel a route for the travel time and speed estimate to have statistical validity.

ii. These systems require the installation of significant roadside infrastructure in the form of AVI tag readers and communications in order to gather data.

*e. Automatic Vehicle Location:* Automatic Vehicle Location (AVL) refers to a suite of probe vehicle-based technologies that track the location of vehicles traveling through the roadway network. The more commonly-used method in AVL relies on Global Positioning System (GPS) data. GPS data is collected continuously by the vehicle and then periodically transmitted back to a central control facility over a radio backbone, cellular service, or satellite communications network. The location data generated by AVL systems could be mined to generate traffic data. Examples for such a system are transit companies which track location of buses on their routes (Dailey and Cathey, 2005). They are combined traffic information providers which fuse their data from several sources including AVL systems such as equipped trucks, buses and taxis.

The advantages of using this system are as follows:

i. Few pieces of fixed infrastructure are required.

ii. Vehicles could be monitored anywhere on the network.

iii. AVL technologies can provide estimates of speed and travel times on roads where no point sensors (that is, ILDs, MRS, cameras) are available.

This system has several limitations:

i. AVL has problem with the sample size limitations where only a small subset of the vehicle population is outfitted with AVL equipment.

ii. The data source is also not widely available since participant companies may not share their data with others due to concerns about losing competitive advantages in the market place.

iii. Usually the routes (*i.e.* AVL drivers' path) are predictable and the generated data using AVL are not enough for monitoring the entire region.

*f. Wireless Location Technology:* Wireless Location Technology (WLT) involves using wireless devices to track the vehicle (generally the mobile passenger) movements or to transfer information from the vehicles for monitoring purposes. WLT systems are mostly based on the presence of cellular phones in vehicles for monitoring traffic. An example of such system is anonymous tracking of cellular phones (Fontaine, 2009; Cellular Telephone and Internet Association, 2006). WLT based traffic monitoring has the potential to expand both the number of vehicles being monitored and the size of the road way network where data could be obtained.

The advantages of WLT using cellular phones are as follows:

i. A majority of car owners own cell phones.

ii. Any road with cellular service can theoretically be monitored without installing any infrastructure on the road.

iii. Aggregated data are not particular to the fixed points on the road and can provide information about several sampled locations on the road.

The major barriers to widespread use of WLT-based monitoring are as follows:

i. The spatial accuracy of the location estimates used by WLT systems is not as precise as GPS data. (*e.g.*, existing systems cannot distinguish between different phones in the same vehicle or even determine differences in travel speeds between adjacent lanes of traffic.)

ii. Producing precise estimates of speed and travel time is highly affected by the precision of location estimates.

iii. WLT has issues with the continuous consumption of bandwidth on the wireless link which can also cause congestion in the wireless network, information drops, or unwanted handoffs.

iv. Questions about who owns the data and what rights a Department of Transportation (DOT) has to distribute the data still remain since the data is generated by a third party vendor that sells the data as a service to a DOT.

v. Privacy of users in these systems is questionable.

### 2.3.2 Existing Software Solutions to Traffic Control Strategies

Yang (1997) developed a traffic simulation laboratory (SIMLAB) capable of evaluating integrated Advanced Traffic Management Systems (ATMS) and Advanced Traveler Information Systems (ATIS) in his PhD thesis work. The SIMLAB can simulate the operations of integrated traffic networks such as traffic prediction, time variant traffic information and dynamic route choice. SIMLAB consists of a microscopic traffic simulator (MITSIM) and a Traffic Management Simulator (TMS). MITSIM accepts input signal control and route guidance from TMS and models the movement of individual vehicles in the network. TMS generates signal controls and route guidance according to the ATMS and ATIS logic under evaluation.

Du *et al.* (2015) proposed a traffic monitoring and estimation system for Shanghai using Virtual Sensor Networks (VSNs). They proposed two methods: circuit patrol and greedy patrol control algorithms to improve the performance of Matrix Completion (MC) based traffic monitoring. Simulation results have shown that the proposed algorithms reduced the traffic estimation error from 35% to 10% compared with the random patrol method. Vehicle-to-vehicle communication also helps in reducing traffic congestion (Knorr *et al.*, 2012).

Dragoi and Dobre (2011) presented a congestion avoidance model for traffic control over a vehicular ad-hoc network created between the sensors and cars in traffic. The road side wireless equipment (also called Wireless Traffic Lights, WTLs) collects the data from cars in different road segments and accumulates it to form a road map and its costs. They evaluated the proposed model using a VNSim simulator. Their evaluation results showed that the average time desired for the vehicle to reach its endpoint recorded a significant decrease of up to 40%.

Abishek *et al*. (2009) proposed a Wireless Sensor Network-based (WSN) solution for Indian city traffic. Their aim was to make the traffic signals adapt to the dynamic traffic flow. The proposed system is simulated using the C++ language. They found that the existing infrastructure can handle 7% more vehicles. Zhou *et al.* (2010) proposed an adaptive traffic light control algorithm for real-time traffic. The proposed algorithm adjusts the length and sequence of traffic lights. The proposed algorithm checks for special circumstances, blank circumstances, Hunger Level (HL), Waiting Time (WT) and Traffic Volume of the lane (TV) and then issues the signaling. The experimental outcomes showed that the proposed algorithm produces the reduction of average waiting time of vehicles and high throughput compared to fixed-time control algorithms.

Torne (2013) proposed the use of both ramp metering and Dynamic Speed Limit (DSL) to reduce the capacity drop phenomenon in the vicinity of a freeway on ramp for his PhD work. This thesis is devoted to assess such conceptual benefits with empirical data and robust traffic flow models. The effectiveness of this proposal is tested using simulation with an extension of the traditional cell transmission model and the result shows that the social profitability of Dynamic Speed Limit (DSL) management in metropolitan freeways is limited when applied alone. Travel time prediction from speed data obtained by detector system is perhaps the most common way to obtain information of travel time based on the available traffic condition information.

Li *et al*. (2006) evaluated the performance and provided some general formulations of the common speed-based travel time estimation models. The instantaneous model calculates travel time on the route by using the speed information, $v(i,k)$ from each detector section along this route collected at the same time interval $k$. The travel time on each detector section is calculated using equation (2.1).

$$t(i,k) = \frac{l_i}{v(i,k)} \tag{2.1}$$

where $t(i,k)$ denotes the travel time on detector section $i$ at time $k$. $l_i$ is the length of detector section $i$. The route travel time under traffic condition at time $k$ can be obtained by the summation of travel times from all detector sections along this route. In graph theory, the shortest path problem is the problem of finding a path between two vertices (or nodes) in graph such that the sum of the weights of its constituent edges is minimized. The problem of finding the shortest path between two intersections on a road map (the graph's vertices correspond to intersections and the edges correspond to road segments, each weighted by the length of its road segment) may be modeled by a special case of the shortest path problem in graphs as shown in Figure 2.4;

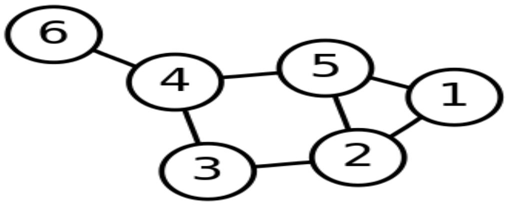



Figure 2.4: Finding shortest path problem in graphs (Shortest Path Problem, 2009)

(6, 4, 5, 1) and (6, 4, 3, 2, 1) are both paths between vertices 6 and 1. Dijkstra's algorithm is an algorithm for finding the shortest paths between nodes in a graph, which may represent, for example, road networks as illustrated in Figure 2.5

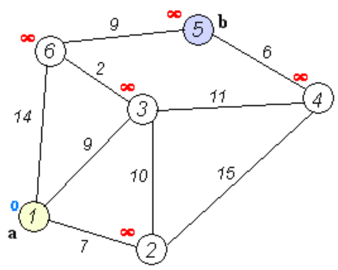



Figure 2.5: Dijkstra’s algorithm to find the shortest path between a and b (Dijkstra, 1959).

Dijkstra's algorithm is an algorithm for finding the shortest paths between nodes in a graph, which may represent, for example, road networks. It was conceived by computer scientist Edsger W. Dijkstra in 1956 and published three years later (Dijkstra, 1959; Frana, 2010). The algorithm exists in many variants; Dijkstra's original variant found the shortest path between two nodes, but a more common variant fixes a single node as the "source" node and finds shortest paths from the source to all other nodes in the graph, producing a shortest-path tree.

For a given source node in the graph, the algorithm finds the shortest path between that node and every other. For example, if the nodes of the graph represent cities and edge path costs represent driving distances between pairs of cities connected by a direct road, Dijkstra's algorithm can be used to find the shortest route between one city and all other cities. As a result, the shortest path algorithm is widely used in network routing protocols called Open Shortest Path First (OSPF).

In Figure 2.5, Dijkstra's algorithm is applied to find the shortest path between a and b. It picks the unvisited vertex with the lowest-distance, calculates the distance through it to each unvisited neighbor, and updates the neighbor's distance if smaller. The limitation of the shortest path is that the real time congestion situation is unknown and when all vehicles with the same request are guided to the same shortest path, this shortest path will face severe congestions and become far from the fastest path (Dijkstra, 1959; Yu *et al.*, 2014).

Yu *et al.* (2014) designed a strategy to split the traffic of vehicles into vehicle set called traffic splitting so as to reduce traffic congestion. The routing target is to make the overall or average travel time of all vehicles to be minimum. The approach is that, for each vehicle in set of $f_i$, the next intersection of the routing result will be$w_1$. In other word, after these vehicles pass road <u, v>, then the vehicle will turn to road <v, $w_i$>. Sink was used as road infrastructure in each intersection distributing the vehicle to the shortest road with minimum travel time. The Traffic Splitting algorithm is discussed below;

Input: $u, v, C_{<u,v>}, w_1 \ldots\ldots w_p$
Output: $vehicle\ sets\ f_1 \ldots\ldots f_p$

1. $f_i = \emptyset, i = 1 \ldots\ldots p;$
2. for i = 1…p do
3. calculate the shortest path from $w_i$ to all other intersections using SSSP algorithm such as Dijkstra;
4. end for
5. while $\sum_{i \in 1 \ldots\ldots p} |f_i| < \left|C_{<u,v>}\right|\ do$
6. for all $c_k \in C_v\ \ do$
7. $m \in \underset{i \in 1 \ldots\ldots p}{\arg\ \min} T\ (< u, v, w_i, \ldots., D_k >)\ ;$

8. $f_m = f_m + \{c_k\};$
9. update $T(< u, v, w_m, \dots \dots \dots., D_k >);$
10. end for
11. end while

Algorithm 1: Traffic Splitting (TS) Algorithm (Yu *et al.*, 2014)

Notation;

u = starting point on the road

v = ending point on the road <u,v>

$C_{<u,v>}$ = total traffic in road <u,v>

$f_i$ = set of flow; i - index for serving as counter

SSSP = Single Source Shortest Path

$c_k$ = Vehicle k

$C_v$ = Vehicles at the Sink

$D_k$ = Destination

m = min $T\ (< u, v, w_i, \dots., D_k >)$ = path with least travel time

The limitation of this strategy can be enumerated below;

a. TS uses the shortest paths which has no dynamic traffic information
b. The performance of TS will degrade when the traffic is heavy
c. When splitting traffic in line 6 to 10, the first vehicle chosen is likely to be designated into shortest path, no fairness in the selection
d. The algorithm may not support most topology of the map of various cities

Lyons (2009) carried out M.Sc in Computer science research on the feasibility of using a Cloud computing infrastructure for urban traffic control systems. A framework of Infrastructure as a Service (IaaS) through Amazon Web Services (AWS) is designed and VISSIM simulation tool is used to simulate the traffic to cloud as shown in Figure 2.6. Although, the author concluded that AWS is promising in terms of being highly scalable, secure, reliable and faster than real-time.

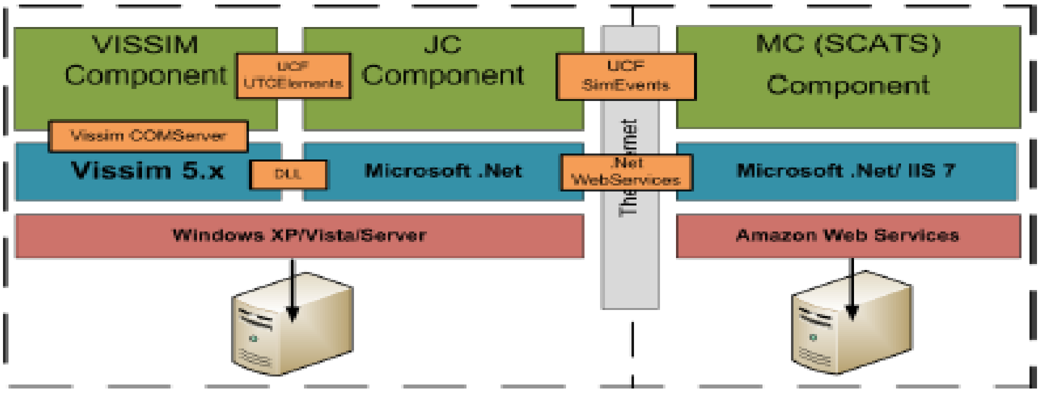



Figure 2.6: System-wide Technical Architecture (Lyons, 2009)

The use of real infrastructures such as Amazon Elastic Cloud Computing limits the experiment to the scale of the infrastructure, and makes the reproduction of results an extremely difficult to undertake.  Evaluation of the hypothesis prior to software development where one can reproduce testing or iteration is not possible. Specifically in the case of Cloud computing, where access to the infrastructure incurs payments in real currency, simulation-based approaches offer significant benefits to Cloud customers by allowing them to: 1) test their services in repeatable and controllable environment free of cost; and 2) tune the performance bottlenecks before deploying on real Clouds. At the provider side, simulation environments allow evaluation of different kinds of resource leasing scenarios under varying load and pricing distributions. Such studies could aid providers in optimizing the resource access cost with focus on improving profits.

Miah and Ahamed (2011) proposed decision support systems based on an intelligent method in which decision/policy makers of the Australian road safety authorities can obtain on-demand monitoring records regarding the behavior of provisional license holding drivers. The studies outline a conceptual framework that can automatically detect when a driver is using a hand-held device, generating an alert message through an onboard device. In order to minimize the risk, if the use of the device continues, they also proposed that relevant information should be automatically wirelessly sent to the legal authority. Figure 2.7 illustrates a model operational scenario of the proposed Decision Support System (DSS) framework with possible input and output data. If the use of a hand-held device continues after the warning, the processing unit will automatically start communicating with a designated server or a legal authority through the cloud server by sending urgent messages. The communication includes vehicle details with its current location (automatically obtainable from the on-board GPS navigation system) and the type of driver activity.

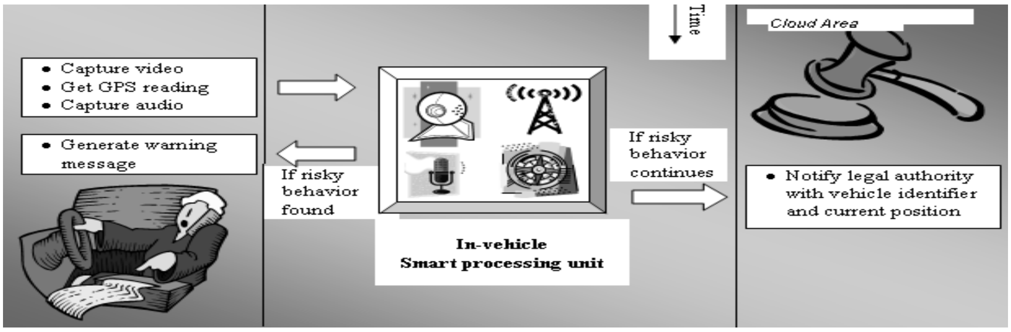



Figure 2.7: Proposed Conceptual Decision Support System Framework with Operational Scenario (Miah and Ahamed, 2011).

Dynamic Traffic Monitoring using vehicular networks (DTMon) has been used to collect high quality travel time in (Arbabi, 2011). The main components of DTMon architecture are: Task Organizers (TOs) and Virtual Strips (VSs). DTMon uses the Task Organizers (TOs) to interconnect with moving vehicles. Virtual Strips (VSs) are the traffic data collection points on the roads. The vehicle rigged with a communication module that communicates with the VS and Traffic Monitoring Control (TMC). They examined the DTMon’s ability using VANET modules. By assigning various tasks and with various locations, the Message Reception Ratio (MRR) and Information Reception Ratio (IRR) are evaluated. The simulation results show better performance of DTMon than an Automatic Vehicle Location (AVL) system in terms of monitoring. The use of virtual strips in DTMon can be extended for detecting and tracking the end-of-queue, caused by congestion

## 2.4 Overview of Cloud Computing

Cloud computing is a model for enabling convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction (Mell and Grance, 2009). Cloud computing use the Internet technologies for delivery of resources 'as a service' to users on demand (Devi and Sujan, 2014). Cloud computing is the realization of the earlier ideals of utility computing without the technical complexities or complicated deployment worries. The cloud works the same as a public utility such as electricity, allowing the customer to use varying amounts in a fixed term, which the customer will then pay at the end of the term. This is the monitoring and accounting side of the cloud. In order to build an accurate understanding of Cloud computing nature, the concept's background must be understood. Many opinions differ on the origin of Cloud computing.

### 2.4.1 Cloud-based Service Delivery Models

Cloud computing providers offer their services according to several fundamental models. The wide range of services provided by Cloud computing has been divided into three main cloud service delivery models;

a. *Software as a Service (SaaS)* – the capability provided to the consumer is to use the provider's applications running on a cloud infrastructure. The applications are accessible from various client devices through web browser or a program interface. With SaaS, a provider licenses an application to customers as a service on demand, through a subscription, in a "pay-as-you-go" model. Thus allow customers to use expensive software as much as their application require and no need to pay ahead much money or even hire more operators to install and maintain that software. IBM is a good example of this category. Cloud computing has all the advantages of SaaS, including ease of installation and maintenance, access from anywhere and centralized control over versioning.

In addition, the fact that the "data is kept safely in the infrastructure" is listed as advantage. In their view Cloud computing would allow SaaS deployment, without building or provisioning a datacenter. The highest of the three tiers is the Software as a Service layer. These are services which allow the user to access software over a network through the use of web-services. Two examples of the use of SaaS are products such as the Facebook Application Framework and Google Maps. In the case of Google Maps, they provide an Application Programming Interface (API) in which the user can create a new instance of a map and have the ability to embed custom data in it by using Google's API. Of course, not all SaaS applications are on a pay-as-you-go paradigm as Google Maps suggests, they rely on a different source of revenue. The Facebook API works on the same principle, where the API itself is downloaded to the user's web server. Some other examples of SaaS services are e-mail, web hosting, social networks, real time data processing and more.

b. *Platform as a Service (PaaS)* – the capability provided to the consumer is to deploy onto the cloud infrastructure consumer-created or acquired applications created using programming languages, libraries, services and tools supported by the provider. In the context of cloud computing, Platform as a Service (PaaS) represents an intersection between IaaS and SaaS. Benefits include the ability to build and deploy scalable web applications without the cost and complexity of procuring server and setting them up (Schofield, 2008). Prominent examples of PaaS are Google AppEngine and SalesForce. com's business software development's platform – Force.com. Microsoft Azure Services on the other hand is a platform that supports general purpose computing by enabling applications written in a .NET language (C#, VB.NET, J#) to run in the cloud environment managed by the underlying Azure OS.

The user has access to some functions that could be integrated in their application code to better take advantage of the automatic scalability properties of the distributed cloud environment (including fail over capabilities), but the user has no control whatsoever on the underlying Windows Azure OS (Armbrust and Fox, 2009). Windows Azure acting as the managing OS, will provide automatic load balancing, geo-replication, application life cycle management and many additional features such as SQL Services, .NET Services and Share Point Services (Microsoft Azure Services FAQ , 2009).

*c. Infrastructure as a Service (IaaS)* – the capability provided to the user is to provision processing, storage, networks, and other fundamental computing resources where the consumer is able to deploy and run arbitrary software, which can include operating systems and applications. The consumer does not manage or control the underlying cloud infrastructure but has control over operating systems, storage, and deployed applications.
The ability to procure or rent virtualized dedicated servers from web hosting providers is nothing new and has been around for years. Implementation and delivery of the services strongly depends on the performance of the cloud infrastructure, her current workload and the possibility of scaling. It is not appropriate to use real-world cloud infrastructures or platforms such as Amazon EC2

### 2.4.2 Cloud Deployment Models

The Cloud Computing Information Technology (IT) infrastructure is amassed in large data centers. It needs to be managed, maintained, upgraded, and consumes huge amount of energy every day, leading to major costs for its owner. Therefore, the deployment of a Cloud infrastructure is a strategic move that need to be evaluated beforehand. Currently, four Cloud infrastructure models have been defined as illustrated in Figure 2.8:

a. Private Cloud: the infrastructure is used by a single organization but can be managed and/or owned by a third party.

b. Public Cloud: the infrastructure is available to the general public over the Internet offering limited security and variable performances.

c. Community Cloud: the infrastructure is shared by several organizations but commonly managed internally or by a third party.

d. Hybrid Cloud: the infrastructure is a combination of Cloud models that remains a unique entity, offering more flexibility at the expense of complexity.

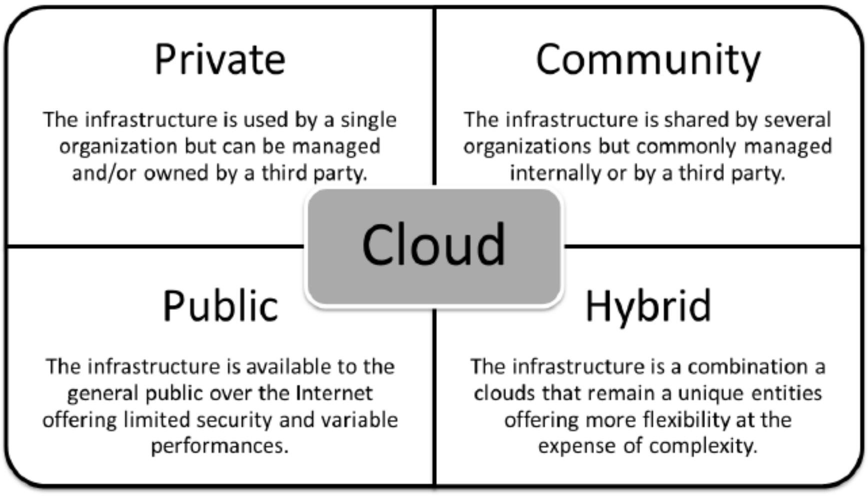



Figure 2.8: Deployment Models of Cloud Solutions **(**Louis, 2015)

### 2.4.3 Cloud Simulation Tools

Cloud simulator tools empowered researchers, engineers and developers to have control on all the layers of their Cloud environment, in a stable, cost-efficient and scalable way. It is not possible to perform benchmarking experiments in repeatable, dependable, and scalable environment using real-world Cloud. It can replicate, repeat and validate scenarios published by the research community. Then, it can apply its own modifications according to the focus area and results can be efficiently reused by others. Also, simulation is a cost effective and highly scalable way to realize tests on a large scale infrastructure since adding resources is basically the matter of changing one variable. Further, simulator tools are often based on discrete time which enables users to launch many different simulations which compute rapidly with minimum computing resources (Ranjan, 2014). According to (Ranjan, 2014; Mahdi *et al.*, 2013; Garg and Buyya, 2011), three popular simulators can be identified: CloudSim, MDCSim and GreenCloud.

*a. CloudSim toolkit*

CloudSim toolkit is the perfect tool for modeling large scale virtualized cloud environment which has components for creating data centers, hosts, virtual machines, brokers and service requests (Bhatt and Bundele, 2013). Considering that none of the current distributed system simulators offer the environment that can be used for modeling Cloud, CloudSim is a simulation tool that allows Cloud developers to test for the performance of their provisioning policies in a repeatable and controllable environment free of cost. It also allows the developer to tune the bottlenecks before real-world deployment. CloudSim is a simulation application which enables seamless modeling, simulation, and experimentation of cloud computing and application services due to the problem that existing distributed system simulators are not applicable to the cloud computing environment (Buyya *et al*., 2009).

Evaluating the performance of cloud provisioning policies, services, application workload, models and resources performance models under varying system, user configurations and requirements is difficult to achieve. To overcome this challenge, CloudSim can be used. CloudSim is new, generalized and extensible simulation toolkit that enables seamless modeling, simulation and experimentation of emerging cloud computing system, infrastructures and application environments for single and internetworked clouds. In simple words, CloudSim (Malhotra and Jain, 2013) is a development toolkit for simulation of Cloud scenarios. CloudSim is not a framework as it does not provide a ready to use environment for execution of a complete scenario with a specific input. Instead, users of CloudSim have to develop the Cloud scenario it wishes to evaluate, define the required output, and provide the input parameters (Malhotra and Jain, 2013).

CloudSim helps the researchers and developers to focus on specific system design issues without getting concerned about the low level details related to cloud-based infrastructures and services (Wickremasinghe, 2009). CloudSim is an open source web application that launches preconfigured machines designed to run common open source robotic tools and robotics simulator Gazebo. The users could analyze specific system problems through CloudSim, without considering the low level details related to Cloud based Infrastructures and services (Zhao *et al*., 2012).

*b.* Multi-Tier Data Center Simulator (*MDCSim)*

MDCSim is a commercial discrete event-based simulator developed at the Pennsylvania State University (Lim *et al*., 2009). Its goal is the simulation of multi-tier data center architectures. It includes multiple vendors' hardware resources models and allows estimation of servers' power consumption.

*c. GreenCloud*

GreenCloud has been built on the top of the well-known network simulator NS-2 (Kliazovich *et al*., 2012). It is a packet level simulator focused on energy-aware data center environment modeling, including communication links, switches, gateways, as well as communication protocols, resource allocation and workload scheduling. GreenCloud is a

CloudSim that have green cloud computing approach with confidently, painlessly, and successfully. In other words, GreenCloud is developed as an advanced packet level cloud network simulator with concentration on cloud communication (Kliazovich *et al*., 2012). GreenCloud extracts aggregates and makes fine grained information about the energy consumed by computing and communication elements of the data center equipment such as computing servers, network switches and communication links (Zhao *et al*., 2012) available in an unprecedented fashion.

Moreover, GreenCloud offers a thorough investigation of workload distributions. In particular, a special focus is devoted to accurately capture communication patterns of currently deployed and future data center architectures. In simple words, GreenCloud is the practice of designing, manufacturing, using and disposing computing resources with minimal environmental damage. The Green Cloud is a supercomputing project under active development at the University of Notre Dame. Green Cloud provides a virtual computing platform by using grid heating which reduces cluster upkeep costs. GreenCloud Simulator is an extension of Network Simulator 2 (NS2) simulator (Zhao *et al*., 2012). GreenCloud simulator implements a full TCP/IP protocol reference model which allows integration of different communication protocols with the simulation. The only drawback of Green Cloud Simulator is that it confines its scalability to only small data centers due to very large simulation time and high memory requirements.

### 2.4.4 Privacy and Security Issues

Shared infrastructure scares many enterprise customers (Geelan, 2009). Placing enterprise data in a public cloud is a serious concern and companies wary about their sensitive data logically question the ability of public cloud computing providers to provide the same level of security as their own datacenters. Depending on the type of Cloud computing service model used (IaaS or PaaS) and the level of abstraction of different security issues in public clouds. The cloud provider is responsible for the physical security of the machines. However, higher level cloud services such as Google AppEngine and platforms like Azure are also responsible for their application-level security and clients have less control controlling it. In addition, downtimes, outright data losses in storage services and risks of cloud provider malfeasance are further threats to be weighted when a company considers public cloud services usage.

## 2.5 State-of- the-art Model

The common state-of-the-art models that are developed by different research institutes and are being used in different parts of the world are explained below;

*a. Traffic on Rural Roads (TRARR) model*

The Australian Road Research Board developed TRARR model (Hoban *et al*., 1991). It is a microscopic simulation model developed for two-lane rural roads with occasional passing lanes. The model simulates uninterrupted traffic. That is, vehicles enter and leave the simulated road only at the ends of the road. Hence, intersections and varying traffic flow along the simulated road is not accounted for. The most recent version was released in the mid 1990's (Koorey, 2002). The model has been used in among others Australia, the US and Canada for evaluation of road alignment and passing lane alternatives (Botha *et al.,* 1993). A time based scanning approach is used for the simulation and the simulation time step is 1 s (Hoban *et al*., 1991). In each time step the speed, acceleration and state of each vehicle is updated. Vehicle states include for example free driving, following, overtaking and so forth.

The details of the TRARR model presented in this section are based on the model description of Hoban *et al*. (1991) unless otherwise stated. The car-following model utilized in TRARR works as follows. Within TRARR each vehicle is assigned a desired following distance. This distance is composed of a time component and a distance component. Vehicles that are constrained by a vehicle in front strive to follow their leader at this following distance. The follower adopts a speed that will allow it to achieve its desired following distance smoothly if the leader maintains a constant speed. Free vehicles strive to travel at its desired speed. Each vehicle is assigned a basic desired speed for ideal road conditions. This basic desired speed is reduced due to horizontal curvature, road width and speed limit through the use of speed multipliers. A vehicle's current desired speed is calculated as the current speed multiplier times the vehicle's basic desired speed.

Different horizontal curvatures, road widths and speed limits are characterized by speed indices with accompanying speed multipliers. The speed indices for the road to be simulated must be specified by the model user. The overtaking model of TRARR is deterministic. A vehicle will always commence an overtaking if the time available for the overtaking is at least a safety factor times the estimated overtaking time. The desired speed and available power of the overtaking vehicle are increased during overtaking and multiple overtaking is also allowed. A Vehicle which is being overtaken may however not commence an overtaking. Another feature of the overtaking model of TRARR is the aggression index. Each vehicle is assigned an aggression index. Vehicles will not overtake if either the vehicle in front or behind have a higher aggression index than the vehicle itself. In connection with auxiliary lanes a vehicle changes lane to the slow lane if there is enough space.

Vehicles that are followed require a shorter space in the auxiliary lane than free driving vehicles. A vehicle in the slow lane will move to the fast lane to overtake a slower vehicle if it has a sufficiently high aggression index and is not being overtaken. The vehicles that are to be moved through the simulated rural road during the simulation are created when needed in the simulation. That is, when a vehicle is loaded onto the road the next vehicle is created. By default, vehicles are assigned normally distributed basic desired speeds and headways drawn from a negative exponential distribution. There is however an option to override the traffic generation process and provide the traffic to be simulated manually. A typical TRARR run requires road and traffic data for the road to be simulated. Horizontal curves, road widths and speed limits must be specified implicitly through speed multipliers whereas vertical grades may be provided directly. Moreover, the model also requires data on driver and vehicle characteristics. The sections and points for which data should be collected must be specified in advance. Available output of the TRARR model includes derived macroscopic traffic measures such as travel times, journey speeds, percent of time spent following and overtaking rates.

*b. Two Lane Passing (TWOPAS) model*

TWOPAS model was developed by the Mid-West Research Institute (McLean, 1989): TWOPAS is a micro-simulation model developed for two-lane rural roads. The model handles two-lane roads with passing lanes. As TRARR, TWOPAS is limited to uninterrupted traffic along the simulated highway stretch. Botha *et al*. (1993) found that TWOPAS and TRARR had comparable capabilities to simulate the traffic operations on a two-lane highway. The latest revision of the TWOPAS model was however made in 1998 (Leiman *et al.*, 1998) and the performance of the updated TWOPAS model has not been compared to TRARR. An example of a TWOPAS-application is generation of data for the US Highway Capacity Manual procedures for capacity and level-of-service of rural two-lane highways (Harwood *et al*., 1999). The following detail of the TWOPAS model is based on the description by Harwood *et al*. (1999) unless otherwise stated.

TWOPAS is a time-based scanning simulation model. The model time step is 1 s. Vehicle speeds, accelerations and positions are updated in each simulation time step. The speed of impeded vehicles is determined according to a car following model that is based on leader, the follower's desired speed and the follower's desire to overtake the leader. Unimpeded vehicles' speed is based on the desired speed distribution and the road geometry. Desired speeds are drawn from truncated normal distributions (Allen *et al*., 2000). TWOPAS includes an empirically based overtaking model. The model is stochastic and includes overtaking gap-acceptance functions that determine the overtaking probability given the speed of the leader and the distance available for the overtaking (McLean, 1989).

The distance available for the overtaking is given by the clear sight distance or the distance to the closest oncoming vehicle. Required input data for a TWOPAS run includes road and traffic data for the road to be simulated. Both horizontal curves and vertical grades may be included directly amongst the input data (Botha *et al.,* 1993). The latest version of TWOPAS also includes an automatic procedure for sight distance calculation with respect to the road alignment and a user defined offset to roadside objects. Available outputs of a TWOPAS run include travel times, journey speeds and overtaking statistics (Botha *et al.,* 1993). The overtaking statistics include both overtaking rates and safety margins, i.e. time margins, at the end of overtaking. TWOPAS also provide travel times at zero traffic, i.e. free vehicle speeds, and the geometrical delay.

*c. The Swedish National Road and Transport Research Institute model (VTISim)*

A Versatile Model for Rural Road Traffic Simulation (VTISim) similar to TRARR and TWOPAS, VTISim is a microscopic rural road traffic simulation model. It allows varying traffic flow along the simulated stretch and the effects of intersections on the main road traffic are however not accounted for. Since the beginning of the model development extensive calibration efforts has been made. As a consequence, McLean (1989) argued that VTISim was the most proven of the rural road simulation tools available in 1989. It has been applied in studying the effects of different road design alternatives (Carlsson, 1993) and to generate data for the Swedish capacity manual (SRA, 2001). All road sections and points for which results are of interest must be specified prior to the simulation. Available output of a VTISim run includes travel times, journey speeds, overtaking rates and platoon lengths. Information on unimpeded and impeded travel time and distance are also included in its output.

## 2.6 Route Choice Model

Drivers who are always observed traveling on the same route will be identified as habitual drivers. The habitual drivers are not aware of changing route decision, for example, even when it is faster to travel on the alternative route or there is an incident on their preferred route. Drivers other than habitual drivers will be considered as the non-habitual drivers. To classify the habitual drivers, it is necessary to observe repeated route choice decisions of each driver from multi-day and multi-period data. This variable will be used in the route switching behavior analysis. A driver's main route may refer to the most frequently used route observed for that driver. Comparing the total number of trips that one particular driver makes on route 1 and route 2: for example, if the number of trips on route 1 is greater than on route 2, in this case, route 1 will be defined as the driver's main route. The various approaches lead to different models of route choice behavior; Figure 2.9 illustrates the route switching behavior (Frejinger *et al.,* 2009):

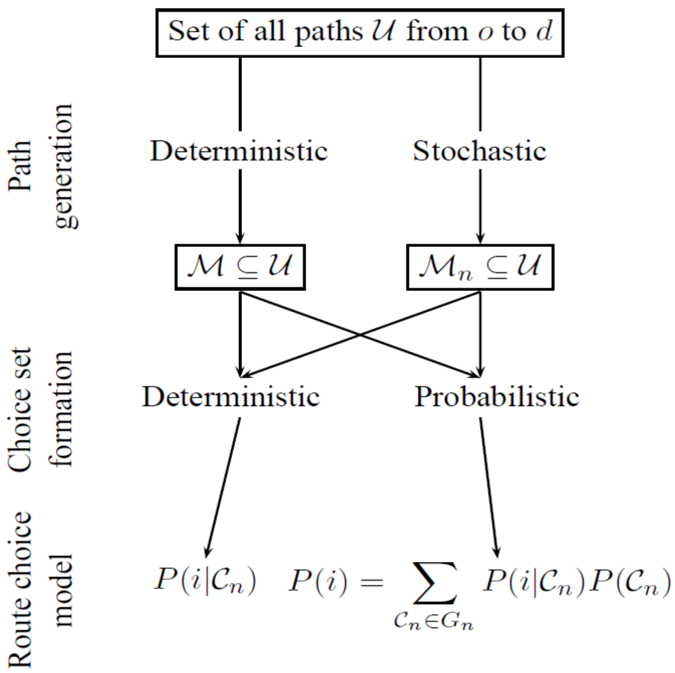



Figure 2.9: Route choice modeling process (Frejinger *et al*., 2009)

Route choice modeling involves several steps and an overview of this process is given in Figure 2.9; the probability that individual n chooses path i given a choice set $C_n$, $P(i|C_n)$. In a real network a very large number of paths connect an origin o and destination d. In this diagram, *U* represents the universal set that includes all possible routes for an OD pair, *M* represents the master set of known routes generated by the researcher using deterministic or stochastic methods in order to approximate a driver's awareness set. And then, if the choice set generation method is deterministic, the probability of a driver choosing route *i* simply equals P(i|C) where *C* is the individual final viable choice set (and where C∈M).On the other hand, if the choice set generation method is a probabilistic approach, the probability would be as shown in the Figure, where *G* represents all the non-empty subsets of *M*. A specific explanation of the different models in different situations is given below.

### 2.6.1 Multinomial Logit (MNL) Model

In the MNL model, choice makers are assumed to be rational decision makers who choose the alternative with the greatest utility. A random utility model is designed to forecast the choice of an individual n among a finite and discrete set of alternatives $C_n$. The main assumption is that each individual associates a quantity, called utility, to each alternative in $C_n$, and selects the alternative with the highest utility. The utility associated by individual n to alternative i, is denoted by $U_{in}$ is a random variable.

Generally, the utility function comprises two additive parts as follows:

$$U_{in} = V_{in} + E_{in} \tag{2.2}$$

where

$V_{in} \in R$ is the deterministic, or systematic component of the utility of alternative *i* to individual *n* and $E_{in}$: *is a* random term

If $z_{in}$ is a vector of attributes of alternative i for individuals n, and $S_n$ is a vector of socio-economical characteristics for individual n, then

$$V_{in} = \beta * (Z_n, S_n) \tag{2.3}$$

Usually, the systematic component is a linear function of the parameter:

$$V_{in} = \beta * X_{in} \tag{2.4}$$

where

$\beta$: the vector of unknown parameters to be estimated;

$X_{in}$: the explainable variables of alternative *i* to individual *n*.

If disturbances are assumed to follow a Gumbel distribution, the probability of choosing alternative *i* in the MNL model would be as follows:

$$P_n(i) = \frac{\exp(V_{in})}{\sum_{j \in M} \exp(V_{in})} \quad (2.5)$$

where

$P_n(i)$ : the probability of individual n choosing alternative i;

$M$: the choice set including all of the alternatives.

2.6.2. Probabilistic Choice Set Model

There may be a huge number of possible routes for an OD pair and a driver would be unable to consider all of them. This means that it is unreasonable to treat the universal set of routes as the choice set for drivers. Researchers therefore use deterministic or stochastic route generation techniques to create a master set of known routes, *M*, that approximates the driver's awareness set. Such master sets, however, may include many non-viable routes since current route generation techniques do not account for individual spatiotemporal constraints such as existing knowledge of routes, driving habits, route preference and so on (Kaplan and Prato, 2012). In this research, the Probabilistic Choice Set (PCS) model proposed by Manski (1977) is introduced as a way to overcome this shortcoming:

$$P_n(i) = \sum_{C \in G} P_n(i|C) * Q_n(C|G) \quad (2.6)$$

where

$P_n(i)$: probability of individual *n* choosing route *i* from master set *M*, see Figure 2.8

$P_n(i|C)$: probability of individual *n* choosing route *i* from given choice set *C*;

*G*: set of all non-empty subsets of *M*;

$Q_n(C|G)$ : probability of individual *n*'s choice set being *C*.

In this model, decision making is taken to be a two-stage process. The first stage is a choice set generation stage; decision makers generate their personal choice sets from the given master set under certain constraints. These constraints are conjunctive, which means that an alternative becomes part of the choice set only if it satisfies all constraints; otherwise it is excluded. The second decision-making stage is a discrete choice model; for this, both the normal and modified MNL models are applied in this research.

### 2.6.3 Behavior-Cognitive Model of Drivers

Lin *et al*. (2013) proposed a route choice behavior-cognitive model for describing the decision-making mechanism of drivers during the travel. The author carried out simulation experiments using Visual Basic -VISSIM platform and the results showed the features of drivers' dynamic behavior to achieve optimal path from the model.

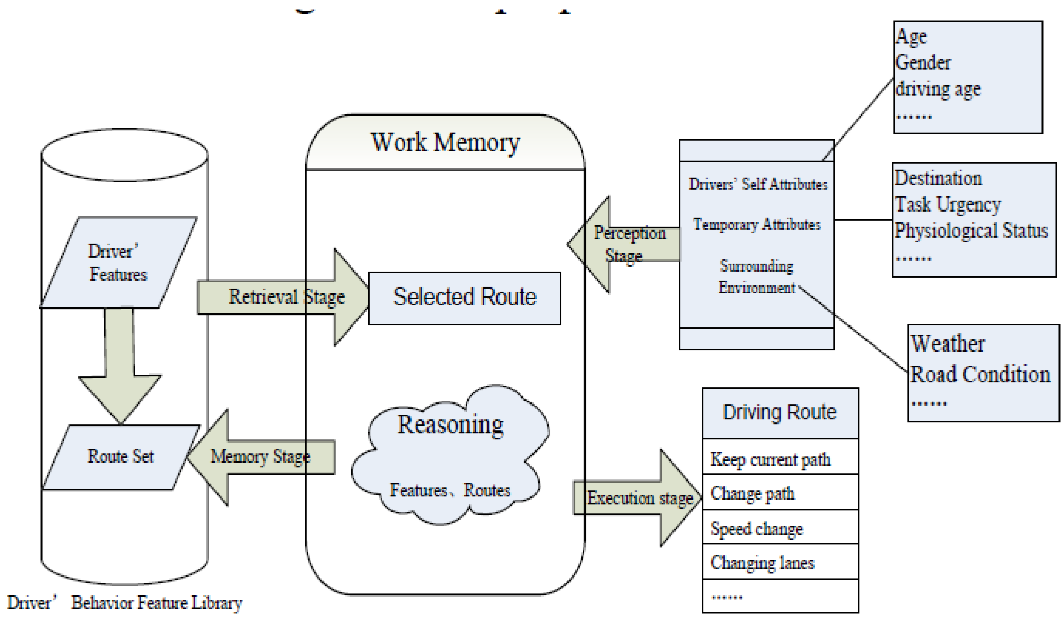



Figure 2.10: Drivers route choice behavior cognition process (Lin *et al.*, 2013).

The framework of drivers' route choice behavior cognition process is given in Figure 2.10. The establishment of drivers' feature library can make route selection more convenient and avoid repeat computation. The library contains corresponding relations. For each set of behavior features, there is a corresponding route choice.

The process is comprised by the following stages:

a. Perception stage: Drivers' self attributes (such as age, gender and driving age), temporary attributes (such as destination, task urgency and physiological status) and surrounding environment (such as weather and road condition) can be sensed by work memory;
b. Retrieval stage: Search the feature library in work memory for corresponding route choice.
c. Execution stage: Drive into the road obtained in retrieval stage. Periodically sense the variation of temporary attributes and surrounding environment and repeat the retrieval process.
d. Reasoning stage: If the feature library does not contain the current feature set, a reasoning process would occur according to current feature and selected road. The newly generated corresponding relation would be stored in the feature library.

## 2.7 Traffic Simulation Tools

A simulation is a system that takes a simulating experiment description to realize the experiment by running episodes and executing models. As a result, a simulation produces data or generates scenarios to reflect the behavior of expected object in the real world. A well-designed traffic simulation is essential to successfully simulate VANETs applications. The simulation tools described in this section are either commercial solutions or lab-tools that broke through their qualities. In selecting appropriate simulator, scalability, which is generally speaking, the ability to either handle growing amounts of work in a graceful manner or to be readily enlarged, gives the researcher an idea on the maximum scenario he is allowed to simulate, in terms of number of mobile nodes, number of simultaneous protocols and details' level of the simulation's outcome. For example, one may simply think to simulate a large network of thousands of nodes with many details per network layer but if the simulation time or the memory consumption start growing too fast, this may turn out to be unfeasible. The common traffic simulation tools in the literature are explained below;

### 2.7.1 PARAMICS

PARAllel MICroscopic Simulation (PARAMICS) is a widely used microscopic traffic simulation tool initially developed at the University of Edinburgh in the early 1990's and was introduced commercially in 1997 by Quadstone Limited in the UK. The advantages of PARAMICS include the real-time dynamic three-dimensional visible user interface, which is easy to operate and understand; capable of using a large number of functionalities to simulate a traffic network and to "evaluate various policies and control strategies and their effects on the transportation network such as vehicle delays and emissions"; similar to AIMSUN, the model allows for the overriding or extending the default models using Application Programming Interface (API) (Quadstone, 2003). Vehicular behavioral model is mainly treated in two folds from literature as lane changing logic and car following logic. According to Duncan (2000), lane changing logic in PARAMICS is applied using "a gap acceptance policy". It means that when the vehicle is trying to change to another lane, the following two conditions have to be satisfied; the subject vehicle will not result in a collision with the front vehicle in the target lane; the subject vehicle will not result in a collision with the vehicle behind it in the target lane.

The car following model in PARAMICS, similar with Wiedemann's car-following model, is based on a psycho-physical model developed by PARAMICS (Fritzche, 1994). In Fritzche's model, the perception thresholds and different regimes are defined as demonstrated in Figure 2.11. For different regimes the model has its corresponding driver behavior.

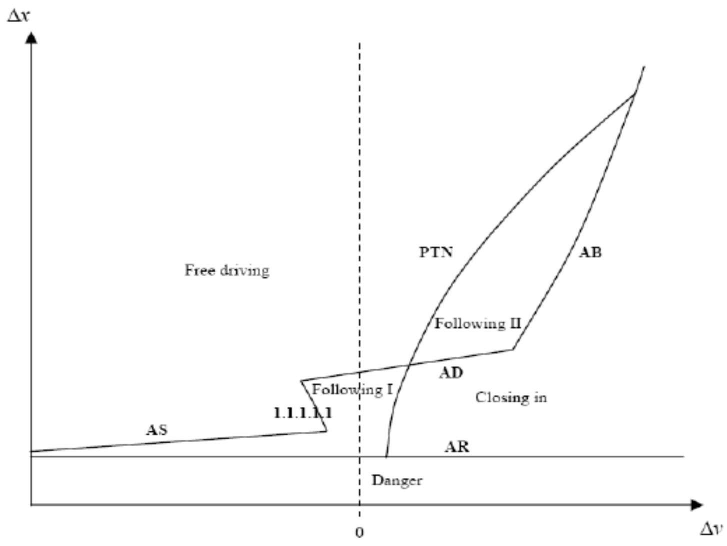



Figure 2.11: Thresholds and Regimes in the Fritzsche Car-Following Model (Fritzche, 1994).

In danger regime, the following vehicle uses its max deceleration to extend the headway; in closing regime, the following need deceleration to keep a distance from the leading vehicle; in following I regime, there is no need for action and as the driver doesn't have the ability to maintain the constant speed, a parameter is assigned to model this; in following II regime, no action is necessary because although the following vehicle realizes the driver is closing in the front vehicle but the distance is too large to make any adjustment; in free driving regime, the vehicle accelerates headway to its desired speed first and then drives around this speed as the driver is unable to maintain the constant speed (Olstam and Tapani, 2004).

The difference between the published Fritzsche model and the model implemented in PARAMICS are not publicly known, (Brockfeld *et al*., 2003). The model studied in this work is therefore the model published by Fritzsche. The Fritzsche model accounts for human perception in the definitions of the model regimes. For example, speed differences have to be of certain magnitude to be perceived by the driver.

Fritzsche has constructed the following regime defining thresholds:

Thresholds for perception of, negative (*PTN*) and positive (*PTP*), speed differences is defined as

$$PTN = -k_{PIN}(\Delta x - s_{n-1})^2 - f_x \tag{2.7}$$

$$PTP = k_{PTP}(\Delta x - s_{n-1})^2 + f_x \tag{2.8}$$

where $k_{PIN}$ , $k_{PTP}$ and $f_x$ are model parameters. The followers do not perceive differences in speed below the thresholds *PTN* and *PTP*. Drivers are assumed to observe smaller negative speed differences than positive, thus *PTN* is smaller than *PTP*.

In addition to the thresholds for the perception of speed differences, the

Fritzsche model incorporates four thresholds for the follower's space headway to its leader:

i. Desired distance, *AD*. The desired distance expresses the gap drivers' wish to maintain to the vehicle in front and is defined as

$$AD = s_{n-1} + T_D.v_n \tag{2.9}$$

where $T_D$ is a parameter representing the desired time gap.

ii. The risky distance, *AR*. The distance keeping behavior gives rise to another distance threshold defined as

$$AR = s_{n-1} + T_r.v_{n-1} \tag{2.10}$$

where $T_r$ is the risky time gap.

For gaps smaller than or equal to the risky distance drivers decelerate heavily to avoid collisions.

iii. The safe distance AS, the smallest headway where positive acceleration is accepted if the distance between follower and leader is increasing is defined as "AS". The safe distance is calculated as

$$AS = s_{n-1} + T_s.v_n \qquad (2.11)$$

where $T_s$ is a model parameter.

The braking distance AB, the maximum deceleration of a vehicle is limited. It is therefore possible that collisions will occur if the initial speed difference between two vehicles is large. To prevent such collisions, the braking distance is defined as

$$AB = AR + \frac{\Delta v^2}{\Delta b_m} \qquad (2.12)$$

where $\Delta b_m$ is given by

$$\Delta b_m = |b_{min}| + a_{n-1}^{-} \qquad (2.13)$$

In the last equation, $b_{min}$ and

$a_{n-1}^{-}$ are model parameters controlling maximum deceleration.

Finally, the time gap parameters$T_D$, $T_r$ and $T_s$ satisfy:

$T_D > T_s > T_r$

The vehicle's behavior in the different regimes is described below:

*Danger*:

The distance to the leading vehicle is smaller than the risky distance *AR*. The follower uses its max deceleration, $b_{min}$ to extend the headway.

*Closing in*:

The speed difference is larger than *PTN* and the space headway is between *AB* or *AD* and *AR*. The follower decelerates in order to obtain the speed of the vehicle in front. The deceleration rate is taken so that the speed of the leader will be obtained when the space headway equals the risky distance (*AR*). The following expression is used for the acceleration of vehicle *n* (Saldaña and Tabares, 2000):

$$a_n = \frac{v_{n-1}^2 - v_n^2}{2d_c} \tag{2.14}$$

Where $d_c$ is the constraint distance given by

$$d_c = x_{n-1} - d_c - AR + v_{n-1}\Delta t \tag{2.15}$$

where

$\Delta t$ is the simulation time step

### 2.7.2 AIMSUN

Advanced Interactive Microscopic Simulator for Urban and Non-Urban Networks (AIMSUN), was developed by the Department of Statistics and Operational Research, “Universitat Poletecnica de Catalunya”, Barcelona, Spain (Xiao *et al.*, 2005). This microscopic traffic simulation software is capable of reproducing various real traffic networks and conditions on a computer platform. The driver behavior models inside AIMSUN such as car-following model, lane changing model and gap-acceptance model provide the behavior of each single vehicle of the entire simulation period (TSS, 2006). As developed in the GETRAM simulation environment, AIMSUN has the Application Programming Interface (API), which enables it to communicate with some user-defined applications. The advantage of AIMSUN also includes the capability of modeling a traffic network in detail and producing a number of measures of effectiveness.

*a. Car-following logic of AIMSUN*

The car following model used in AIMSUN is based on the model developed by Gipps (1981), which considers the speed of the following vehicle to be either free or constrained by the leading vehicle. Equation 2.16 to equation 2.21 showed the detailed description of the model.

The speed of the vehicle ($n$) during time interval ($t$, $t$+$T$) is the minimum of the two expressions in equation 2.16:

$$v_n(t+T) = \min\{v_n^a(t+T), v_n^b(n,t+T)\} \qquad (2.16)$$

Then, the position of the vehicle $n$ on the current lane is updated taking this speed into the movement equation:

$$x_n(t+T) = x_n(t) + v_n(t+T)T \qquad (2.17)$$

where $v_n^a(t+T)$ is the maximum speed the following vehicle can accelerate to,

$$v_n^a(t+T) = v_n(t) + 2.5a_n^{max}.T.\left(1 - \frac{v_n(t)}{v_n^{desired}}\right)\sqrt{0.025 + \frac{v_n(t)}{v_n^{desired}}} \qquad (2.18)$$

The maximum safe speed for vehicle n with respect to the vehicle in front at time t is calculated as

$$v_n^b(t+T) = d_n^{max}\ .\ T + \sqrt{(d_n^{max}.T)^2 - d_n^{max}.[2[x_{n-1}(t) - s_{n-1} - x_n(t)] - v_n(t).T - \frac{v_{n-1}(t)^2}{D_{n-1}}} \qquad (2.19)$$

where;

$a_n^{max}$ Maximum desired acceleration, vehicle n, [$m/s^2$]

$d_n^{max}$ Maximum desired deceleration, vehicle n, [$m/s^2$]

$D_{n-1}$ Estimation of maximum deceleration desired by vehicle n-1, [$m/s^2$]

T The apparent reaction time, a constant for all vehicles

The effective length of a vehicle, $s_{n-1}$, consists of vehicles length and the user specified parameter *minimum distance between vehicles*. According to the (TSS, 2002), there are two ways for the follower to estimate the leader's desired deceleration, the first way is to simply assume that the driver can estimate the leaders deceleration perfectly, thus the estimation will be equal to the leaders desired deceleration, $d_{n-1}$ that is

$$D_{n-1} = d_{n-1} \tag{2.20}$$

and the second way is to calculate the estimation of the leader's desired deceleration as average of the leader's and the follower's desired decelerations, that is

$$D_{n-1} = \frac{d_n + d_{n-1}}{2} \tag{2.21}$$

*a. Lane-changing logic of AIMSUN*

The lane-changing model applied in AIMSUN is also developed based on the Gipps's lane changing model (Gipps, 1986). Similar with the other lane-changing models, the lane-changing model in AIMSUN is also a decision based model which addresses three questions: the necessity, desirability and feasibility of the lane change. The turning feasibility, the distance to next turning and the traffic conditions in the current lane are three dominant factors deciding the necessity of the lane change; the desirability of lane change depends on whether there is improvement after changing lanes, for instance, the speed is faster or the queue length is shorter; the feasibility of lane change means that if there is a sufficient safety distance, lane changing is possible, otherwise it's impossible.

In AIMSUN, three different zones corresponding to different lane changing motivations are considered to generate a more accurate decision, as demonstrated in Figure 2.12. These three zones are defined by the distance to zone 1 and distance to zone 2 in seconds. For zone 1, the main concern about lane change is the traffic condition of these lanes; for zone 2, the desired turning lane is the main concern; for zone 3, the decision of lane changing mainly depends on the feasibility, which means whether the lane change is possible (Barcelo, 2004).

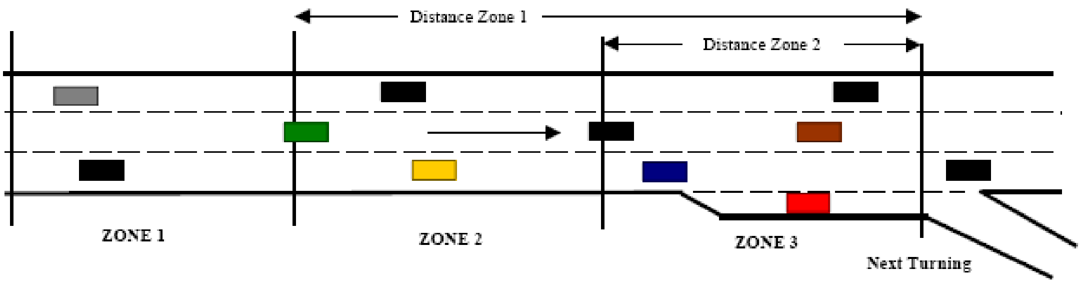



Figure 2.12: Lane-changing Zones of AIMSUN Lane-changing Model

The possibility to overtake slower vehicles is central for the performance of all types of road environments. Models controlling this part of the driving task are therefore important in all traffic micro-simulation models. On freeways and on urban streets overtaking slower vehicles is one of the reasons to change lane. Other reasons behind lane-changing decisions include positioning for upcoming turns or lane-drops. Simulation models for urban streets and freeways do consequently include lane-changing models that control these lane-changing decisions. In lane-changing models the decision to change lane is commonly governed by the following conditions (Gipps, 1986):

i. The need to change lane
ii. The driver's desire to change lane
iii. The possibility to change lane

The impact of oncoming traffic on the lane changing decisions is usually negligible in urban street networks. Overtaking models for rural road traffic simulation must therefore account for the effect of oncoming traffic. The driver's willingness to conduct an overtaking is controlled by gap-acceptance considerations that take into account the predicted overtaking distance given the relative speeds of the vehicles and the distance to the closest oncoming vehicle within sight or the sight distance. Overtaking should also be abandoned if it is no longer possible to overtake the vehicle in front. Overtaking models may consider aborted overtaking due to upcoming overtaking restrictions, oncoming vehicles and too low engine power of the overtaking vehicle in steep upgrades.

2.7.3 VISSIM

VISSIM is a German acronym for "Traffic in Towns -Simulation", the name is derived from "VerkehrInStädten–SIMulationsmodel". It is a time step and behavior based microscopic traffic simulation model developed at the University of Karlsruhe, Karlsruhe, Germany, in the early 1970s by Planung Transport Verkehr, (PTV) Transworld AG, German company which began the commercial distribution of VISSIM from 1993 and continues to maintain the software up to this date. VISSIM is preferable to other traffic simulation models because of the following reasons; It is easy to build one's model effectively by taking advantages of various interfaces it possesses such as Component Object Model(COM), DriverModel, DrivingSimulator, SgnalControl) to import from existing network and to connect with external signal controllers.

The software package is based on decades of intensive research and close networking with customers and continuous development. It is stable simulation tool that always incorporates the latest findings from research and practice and that sets new standards. It is the world's leading multimodal microscopic simulation software, for the evaluation of the behavior of any level of automated vehicles as a cost-effective and efficient alternative to field testing; "Multi-modal simulation" describes the ability to simulate more than one type of traffic. In VISSIM the following types of traffic can be simulated; Vehicles (cars and trucks), Public transport (trams, buses), Cycles (bicycles, motorcycles), Pedestrians. The capability of the software to model all modes of transport and their interactions integrated in a single tool allows users not only to test the dynamics of automated vehicles but also to convey a valid assessment of all traffic-related aspects (http://www.issd.com.tr/en/22992/PTV-VISSIM-Traffic-Simulation-Software).

This traffic simulation software is developed to model urban traffic and public transit operations and it is composed of two main components: a Traffic Simulator (TS) and Signal State Generator (SSG) as illustrated in Figure 2.13. The traffic simulator is in charge of the movement of vehicles, while the signal state generator models the signal status decision from detector information of the traffic simulator and then passes the signal status back to the traffic simulator (Bloomberg and Dale, 2000).

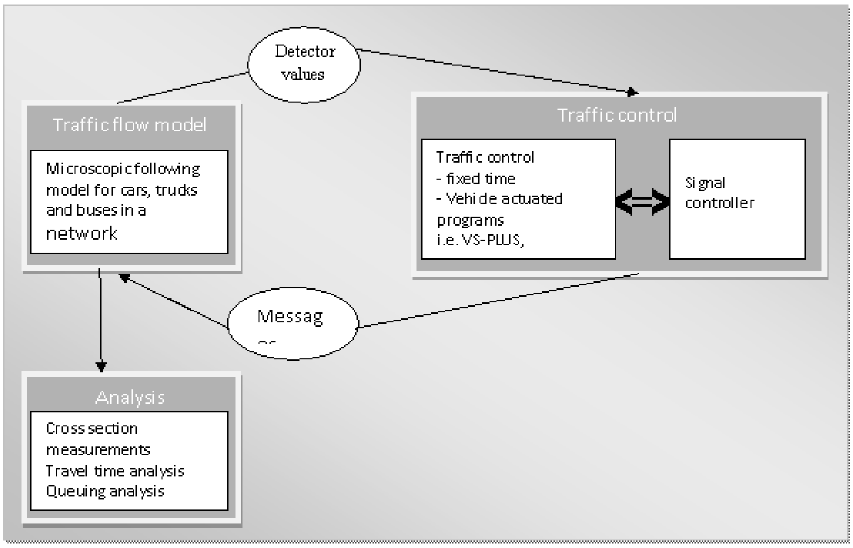



Figure 2.13: Illustration of the Communication between TS and SSG (PTV, 2007).

The VISSIM model can produce almost all the commonly used measurements of effectiveness in the traffic engineering area. The user begins by importing either an aerial photo or schematic drawing of the study area into the simulator. The user then begins building the network and applies attributes (e.g. lane width, speed zones and priority rules). The SSG permits the user to analyze impacts from signal operations including fixed time, actuated, adaptive, transit signal and ramp metering. The signal status is then determined for the following time step and returns this information to the traffic simulator. The modeling of car-following and traffic stream behavior requires a mathematical representation that captures the most important features of the actual behavior and is thus an important attribute in traffic simulation models. The car-following model incorporated in VISSIM is a modified version of two models developed by Wiedemann that is Weidemann74 and Weidemann 99 models and belongs to a family of models known as Psycho-physical or action-point models (Rakha and Gao, 2008).

This family of models uses thresholds or action-points where the driver changes the driving behavior. Drivers react to changes in spacing or relative speed only when these thresholds are crossed. The thresholds and the regimes they define are usually presented in the relative speed/spacing diagram for a pair of lead and follower vehicles.

*b. Car-following logic of VISSIM*

VISSIM uses a psycho-physical car-following model based on the model developed by Wiedemann (1974), which defines the driver perception thresholds and the regimes formed by these thresholds. There is another car-following model called Wiedemann 99 car-following in VISSIM, the Wiedemann 99 car-following model is in many ways similar to Wiedemann 74 car following model, except that some of the thresholds in the 99 model are defined in a different way to model freeway traffic better. In addition, many more of the thresholds are user adjustable in the Wiedemann 99 model.

i. The Wiedemann Model

In 1974, Wiedemann (1974) introduced a car-following model that is based on psychophysical behavior. Psychophysical models presume that a driver does not respond until passing an action point. These models determine how drivers react to a perceived situation, mainly the perception of distance and speed differences by adapting their driving manners

(Wiedemann and Reiter, 1992). The Wiedemann Psychophysical model is tested based on the formulation in Wiedemann and Reiter (1992), and Leutzbach and Wiedemann (1986). The basic idea of the Wiedemann model is the assumption that a driver can be in one of four driving modes as follows:

1) Free driving: No influence of preceding vehicles observable. In this mode the driver seeks to reach and maintain a certain speed as individually desired speed. In reality, the speed in free driving cannot be kept constant, but oscillates around the desired speed due to imperfect throttle control.

2) Approaching: The process of adapting the driver's own speed to the lower speed of a preceding vehicle. While approaching, a driver applies a deceleration so that the speed difference of the two vehicles is zero in the moment the driver reaches desired safety distance.

3) Following: The driver follows the preceding car without any conscious acceleration or deceleration. The driver keeps the safety distance more or less constant, but again due to imperfect throttle control and imperfect estimation the speed difference oscillates around zero.

4) Braking: The application of medium to high deceleration rates if the distance falls below the desired safety distance. This can happen if the preceding car changes speed abruptly, or if a third car changes lanes in front of the observed driver.

*Car following model* selects the basic model for the vehicle following behavior. Depending on the selected model,

i. *Wiedemann 74*: Model mainly suitable for urban traffic and merging/weaving areas

ii. *Wiedemann 99*: Model mainly suitable for interurban (motorway) traffic except merging/weaving areas.

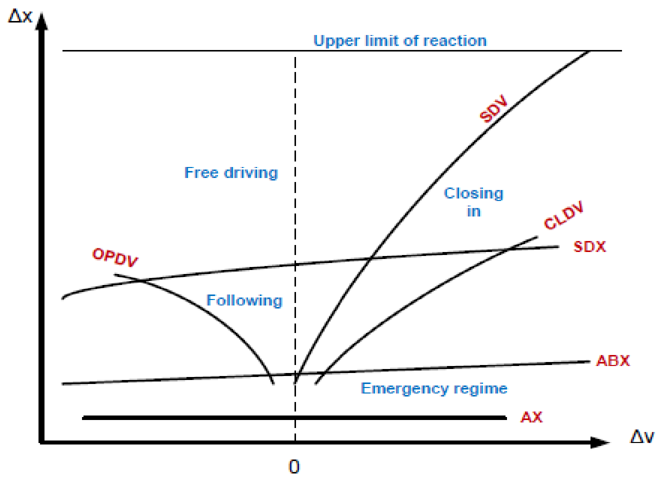



Figure 2.14: Graph of Wiedemann car-following logic or model's thresholds (Wiedemann and Reiter, 1992)

From 0 point to the left, the distance is increasing and from 0 point to the right, the distance is decreasing. The following is a definition of the Wiedemann car-following model's thresholds:

i. The threshold AX represents the average desired distance between stationary vehicles. This distance consists of the leading vehicle length and the desired front-to-rear distance.

$$AX = L_n + AX\_add + z * AX\_mult \quad (2.22)$$

where

AX= average standstill distance

$L_n$ = the leading vehicle length,

AX_add = additive part of the safety distance

AX_ mult = multiplicative part of the safety distance

z is a normal distributed random number for vehicle (n).

Definition of AX_add and AX_mult

AX_add is the adjustment factor for safety distance while moving.

AX_mult is also the adjustment factor for safety distance while moving and both of them are calibration parameters

ii. The threshold ABX represents the desired minimum following distance at low speed differences

$$ABX = AX + BX \quad (2.23$$

where

$$BX = (BXadd + BXmult * RNDl_n) * \sqrt{v} \quad (2.24)$$

BX is the safety distance to a lead vehicle depending on travelling speed

$$v = \begin{cases} V_{n-1} \ \ for\, V_n > V_{n-1} \\ \\ V_n \quad for\, V_n \leq V_{n-1} \end{cases} \quad (2.25)$$

where

BX_add and BX_mult are calibration parameters representing the variations of desired spacing and

v is the minimum of the leader or follower vehicle velocity.

$V_{n-1}$ is the velocity of the lead vehicle

$V_n$ is the velocity of the followed vehicle

iii. SDX: Recognizing the expansion of the spacing in the following situation, the threshold for maximum following distance, SDX, fall between 1.5 and 2.5 times ABX

$$SDX = AX + EX * BX \quad (2.26)$$

where:

$$EX = (EXadd + EXmult \ * (\ NRND1_n - RND2_n)) \quad (2.27)$$

where

EX_add and EX_mult are calibration parameters,

$\mathrm{NRND1}_n$ is a normal distributed random number, and

$\mathrm{RND2}_n$ is normal distributed driver dependent parameter

iv. The threshold approaching point, SDV, represents the point where the driver notices that the vehicle in front is moving slowly and the driver is approaching it.

$$SDV = \left(\frac{\Delta x - L_{n-1} - AX}{CX}\right)^2 \tag{2.28}$$

$$CX = CXconst * (CXadd + CXmult * (NRND1_n + RND2_n)) \tag{2.29}$$

where

CX_const, CX_add, and CX_multi are calibration parameters.

$\Delta x$ is the change in distance

$L_{n-1}$ is the length of the lead vehicle

AX is average standstill distance

v. The decreasing speed differences or CLosing Driving Velocity (CLDV) threshold provides a mechanism for a different behavior when the driver approaches the leading vehicle more closely than the approaching point. In VISSIM, CLDV is ignored and simply assumed to be equal to SDV. After passing the CLDV threshold, the point at which the approaching and getting close to the leader and needs to decelerate to prevent any collision is recognized by the driver.

vi. The OPening Difference in Velocity (OPDV) curve is primarily a boundary to the unconscious reaction region. It represents the point where the driver notices that the distance between the driver's vehicle and the lead vehicle is increasing over time. When this realization is made the driver will accelerate in order to maintain desired space headway. The increasing speed difference (OPDV) threshold describes the point where it is observed that the driver is traveling at a lower speed than the leader.

$$OPDV = CLDV * (-OPDVadd - OPDVmult * NRND) \qquad (2.30)$$

where

OPDV_add and OPDV_mult are calibration parameters and indicate the range. *NRND* represents variation of same driver and is a normally distributed random number. Based on the defined threshold, four types of driving behavior, namely, free flow, closing, following and emergency braking are classified. In the Psychophysical model, for each of these driving phases, an acceleration function is defined.

ii. Wiedemann 99 Model

Wiedemann's 1999 car following model has the following parameters;

1) *CC0 (Standstill distance)* defines the desired distance between stopped cars. It has no variation.

*2) CC1 (Headway time)* is the time (in s) that a driver wants to keep. The higher the value, the more cautious the driver is. Thus, at a given speed *v [m/s]*, the safety distance $dx_{safe}$ is computed to:

$$dx_{safe} = CC0 + CC1.v \qquad (2.31)$$

where

v is the speed *[m/s]*,

3) The safety distance is defined in the model as the minimum distance a driver will keep while following another car. In case of high volumes this distance becomes the value with the strongest influence on capacity.

4) *CC2 ('Following' variation)* restricts the longitudinal oscillation or how much more distance than the desired safety distance a driver allows before he intentionally moves closer

to the car in front. If this value is set to e.g. 10m, the following process results in distances between $dx_{safe}$ and $dx_{safe}$ + *10m*. The default value is 4.0m which results in a quite stable following process.

5) *CC3 (Threshold for entering 'Following')* controls the start of the deceleration process, i.e. when a driver recognizes a preceding slower vehicle. In other words, it defines how many seconds before reaching the safety distance the driver starts to decelerate.

6) *CC4 and CC5 ('Following' thresholds)* control the speed differences during the 'Following' state. Smaller values result in a more sensitive reaction of drivers to accelerations or decelerations of the preceding car that is the vehicles are more tightly coupled. CC4 is used for negative and CC5 for positive speed differences. The default values result in a fairly tight restriction of the following process.

7) *CC6 (Speed dependency of oscillation)*: Influence of distance on speed oscillation while in following process. If set to 0 the speed oscillation is independent of the distance to the preceding vehicle. Larger values lead to a greater speed oscillation with increasing distance.

8) *CC7 (Oscillation acceleration)*: Actual acceleration during the oscillation process.

9) *CC8 (Standstill acceleration)*: Desired acceleration when starting from standstill. This model, as was the case with the Gipps model, computes the vehicle speed as the minimum of two speeds: one based on the vehicle acceleration restrictions and the other based on a steady state car-following model. The model considers a vehicle kinematics model with a linear speed acceleration relationship where *CC8* is the maximum vehicle acceleration at a speed of 0 km/h (m/s$^2$)

10) *CC9 (Acceleration at 80 km/h)*: is the maximum vehicle acceleration at a speed of 80 km/h (limited by maximum acceleration defined within the acceleration curves).

b. Lane-changing logic of VISSIM

The lane-changing behavior is divided into two types: Lane change to a faster lane and lane change to a slower lane (Gao, 2008). To make the decision of lane change, three questions need to be evaluated: Whether there is a desire to change the lane, whether the present driving situation in the neighboring lane is favorable, whether the movement to a neighboring lane is possible (Kan and Bhan, 2007). There are also two kinds of lane changes in VISSIM: Necessary lane change and free lane change. The necessary lane change is applied when the vehicle needs to reach the connector of next routine. The free lane change happens when the vehicle is seeking more space or higher speed. No matter which type of lane change it is, the first step for the vehicles in VISSIM is to find “a suitable gap (time headway)” ( PTV, 2007).

## 2.8 Statistical Evaluation of Traffic Simulation Model

Since no single measure can determine how well a simulation model performs, a combination of statistical indices are generally used to evaluate the model (Anjum *et al.,* 2014). The agreement between the measured and the simulated values can be assessed using the following statistical indices;

a. Root Mean Squared Error (RMSE)
b. Coefficient of Variation (CV)
c. Modeling Efficiency (EF)
d. Coefficient of Residual Mass
e. Root Mean Square Normalized Error (RMSNE)
f. Correlation Coefficient (CC)
g. Mean Absolute Percentage Error (MAPE)

The RMSE is the most popular evaluation metric used in regression problems. It follows an assumption that errors are unbiased and follow a normal distribution. Model errors are likely going to have a normal distribution rather than a uniform distribution. It also gives the weighted variations in errors (residual) between the modeled and observed values and is calculated from equation 2.32 (Nash and Sutcliff, 1970).

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(M_i - S_i)^2} \quad (2.32)$$

According to Chai and Draxler (2014), RMSE has one distinct advantage, it avoid the use of absolute value which they considered highly undesirable in many mathematical calculations. It has been used as a standard statistical metric to measure model performance in Meteorology, Air quality, and Climate research studies. In the field of Geosciences, many present the RMSE as a standard metric for model errors (McKeen *et al.*, 2005; Savage *et al.*, 2013; Chai *et al.*, 2013). There is no universally accepted threshold limit for error magnitude when judging the degree of accuracy of model performance. However, Singh *et al.* (2004) stated that if *RMSE* value is smaller than half of the standard deviation of the measured data, then it may be considered low and appropriate for model evaluation.

The standard deviation of an entire population is known as σ (sigma) and is calculated using:

$$\sigma = S.D = \sqrt{\frac{\sum(x - \mu)^2}{\sum F}} \quad (2.33)$$

Where x represents each value in the population, μ is the mean value of the population, Σ is the summation (or total), and F is the number of values in the population. The Coefficient of Variation is a measure of variability expressed by equation 2.34 (Willmout and Matsuura, 2005).

$$CV = 100. \sqrt{\frac{1}{n}\frac{\sum(M_i - S_i)^2}{S_I}} \quad (2.34)$$

where

$S_i$ is simulated value, $M_i$ is measured value and n is the number of measurements.

Modeling Efficiency (MEF) is a measure of the degree of fit between simulated and measured data, similar to the coefficient of determination, and varies from negative infinity for total lack of fit to 1 for an exact fit. The expression is given in equation 2.35 (Willmott, 1982).

$$MEF = \frac{\sum(S_i - S_m)^2 - \sum(M_i - S_i)^2}{\sum(S_i - S_m)^2} \qquad (2.35)$$

where

$S_m$ is the measured average

The Coefficient of Residual Mass (CRM) is an indicator of the tendency of the model to either over-or under-predict measured values, a positive value indicates a tendency of under-prediction, while a negative value indicates a tendency of over-prediction as is shown in equation 2.36 (Igbadun, 2012; Kahimba *et al.*, 2009).

$$CRM = \frac{\sum S_i - \sum M_i}{\sum S_i} \qquad (2.36)$$

The Mean Absolute Percentage Error (MAPE) measures the size of the error in percentage. It is estimated as the average of the unsigned errors for data that is strictly known to be positive. The advantage of this statistics is lack of effect of averaging positive and negative errors. Since this statistic is expressed in percentage terms, it is easier to comprehend without knowing what constitutes a big error in the measurements. Mathematically, MAPE is expressed as:

$$MAPE = \frac{100}{n}\sum_{i=1}^{n} \left| \frac{y_{i,sim} - y_{i,obs}}{y_{i,obs}} \right| \qquad (2.37)$$

MAPE statistic should not be used when working with low-volume data because it is scale sensitive.

Very low $y_{i,obs}$ values results into higher MAPE static.

The Correlation Coefficient (CC) indicates the degree of linear association between simulated and observed data. The mean and variance of the simulated and observed data should be known. Mathematically, it is expressed as:

$$CC = \frac{1}{n-1}\sum_{i=1}^{n}\frac{(y_{i,sim} - \bar{y}_{sim})(y_{i,obs} - \bar{y}_{obs})}{s_{sim}s_{obs}} \qquad (2.38)$$

Where n is the total number of traffic measurement observed $\bar{y}_{sim}$ and $\bar{y}_{obs}$ are means of the simulation and observed measurements, respectively. $s_{sim}$ and $s_{obs}$ are the standard deviations of the simulated and observed measurements, respectively. This statistic is also referred to as Pearson Product-Moment Correlation Coefficient (PPMCC). A Correlation Coefficient of 1 shows a perfect and direct relationship while a correlation coefficient of -1 shows a perfect and inverse relationship. A Coefficient of Correlation of 0.85 is considered acceptable for model calibration.

The Root Mean Squared Normalized Error (RMSNE) or Normalized Root Mean Square Error (NRMSE) measures the percentage deviation of the simulation output from observed data. This statistic measures the percentage of the typical relative error and it can be used to determine the width of the confidence intervals for the predictions. Mathematically, it can be expressed as:

$$RMSNE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(\frac{y_{i,sim} - y_{i,obs}}{y_{i,obs}})^2} \qquad (2.39)$$

where *n* is the total number of traffic measurement observations, $y_{i,sim}$ and $y_{i,obs}$ are simulated and observed data points , respectively, at time-space domain, *i*. $y_{i,sim}$ is an average of the total number of simulated output. RMSNE is also called Root Mean Squared Percent Error (RMSPE). A RMSNE of less than 0.15 is considered acceptable for traffic model calibration. Lower measurements may lead to higher RMSNE values (FDOT, 2014).

## 2.9 Summary

The concept of traffic congestion, causes and its remedies has been discussed according to the findings of some researchers from their survey. Some related works on traffic control reduction has been reviewed and their findings still called for more studies on how to reduce traffic congestion especially the waiting time at the roundabout. Some common traffic simulation tools and vehicular behavior models that were used for the development of the simulators are reviewed. It has been observed that the existing traffic flow models are not adequate in handling mixed traffic streams and the model that can classify the vehicle classes or types on the road network is also essential. From the review, the implementation of drivers' cognitive behavior model, route choice models and Dijkstra's algorithm are not enough in reducing traffic congestion.

Traffic information system will be essential to provide information for routing request and reduce traffic congestion considerably. Traffic and network simulators are identified with a focus on their operations and how they can be used. Finally, statistical indicators for the evaluation of traffic simulation model are also discussed so as to identify the appropriate tools to validate our simulation model.

# CHAPTER THREE

# FRAMEWORK FOR TRAFFIC CONTROL STRATEGIES

## 3.1 Introduction

In this chapter, the conceptual framework of the proposed Traffic Control Strategies (TCSs) are discussed by looking at its main components such as Segment Controller (SC) as road side unit, equipped vehicles, and cloud controller. The TCSs System Model is also developed and its components are discussed in details. Simulation algorithms are designed for the implementation of the framework on both VISSIM and CloudSim platform. Vehicular movement model is developed to enhance the Wiedemann car following model and traffic congestion reduction planning schemes are also developed to reduce congestion on Nigerian roads.

## 3.2 Conceptual Framework for Traffic Control Strategies

In this section, the designed Traffic Control Strategies framework is presented and it looks at the Segment Controller (which contains Cloudlet, detector, and transceiver), Cloud controller and the equipped vehicle. It also looks at how vehicle information are transmitted to the road infrastructure and consequently sent to the cloud. The framework is furthered explained with the designed simulation algorithms.

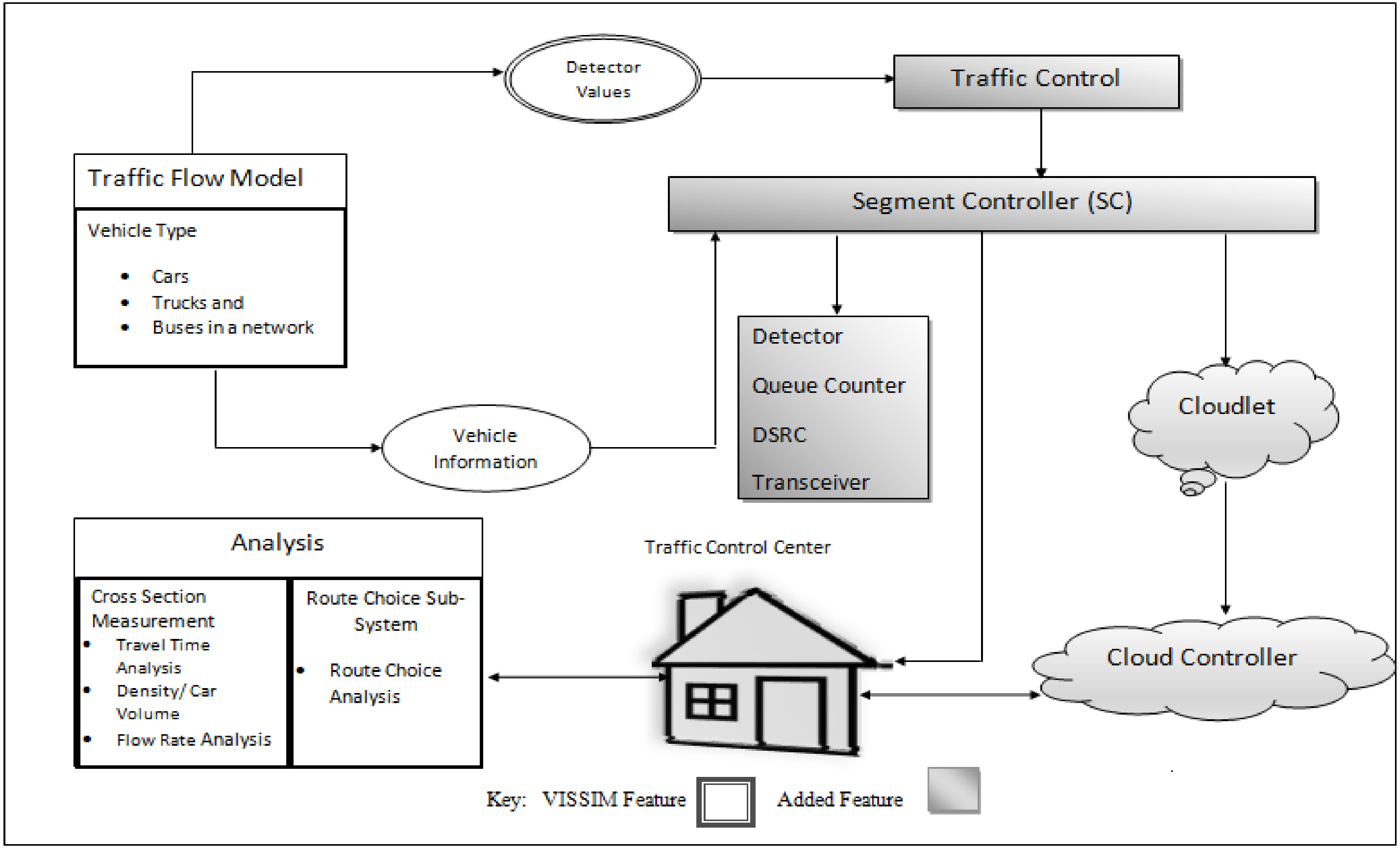



Figure 3.1: Conceptual Framework for Traffic Control Strategy.

*a. Segment Controller (SC).*

In order to perform any kind of traffic control, the traffic situation on roads has to be constantly monitored. Segment Controller (SC) is a Road Side Unit (RSU) introduced in this research as the road infrastructure. The SC is tasked with gathering vehicle information from the equipped vehicles on the road network and maintaining an up to date traffic situation. The SC is designed to be the property of Traffic Control Center (TCC) and should be able to directly communicate with the cloud controller and the information in the cloud could be downloaded by the TCC. The Traffic Control center is acting as the cloud broker in this framework. The goal of the SC is to provide accurate traffic information to the TCCs, drivers and to disseminate timely messages or traffic reports from the equipped vehicles to the cloud controller through the cloudlet.

It is expected that there should be at least one SC deployed along the road within an ad-hoc network. In doing that, it is responsible for collecting, processing and posting data from the equipped vehicle to the cloud. Each SC is equipped with a Dedicated Short Range Communications (DSRC) transceiver to communicate with cooperative equipped vehicles when needed. Deploying multiple segment controllers along the road and applying the union of information gathered by them is an option for complex roads and for higher performance. Each of the SC is assumed to having address location. The equipped vehicles and the SCs use a common piece of application software for communication. Overall, SCs can be deployed to any desired point of interest on the road as long as they are supplied with power. SCs have the following advantages over previously discussed technologies (see chapter two;

i. Weather conditions, occlusion, mounting height and location, vehicle mixture, road configuration do not affect the strategy of its deployments

ii. SCs are not limited to only fixed points on the road. Its coverage is the ad-hoc network communication range. It can be re-installed in another strategic area.

iii. The Traffic Control Center (TCC) are able to collect data from the SC in a wide area outside its communication range by downloading the messages from the cloud and recognized the SC and the equipped vehicle through the address of SC.

iv. The vehicle information is temporarily stored in the cloudlet in SC for processing before being sent to the cloud controller for permanent storage.

*b. Cloud Controller (CC)*

A Cloud Controller is a storage appliance that automatically moves data from on-premises storage to cloud storage. It uses hard disk drives, solid-state drives or a combination of the two to store data on-premises. Connections between the Cloud, equipped vehicles and road infrastructure can be implemented using wireless communication. For example, it depends on the geographical location of the lane, General Packet Radio Service (GPRS) which is a packet oriented mobile data service on the Two Generation (2G) and Three Generation (3G) cellular communication system using a private Access Point Name (APN) or even use fiber connection.

The mobile communication connections are more useful in a place where 3G/GPRS is freely available. For this research, VISSIM multi-model traffic flow simulator will be used, as it has being a proven environment for over 15 years (Fellendorf and Vortisch, 2010). It is capable of carrying out microscopic simulations, which is the more proven of the different types as individual behavior is captured. As well, it has a very extensive system for carrying out evaluation of simulations. CloudSim will be used for simulation of the cloud environment and it contains the data center, cloudlet, broker and virtual machine. A data center is a centralized repository for the storage, management, and dissemination of data and information. Typically, a data center is a facility used to house computer systems and associated components, such as telecommunications and storage systems. Cloudlet is a class that models the Cloud-based application services (such as content delivery, social networking, and business workflow) in CloudSim. Cloudlet defined in CloudSim as job submitted to cloud. The job or task in CloudSim is called cloudlets and it can be viewed as data center in a box.

*c. Equipped Vehicles*

It is assumed that the equipped vehicles contain the Global Positioning System (GPS) device for positioning and a transceiver for communication (Dedicated Short Range Communication (DSRC) device). An on-board unit (OBU) consists of a wireless transceiver in a vehicle that provides the communication with nearby road-side units (RSU) using (DSRC). DSRC provides short-to-medium range wireless communication channels (5.9 GHz up to range of 300 meters) specifically designed for automotive use. It is also expected that equipped vehicles will contain the Vehicle_ID which is the vehicle identification number or an address to be mapped to the vehicle network, digital road map (It is assumed that digital road maps may contain information about the number of lanes on each roadway), processor/memory which interacts with the GPS device and DSRC transceiver and common piece of application software for network communication between the equipped vehicle, segment controller, Traffic Control Center and the cloud controller.

More so, each vehicle transmits to the message containing vehicle information. The vehicle information form a set of Vehicle_ ID as the Vehicle Identification number, Vehicle type, Vehicle length, Speed, Acceleration, the Entry time and Exit time as follows;

*Vehicle Information = {Vehicle_ ID, Vehicle_ type, Vehicle_ length, Speed, Acceleration, Entry_ time, Exit_ time}*

Traffic flow is a difficult phenomenon to describe without the use of a common set of terms. Apart from the vehicle information, there are some other traffic variables that can be used to describe traffic on any roadway such as volume, flow rate, speed, space headway, density, travel time and delay time. These traffic variables can be explained as follows;

*i. Volume and Flow rate*

These are variables that usually quantify demand, that is, the number of vehicle occupants or drivers (usually expressed as the number of vehicles) who desire to use a given facility during a specific time period. Volume and flow rate are two measures that quantify the amount of traffic passing a point on a lane or roadway during a given time interval. These terms are defined as follows:

1) Volume is the total number of vehicles observed or predicted to pass over a given point or section of a lane or roadway during a given time interval; volumes can be expressed in terms of annual, daily, hourly, or sub-hourly periods. Volume is simply the number of vehicles that pass a given point on the roadway in a specified period of time. By counting the number of vehicles that pass a point on the roadway during a 15-minute period, you can arrive at the 15-minute volume.

2) Flow is one of the most common traffic parameters. Flow is the rate at which vehicles pass a given point on the roadway, and is normally given in terms of vehicles per hour. The 15-minute volume can be converted to a flow by multiplying the volume by four. If 15-minute volume is 100 cars, it could be reported that the flow is 400 vehicles per hour. For that 15-minute interval of time, the vehicles can cross designated point at the rate of 400 vehicles/hour.

*ii. Speed*

The speed of a vehicle is defined as the distance it travels per unit of time. Most of the time, each vehicle on the roadway will have a speed that is somewhat different from those around it. In quantifying the traffic flow, the average speed of the traffic is the significant variable. The average speed, called the space mean speed, can be found by averaging the individual speeds of all of the vehicles in the study area. Speed is defined as a rate of motion expressed as distance per unit of time, generally as kilometers per hour (km/h). In characterizing the speed of a traffic stream, a representative value must be used, because a broad distribution of individual speeds is observable in the traffic stream. Usually the average travel speed is used as the speed measure because it is easily computed from observation of individual vehicles within the traffic stream and is the most statistically relevant measure in relationship to other variables. Average travel speed is computed by dividing the length of the highway, street section, or segment under consideration by the average travel time of the vehicles traversing it. If travel times $t_1$, $t_2$, $t_3$,...,$t_n$ (in hours) are measured for n vehicles traversing a segment of length L, the average travel speed is computed using Equation 3.1

$$S = \frac{L}{t_i} \tag{3.1}$$

where

S = average travel speed (km/h),

L = length of the roadway segment (km),

$t_i$ = travel time of the $i^{th}$ vehicle to traverse the segment (h),

Free-flow speed - The average speed of vehicles on a given facility, measured under low-volume conditions, when drivers tend to drive at their desired speed and are not constrained by control delay or congestion.

*iii. Travel Time and Delay*

Travel time is the amount of time that takes a vehicle to travel between two points on the road. It is the piece of data most understandable for the driving public and, thus, is the most desired data for traffic engineers. Historically, gathering travel times has been challenging. Travel time is a variable used in calculation of average running speed and average travel speed and also space mean speed. Delay, or expected delay, is also a piece of data useful for the driving public. This is the time difference between the observed travel time of the road segment and the travel time usually measured directly by knowing the length of the segment and the desired speed on that segment. Travel time is an important quantitative indicator representing traffic condition, it is also considered as the vital information for both road users and traffic operators.

In the view point of road users, knowing travel time or traffic condition could help making informed decision in pre-trip planning and/or on road rerouting. For traffic operators, as a key performance for advanced traffic management system, overall travel time is the important marker for evaluating the efficiency of road network and ongoing operational plan. For example, the travel time for a 5 km segment of a roadway with a speed limit (desired speed) of 80 km/h is 0.0625 h (1 km ÷ 80 km/h). If the observed average travel time of the vehicles that have passed the same segment is 0.09 h, then the average delay can be estimated as 0.0275 h (1.65 min). This delay can be assumed as the average delay that the drivers have encountered during their journey through the segment or can be used as an estimate for the expected delay, the delay that drivers may expect to encounter upon entering the same segment.

*iv Density*

Density refers to the number of vehicles present on a given length of roadway. Normally, density is reported in terms of vehicles per mile or vehicles per kilometer. High densities indicate that individual vehicles are very close together, while low densities imply greater distances between vehicles. Direct measurement of density in the field is difficult, requiring a vantage point for photographing, videotaping, observing significant lengths of highway, or surrogating based on other metrics. Density can be computed, however, from the average travel speed and flow rate, which are measured more easily. Equation 3.2 is used for under-saturated traffic conditions.

$$D = \frac{v}{s} \tag{3.2}$$

where

v = flow rate (veh/h),

s = average travel speed (km/h), and

D = density (veh/km).

Density is a critical parameter because it characterizes the quality of traffic operations. It describes the proximity of vehicles to one another and reflects the freedom to maneuver within the traffic stream. Roadway occupancy is frequently used as a surrogate for density in control systems because it is easier to measure. Occupancy in space is the proportion of roadway length covered by vehicles, and occupancy in time identifies the proportion of time a roadway cross section is occupied by vehicles.

*iv. Spacing or Space headway*

Spacing or Space headway is the distance between successive vehicles in a traffic stream, measured from the same point on each vehicle (for example, front bumper and rear axle). Headway, or time headway, is the time between successive vehicles as they pass a point on a lane or roadway, also measured from the same point on each vehicle. These characteristics are microscopic, since they relate to individual pairs of vehicles within the traffic stream. Within any traffic stream, both the spacing and the headway of individual vehicles are distributed over a range of values, generally related to the speed of the traffic stream and prevailing conditions. In the aggregate, these microscopic parameters relate to the macroscopic flow parameters of density and flow rate. Spacing is a distance, measured in meters. It can be determined directly by measuring the distance between common points on successive vehicles at a particular instant. This generally requires complex techniques, so that spacing is usually derived from other direct measurements. Headway, in contrast, can be easily measured with time observations as vehicles pass a point on the roadway. Since headway and spacing are related, knowing the headway allows the spacing to be determined as shown in Equation 3.3. The relationship between average spacing and average headway in a traffic stream depends on speed, as indicated in Equation 3.3

$$Headway\left(\frac{s}{veh}\right) = \frac{Spacing\,(\frac{m}{veh})}{speed(\frac{m}{s})} \tag{3.3}$$

This relationship also holds for individual headway and spacing between pairs of vehicles. The speed is that of the second vehicle in a pair of vehicles. The average vehicle spacing in a traffic stream is directly related to the density of the traffic stream, as determined by Equation (3.4)

$$\text{Density}\left(\frac{\text{veh}}{\text{km}}\right) = \frac{1000}{\text{Spacing}\,(\frac{\text{m}}{\text{veh}})} \tag{3.4}$$

There are a corresponding set of protocols and standards (IEEE 802.11p (Jiang and Delgrossi, 2008)) associated with DSRC. Cloud computing is being used to storing useful data during their trip for later delivery. The information gathered by OBUs and RSUs can be mined to derive traffic data and its derivatives.

### 3.2.1 Message Transmission Algorithm.

The Segment Controller (SC) uses vehicle discovery method, routing, store and message forwarding techniques to pass the report and information to the Traffic Control Center through the Cloud Controller. For the deployment of SC, it is assumed that, the topology of the roads and the paths that messages may travel are known, therefore geographical routing will be appropriated for the system. The focus of this section is on how to collect, monitor traffic data and method of transmitting data using forwarding or routing algorithm. Once a report is received from the vehicle, the vehicle list is cross checked in the Segment Controller. If the vehicle is unknown (that is, does not exist in the list), it is added. If the vehicle appears in the list, its information is updated. If no reports from a particular vehicle are received for a certain number of years, it is removed from the vehicle list. It is assumed that all vehicle registered are equipped vehicle and in any occasional checking, if any vehicle has its message sender spoiled, the vehicle will be ceased. Algorithm 2 shows how messages can be transferred from the vehicle to the cloud through the Segment Controller.

```
1.  // This is a simulation algorithm on the VISSIM and CloudSim platform
2.  /* Vehicle list ( V_ list) contains all the information of each vehicle on the network */
3.   /* Compiled V_ list contains both the traffic flow when traffic is free flow and
4.  maximum road capacity as max_ free_ flow*/
5.      SC: Segment Controller
6.       d: distance
7.       CC: Cloud Controller
8.  C_ Range: Communication Range
9.  Veh_ info:  Vehicle Information(Vehicle_ ID,  Vehicle_ type, Vehicle_ length,
    Speed,  Acceleration, Entry_ time, Exit_ time) */
10. input: Vehicle_ ID
11. procedure
12.         if ( d( Vehicle_ ID, SC ) <= C_ Range )
13.                 SC detect Vehicle_ ID
14.         Veh_ info transmitted to SC
15.                 Update V_ list
16.                 forwardMessage ( V_ list )
17.         else
18.                 Vehicle_ ID not found
```

19. end if

20. Output: Display V_ list, Compiled V_ list

21. exit

Algorithm 2: Message transmission Algorithm

Through vehicle discovery, it is assumed that equipped vehicles and the segment controllers are aware of the position of equipped vehicles within the standard DSRC communication range (300 meters). Messages can be stored and carried or forwarded in any direction along a road to reach the desired location of the vehicle, or SC. Vehicles and SCs update their vehicle list of reachable vehicles, that is, those within the DSRC range of C_ Range meters, periodically as described in this section. In addition to sending messages to vehicles, messages can also be forwarded to a cloud controller through the SC within the sender's range. The basic outline of the forwarding process is shown in Algorithm 3;

1. // This is a simulation algorithm on the VISSIM platform
2. forwardMessage ( V_ list)
3. send V_ list directly to CC
4. send Compiled V_ list to CC
5. CC acknowledge SC
6. Exit

Algorithm 3: *Forwarding Messages to the Cloud*

If the vehicle is within the ad-hoc network, the message is sent directly to the SC, the message is forwarded to the cloud through the SC and the message containing the traffic data in the set of vehicle information. The report of the vehicle will be updated for the road safety authority to download and used for future purposes and since the report is in the cloud, updated version can be gotten in from the cloud. The compiled data contains both the traffic flow when traffic is free flow and maximum free flow (max_ free_ flow) when the traffic is congested.

### 3.3 Traffic Control Strategies (TCSs) System Model

This section provides a brief list of all the requirements needed to build the TCS system model, which are divided into sections which correspond to the sub-components of the control strategies as shown in Figure 3.2. The first set of requirement applies to the VISSIM component, the second is Segment Controller (SC) and the third is the Cloud Controller (CC) component. Java Database Connectivity (JDBC) API is used to serve as interface between the VISSIM simulator and cloud database (storage) in CloudSim simulator. *VISSIM* Traffic simulation is an indispensable instrument for transport planners and traffic engineers. It is a microscopic, behavior-based multi-purpose traffic simulation to analyze and optimize traffic flows. It is a discrete traffic simulation system that offers a wide variety of urban and highway applications, modeling motorway traffic, integrating public and private transportation. Complex traffic conditions are visualized in high level of detail supported by realistic traffic models.

The VISSIM Component is required to build an interface between VISSIM and the CC, allowing a translation of traffic data between VISSIM and CloudSim. The requirements for the VISSIM component are:

a. The VISSIM module will generate the primary data from the equipped vehicle while the vehicle information is read by the road infrastructure. JDBC is the interface that transmits the traffic data to the cloudlet in the SC and later to the Cloud.

b. The VISSIM module must be on a machine fast enough to run simulations in at least real-time and JDBC API drivers must also be installed on the machine.

The system model split up into the VISSIM component where VISSIM is running on a Microsoft .Net framework 3.5 SP1 and Cloud Controller (CC) component where CloudSim is running on JAVA IDEs (NetBeans is used) and both simulators are run on the Microsoft Windows 8 machine as illustrated in Figure 3.2;

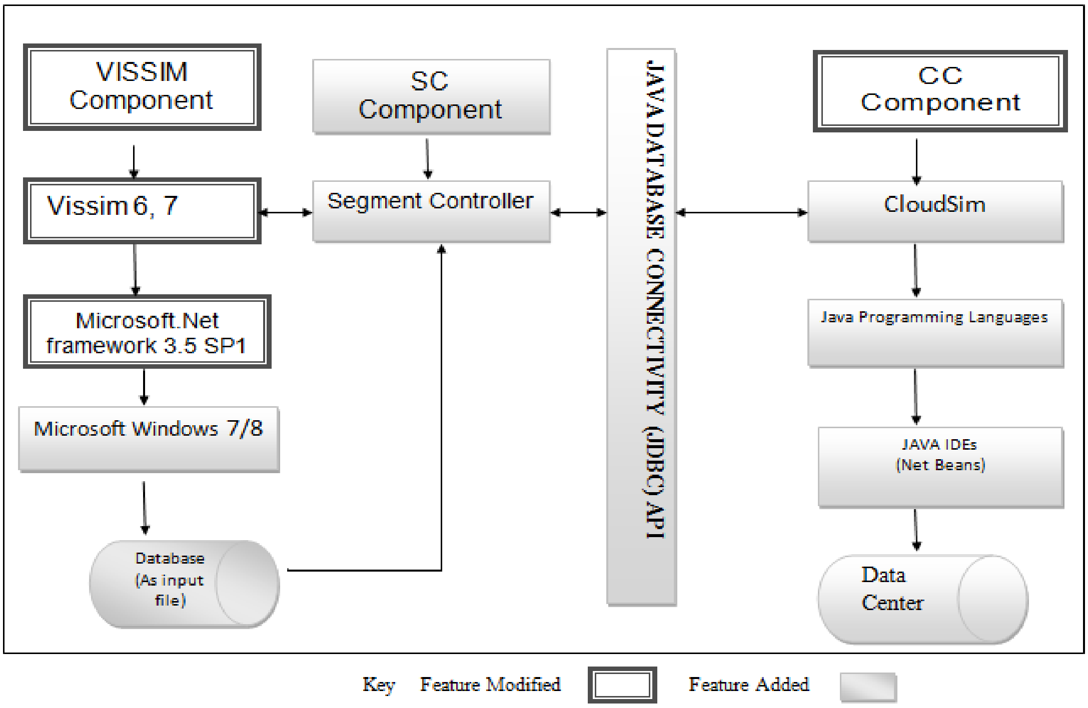



Figure 3.2: TCSs System Model

### 3.4 Description of the Proposed Vehicular Behavior Model (VBModel)

This section presents the vehicle movement logic on the road network. For this study, the Wiedemann model is used as the car-following model. The Wiedemann model is a psychophysical model which estimates the thresholds for a driver's decision to accelerate or decelerate based on drivers' perceptions of changes in relative velocity. The model uses four stages: free driving, following, approaching, and braking/emergency. It looks at the movement of the vehicles in an urban area Wiedemann model (1974) and in highway Wiedemann model (1999). Detail of Wiedemann model is described in Chapter 2, Section

2.7.3. The model is enhanced to reflect the movement of vehicles of the same type and vehicles of different types or classes on the road network.

The following notations are introduced to describe the position of the vehicles. The utilized notation is displayed in Figure 3.3,

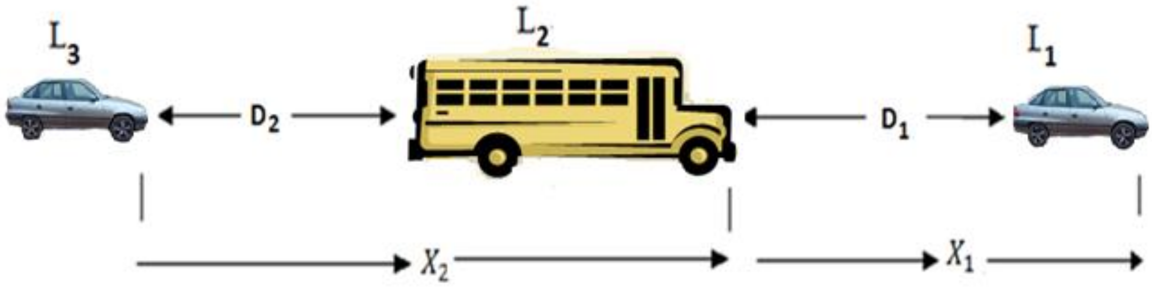



Figure 3.3: Vehicle Movement Notations

Where

$L_1$ = length of lead vehicle 1

$L_2$ = length of vehicle 2

$L_3$ = length of vehicle 3

$D_1$ = desired front to rear distance of vehicle 2

$D_2$ = desired front to rear distance of vehicle 3

A vehicle traveling behind a faster vehicle is considered to be free unless the distance to the vehicle in front is shorter than the minimum following distance. A vehicle traveling behind slower vehicle may be either free or car-following depending on vehicles' state. The desired distance between stationary vehicles in the threshold AX in Wiedemann model 1974 consists of the length of the front vehicle and the desired front – to – rear distance (see Chapter 2, Section 2.7.3). Then the desired distance to be covered by the following vehicle 2 is defined as:

$$X_1 = L_1 + D_1 \qquad (3.5)$$

Where:

$D_1 = X\_add_1 + z_1 * X\_mult_1$

$X_1 = L_1 + X\_add_1 + z_1 * X\_mult_1$ (3.6)

$L_1$ = the leading vehicle length,

$z_1$ is a normal distributed random number

$X\_add_1$ = additive part of the safety distance of vehicle 2 used to define minimum following distance

$X\_mult_1$ = multiplicative part of the safety distance of vehicle 2 used to define decelerating distance of if the value is negative and accelerating distance if positive.

Hence, with this understanding, the model is more realistic and a particular vehicle type can be identified.

For moving vehicles, the desired distance for two vehicles when three vehicles are on the road network and they are in another threshold AZ is defined as,

$AZ = X_2 + X_1$ (3.7)

where

$X_1 and X_2$ are defined in the Figure 3.3

$AZ = L_1 + X\_add_1 + z_1 * X\_mult_1 + L_2 + X\_add_2 + z_2 * X\_mult_2$ (3.8)

$D_2 = X\_add_2 + z_2 * X\_mult_2$ (3.9)

For multiple vehicles on the road network, AZ becomes,

$AZ = L_1 + X\_add_1 + z_1 * X\_mult_1 + L_2 + X\_add_2 + z_2 * X\_mult_2 + L_3 + X\_add_3 + z_3 * X\_mult_3 + \ldots\ldots\ldots\ldots\ldots\ldots + L_{n+1} + X\_add_{n+1} + z_{n+1} * X\_mult_{n+1}$

(3.10)

$AZ = \sum_{i=0}^{n}(L_{i+1} + X\_add_{i+1} + z_{i+1} * X\_mult_{i+1})$ (3.11)

Equation 3.11 is a generic equation with the following explanation;

If $L_i = L_{i+1}$, for i = 1, 2, ……. n, then the leading vehicle are of the same length with the following vehicle which implies that the vehicle is in homogeneous traffic stream that is car-to-car or bus-to- bus.

If $L_{i+1} > L_i$ , then the vehicle behind is of greater length than the following vehicle which implies that the vehicle is in heterogeneous traffic stream that is bus-to-car or truck-to- bus.

If $L_{i+1} < L_i$ , then the vehicle behind is of smaller length than the following vehicle which implies that the vehicle is in heterogeneous traffic stream that is car-to-bus or car-to- truck.

If $D_i$ is increasing, then the front vehicle is moving faster or the following vehicle is moving slower

If $D_i$ is decreasing, then the front vehicle is moving slower or the following vehicle is moving faster

If $D_i$ tends to zero, then collision is likely.

From the proposed vehicular movement model, it can be concluded that, the model will;

a. classify the vehicles with different length on the road network
b. identify the point of collision and congestion situation can be determined
c. identify when the stream of traffic is homogeneous and when it is heterogeneous

## 3.5 Study Area

The study area is chosen from Zaria metropolis located in the Northern part of Kaduna State and is the largest town apart from the state capital. Figure 3.4 illustrates the location and provides schematics diagram of the study site.


Figure 3.4: Background Map of the Study area

Zaria metropolis comprises of Sabon-Gari and Zaria Local Government Areas (LGAs) located approximately within longitudes $7^{o}$ $^{-}70^{'}$ E and latitudes $10^{o}$ 90' and $11^{o}$ 30'N. The LGAs fall within the northern Kaduna sub-region. The area has a characteristic tropical continental climate, marked by distinct wet and dry seasons. Generally, Kaduna northern area has a relatively low precipitation with average annual rainfall of about 127mm. The peak period of rainfall is August-September.

According to the 2006 census, the population of Zaria Local Government Area was 408,198 while that of Sabon-Gari LGA was 286,871 making a total of 695,069 people (NPC, 2006).
The residents are located in mostly urban neighborhoods and rural settlements. The urban neighborhoods that are the focus of this study include Samaru, Tundun Wada, Sabon- Gari town, Kwangila, Patterson Zochonis (PZ) area, Chikaji, Muchiya, Palladan, Gyellesu, Tundun Junkun, Dan-Magaji Zaria walled city, among others. Socio-culturally, the indigenous people are Hausa by Language and culture but other ethnic groups such as Igbo, Yoruba, Ibibio are also present especially in the urban areas.

## 3.6 Road Network

VISSIM describes road as a set of pairs of one-way *links* joined together at connectors. Links represent the roads in the network and thus have attributes such as speed, width, number of lanes and any lane-based restrictions, e.g. bus lanes. The network size for our simulation is 1200 meters. The vehicle enters into the network from the origin and travel along the road during simulation run to the designated destination. A node typically marks an area where links join to form junctions. Nodes can also mark points where links change characteristics, which can be any of their attributes, such as speed limit, number of lanes or a change in curvature or direction. A sectional road network of the Zaria metropolis has been modeled to represent the road network download through the Google map as shown in Figure 3.5 as a case study. The map or road network contains four links: Hospital road, New Jos road, Dan Magaji and Kofan Doka road.

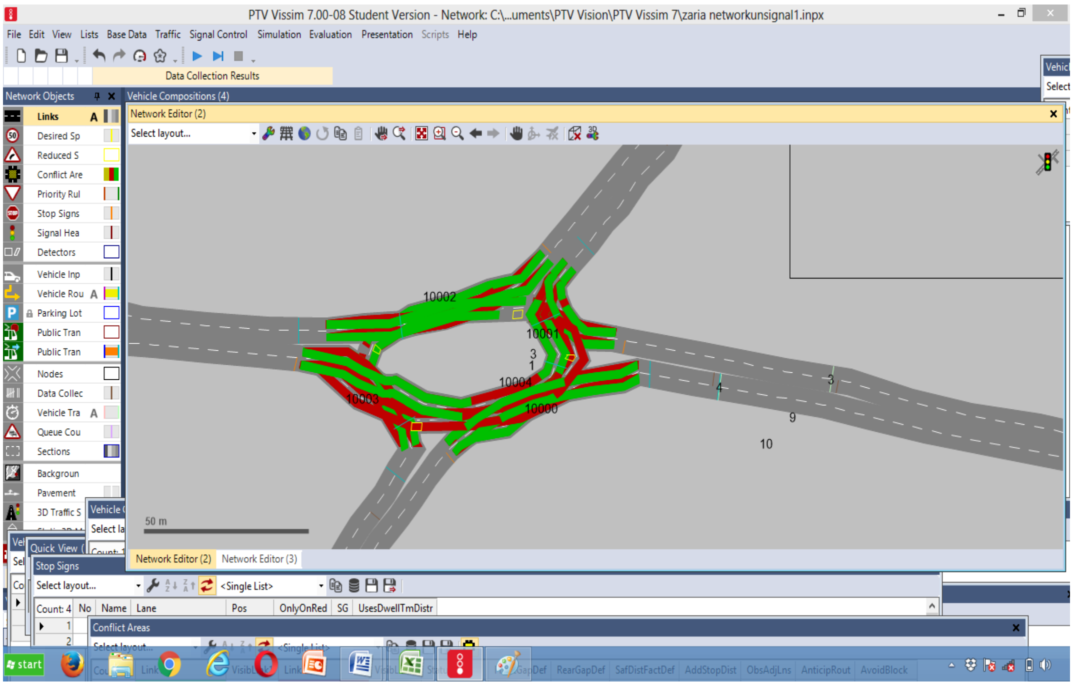



Figure 3.5: A Snapshot of Road Network based on the map of a sectional part of Zaria contains four routes as Study case

### 3.7 Impact of Vehicle Length Variation on Traffic Congestion

Direct implementation of the common existing traffic models such as Wiedemann model (1974), Gipps model (1981) and Fritzsche model (1994) will give homogeneous traffic stream. Detail of the three mentioned models in this section is described in Chapter 2, Section 2.7. There is a reflection that if the models are implemented, it will result into homogeneous traffic stream, for transport institution to achieve the heterogeneous traffic, the model needs to be modified and in this thesis, Wiedemann model is enhanced to address both homogeneous and heterogeneous traffic stream on the road as shown in Chapter 3, Section 3.4. This is because, Wiedemann model has differentiated the vehicle behavior in an urban area and in the highway as Wiedemann model 74 and Wiedemann model 99 respectively.

Simulation is carried out to implement the proposed model on the VISSIM Simulation tool as a platform. The simulation parameters for two different links (that is Hospital road in Tudun Wada, Zaria as link 1 and New Jos road as link 2) are given in Table 3.1 and Table 3.2.

Table 3.1: Simulation parameter for link 1(Hospital road, Tudun Wada, Zaria)

| LINK-1<br>(Hospital Road, Tudun Wada, Zaria) | VALUES |
|---|---|
| DISTANCE | 150 Meters |
| TRAVEL TIME | 30Mins. |
| SPEED | 144m/s (40Km/Hr) |
| Vehicle_ length for bus | 11.540m |
| Vehicle_ length for truck | 10.220m |
| Vehicle_ length for average Car | 4.335m |

Table 3.2: Simulation parameter for link 2 (New Jos Road, Zaria)

| LINK-2 (New Jos Road, Zaria) | VALUES |
|---|---|
| DISTANCE | 150 Meters |
| TRAVEL TIME | 30Mins. |
| SPEED | 144m/s (40Km/Hr) |
| Vehicle_ length for bus | 11.540m |
| Vehicle_ length for truck | 10.220m |
| Vehicle_ length for average Car | 4.335m |

3.7.1 Vehicle characteristics

Vehicles are defined by the individual vehicle characteristics. The vehicle characteristics can be divided into static vehicle properties that remain constant during the simulation and dynamic vehicle properties that change as the vehicle travels along the road during the simulation. The static vehicle properties are, with index n referring to vehicle;

a. Vehicle type, $Veh_n$,
b. Vehicle Length, $L_{n\,(m)}$,
c. Desired speed, $V_n^{desire}$ $(m/s^2)$,
d. Origin, $O_n$,
e. Destination, $D_n$,
f. Entry_ time, $t_n^{depentry}$(s) and
g. Exit_ time, $t_n^{exit}$ (s).

All static vehicle properties are set in the traffic generation process. The traffic generations model includes three vehicle classes, $Veh_n$ such as car, truck and bus. The desired speed is the individual basic desired speed. The origin, $O_n$ and destination, $D_n$ , includes the road coordinate of the entrance or destination point respectively. For vehicles with origin or destination at the ends of the main road the entrance or exit is at the centre of the road. The entry time, $t_n^{depentry}$(s) is the first time that the vehicle will try to enter the main road. The exit time, $t_n^{exit}$ (s), is the time the vehicle will be leaving the road.

### 3.8 Traffic Congestion Reduction Planning Scheme

Traffic congestion can be reduced on the part of the government only by expanding the road to contain more vehicles which may eventually leads to traffic free flow. This solution can be termed short – term solution because, as the economy of the nation is increasing, citizens are liable to purchase more vehicles and the road could by that time congest with vehicles but for the road to have long term solution, route alternation guiding scheme needs to be employed. Drivers will be guided on which route to take as route information system would have been installed in each of the vehicle's on-board unit. The simple framework is depicted in Figure 3.6 below;

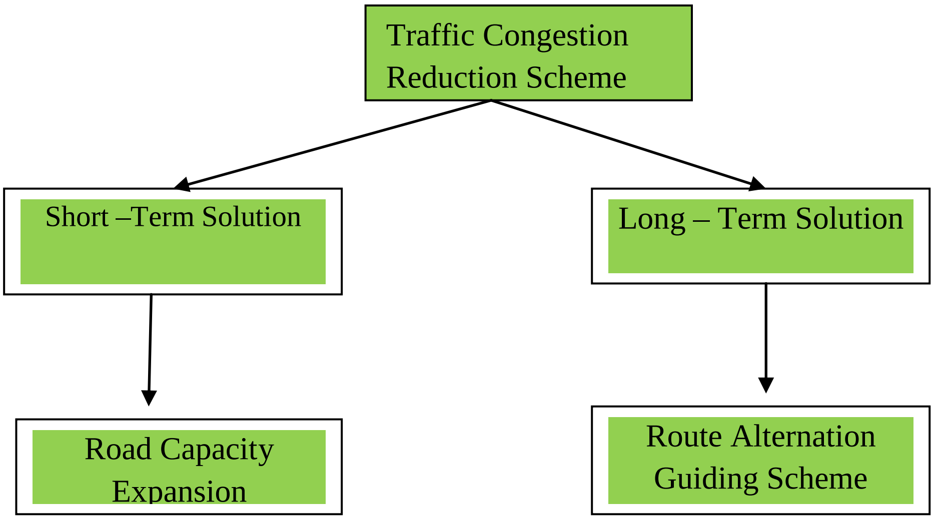



Figure 3.6: Traffic Congestion Reduction Planning Scheme

a. *Route Choice Model for Drivers' Alternation:* Vehicular behavior in an ad-hoc network involves some factors such as drivers, vehicles, roads, surrounding environment and roads infrastructures during the driving process; drivers are accompanied with complex decision variable. Every vehicle is expected to install route information system in their vehicle and this can be more effective if it is a government policy. All the vehicle details would have been collected before the installation of the route information system and traffic authority would know how to handle the violators. The driver will only need to supply the name of his present position and the destination. The system will provide the road information for the driver to make decision on the route to take. The system will provide the least traffic flow if other available route(s) is congested and all the route information to the destination chosen by the driver will be provided if not congested.

Then, information on all the routes will be updated and invariably free flow will be maintained in all the trips that has alternative route. This scheme will provide long term solution to traffic congestion reduction since there will be constant update of the road information. The routing processes of the traffic routing scenarios can be explained with the route alternation algorithm 3:

---

Route Guiding System Algorithm

---

```
// Route Alternation Algorithm 3
//Input: Registered driver's source and destination
//Output: List of free traffic flow routes for the registered driver
// numOfRoutes = number of available routes from the source to the destination
Input: source, destination
 if (numOfRoutes < 1)
                return "No route from the source to the destination"
        else if (numOfRoutes == 1)
                 return "No alternative route"
        else
```

```
                    j = 0
            while ( j <  numOfRoutes )
                  trafficFlow [ j ] = traffic_ Flow_j
                  maxFreeFlow [j] = max_ Free_ Flow_j
                     j ++
            end while
    for ( i = 0 to numOfRoutes - 1)
        if (trafficFlow[ i ] < maxFreeFlow[ i ])
               routeList [ i ] = route_ info_i
        end if
    end for
        return routeList     // only route not congested
        driver takes route with least traffic
        update  route traffic flow
end if
```

Algorithm 4: Route Alternation

The drivers' route alternation algorithm developed will be implemented with JAVA programming language. Then, the traffic information received from different route will lead to the drivers switching to alternative routes which eventually reduce the traffic congestion on the road. However, positive effect can be achieved from the periodic information received from the cloud through the road infrastructures about the road condition.

*b. Road capacity Expansion:* Expansion of road is a physical means of solving the problem of traffic congestion and it is proposed so as to take care of the road without alternative routes and since it cannot be controlled, it is still remaining the only physical means to solve immediate traffic problems by the government or road authorities.

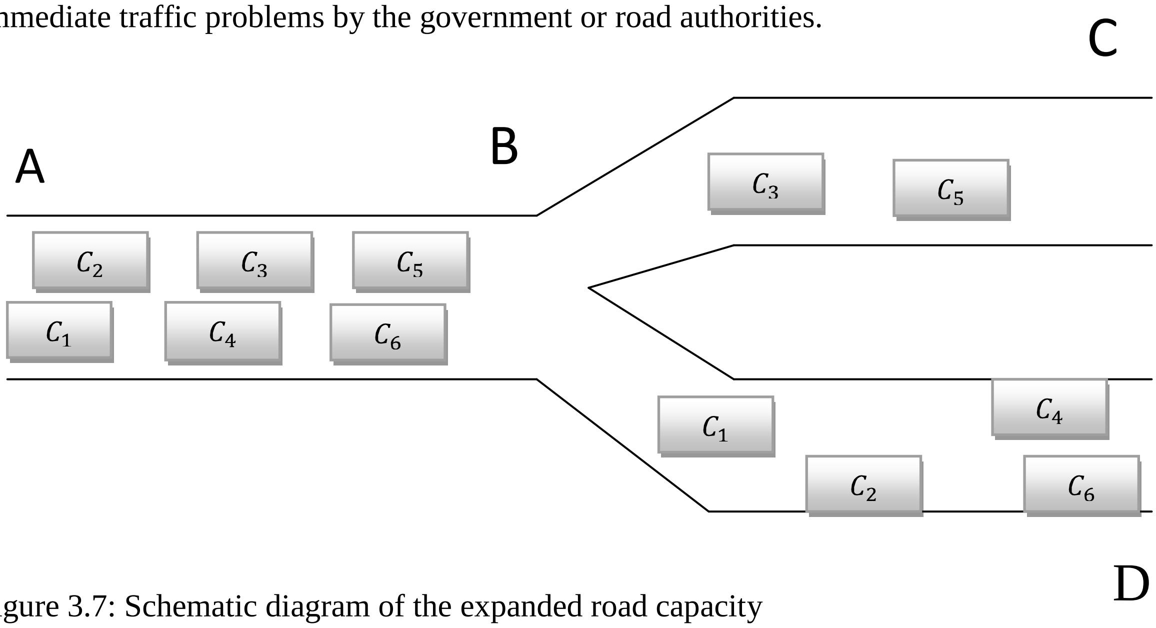
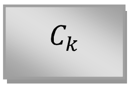


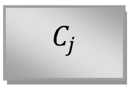

Figure 3.7: Schematic diagram of the expanded road capacity

where

is to represent each vehicle on AB as link-1



is to represent each vehicle on BC as link-2



is to represent each vehicle on BC as link-3

$C_s = C_1, C_2, \dots \dots \dots \dots .. C_n$

$C_k = C_1, C_2, \dots \dots \dots \dots .. C_n$

$C_j = C_1, C_2, \dots \dots \dots \dots .. C_n$

n = maximum number of the vehicles in each road.

AB= Original road, $R_1$

BCD = expanded roads which contains the road BC and BD

R is the set of roads

R = $\{R_1, R_2, R_3\}$

$R_1 = AB$ , $R_2 = BC$, $R_3 = BD$

Note, each road has equal distance

$Totf_{free}$ denotes the total capacity of $R_i$ for free flow of vehicles on the road

f($C_s$) = AB; f($C_k$) $= BC$; f($C_j$) = BD

Traffic flow = f($C_i$)

TT = Travel Time

---

Road Capacity Expansion Algorithm

---

1. Input: $R_i \in R$ ∀ i = 1 to 3
2. f($C_s$) , f($C_j$), f($C_k$) $\in R$
3. $R_1$ = f($C_s$), $R_2 =$ f($C_j$) $and$ $R_3 =$ f($C_k$)
4. If $R_i = M(f_{free})$ then
5. $R_1^{M(f_{free})} < R_2^{M(f_{free})} + R_3^{M(f_{free})}$
6. end if
7. if $1/n \sum_{s=1}^{n} TT_{f(C_s)} > 1/n \sum_{j=1}^{n} TT_{f(C_j)} + 1/n \sum_{k=1}^{n} TT_{f(C_k)}$ then
8. average travel time AB is greater
9. Else
10. average travel time AB is lesser
11. end if
12. Output:
13. f($C_s$) $and\ total$ ( f($C_j$) $and$ f($C_k$)) is compared
14. $TT_{f(C_s)}$ $and\ total$ ( $TT_{f(C_j)}$ $and$ $TT_{f(C_k)}$) is compared

---

Algorithm 5: Road Capacity Expansion Algorithm

## 3.9 Hardware and Software Requirement for VISSIM

VISSIM runs on Windows based machines including XP, Vista (32-bit and 64-bit), and Windows 7 & 8 (32-bit and 64-bit). It can run on Linux and Intel-based Apple Macs using a Windows Emulator called WINE. VISSIM only requires 25 MB RAM for small applications, but can use much more RAM for large applications or large user matrices. While there are no special requirements for the graphics, it is recommended that a reasonably powerful graphics card be used, especially if 3D graphics seem important. Microsoft.net framework 3.5 is required

For 32-bit operating system Microsoft.Net framework 4.5 is required.

For hardware requirement:

a. Processor: minimum of Pentium IV and core i7 is recommended.

b. Speed minimum 2 GH3 (faster computer speed results in faster simulation speed

c. Memory (RAM) with 2GB (4GB for 64 bit edition), 4-8GB for large network

d. Hard disk space depending on the installation settings up to 1.5GB

e. One fully functional USB part

f. Screen resolution with minimum of 1280 x 800 or 1368 x 768 Pixel

g. Graphics card for 3D Graphics Open GL-support

# CHAPTER FOUR

# RESULTS AND DISCUSSIONS

## 4.1 Introduction

In this Chapter, cloud-based traffic control strategies are implemented to reduce traffic congestion in urban area. This is achieved by looking at the expansion of road capacity to accommodate free flow of the vehicles and by providing real time information to drivers for their routing request to guide them on which route to take in order to maintain free flow on the roads. Traffic simulation model is developed by using VISSIM simulation tool as a platform to model the road network for the study area and CloudSim simulation tool for simulating cloud environment to accommodate route and vehicle information.

## 4.2. Comparison of Homogeneous Traffic Stream with Heterogeneous Traffic Stream

Vehicle behavior simulation is one of the fundamental tasks of the simulator. Traffic flow is defined by the movement of vehicles and each vehicle in the simulation is a semi-independent agent that can have its behavior customized. All vehicles share the same behavior model but it can be parameterized to make each vehicle distinct. It is assumed that all equipped vehicles have wireless communication that makes it possible for them to communicate with the infrastructure using Vehicle to Infrastructure (V2I) technology. Vehicles that are not equipped with wireless communication are referred to as normal or manual vehicles.

All vehicles are expected to be equipped with Internet connectivity. The Vehicle mix used in the simulation to experiment heterogeneous traffic stream is seven different types of cars, bus and truck (Heavy Gross Vehicle- HGV) and for homogeneous stream; single vehicle type is simulated as bus, car and truck.

Figure 4.1 shows the graphical representation of the result obtained from the simulation of link 1 (Hospital Road, Tudun Wada, Zaria). It has been able to compare the effect of the variation in the length of the vehicles in both homogeneous and heterogeneous traffic stream based on the vehicle types.

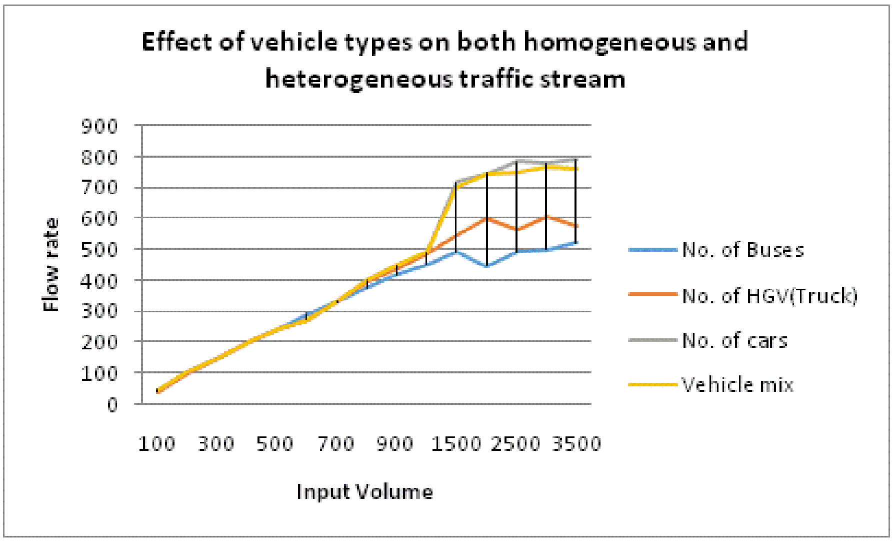



Figure 4.1: Effect of Vehicle Types in both Homogeneous and Heterogeneous Traffic Stream on Link 1

Vehicles are simulated with different vehicle types at different volume of vehicle input starting from 100 to 3500 and the result of the flow for every 30 minutes is shown in Table 4.1 along with vehicle mix. Vehicle mix is heterogeneous traffic stream that contain different vehicle types. From the Table 4.1, the effect of vehicle types in homogeneous and heterogeneous traffic stream when the road is congested and when there is free flow could be compared. It also showed that vehicle types with different length has different effect on road congestion.

Table 4.1: Dataset of vehicle types in both homogeneous and heterogeneous traffic stream on Link 1

| Volume | No. of Buses | No. of HGV(Truck) | No. of cars | Vehicle mix |
|---|---|---|---|---|
| 100 | **39** | **39** | **45** | **45** |
| 200 | **102** | **102** | **102** | **102** |
| 300 | **147** | **147** | **147** | **147** |
| 400 | **198** | **198** | **198** | **198** |
| 500 | **243** | **243** | **243** | **243** |
| 600 | **291** | **273** | **273** | **273** |
| 700 | **330** | **330** | **333** | **333** |
| 800 | 378 | 396 | **402** | **402** |
| 900 | 420 | 441 | **450** | **450** |
| 1000 | 453 | 489 | **492** | **492** |
| 1500 | 492 | 546 | 717 | 702 |
| 2000 | 447 | 600 | 744 | 741 |
| 2500 | 492 | 570 | 783 | 747 |
| 3000 | 499 | 609 | 777 | 765 |
| 3500 | 522 | 576 | 789 | 759 |

From the traffic count collected by Federal Road Safety Commission of Zaria command RS1.13 as at June, 2015 from Zaria to PZ, the relative ratio of car to luxurious bus to lorry/truck is 0.89, 0.03, 0.08 respectively and the researchers as at another June, 2016 collected traffic count of car, luxurious bus, lorry/truck from the same route Hospital road PZ is of the relative ratio of 0.90, 0.01, 0.09 respectively. The traffic count collected by both the researcher and the FRSC was done manually. Although, the density of flow has increased in the following year but the result of the traffic count at different years has the same relative ratio, the researchers decided to use the most recent information to simulate the vehicle mix. The detailed traffic count information collected by both FRSC and the researchers is at Appendix 9. When traffic simulation is also carried out on the link 2, the data set illustrating the effect of vehicle types in both homogeneous and heterogeneous traffic stream is shown in table 4.2 and graphically represented in Figure 4.2 below;

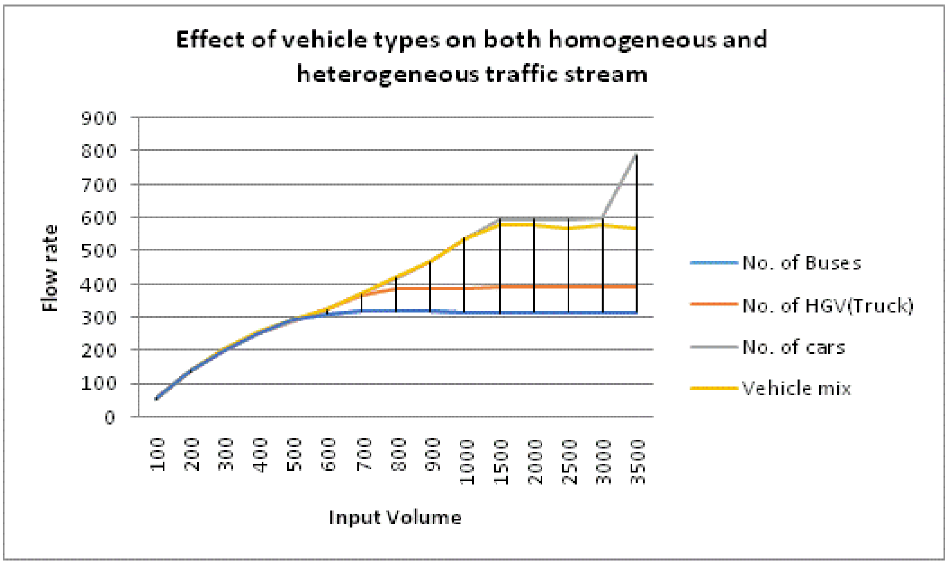



Figure 4.2: Effect of Vehicle Types in both Homogeneous and Heterogeneous Traffic Stream on Link-2

The observation made in link-1 is the same as the one in link-2.

Table 4.2: Dataset of Vehicle Types in both Homogeneous and Heterogeneous Traffic Stream

| Volume | No. of Buses | No. of HGV(Truck) | No. of cars | Vehicle mix |
|---|---|---|---|---|
| 100 | **54** | **54** | **57** | **57** |
| 200 | **138** | **138** | **138** | **141** |
| 300 | **201** | **201** | **204** | **204** |
| 400 | **252** | **252** | **252** | **255** |
| 500 | **291** | **291** | **291** | **291** |
| 600 | 309 | 324 | **324** | **324** |
| 700 | 318 | 369 | **369** | **369** |
| 800 | 318 | 390 | **420** | **420** |
| 900 | 318 | 390 | **468** | **468** |
| 1000 | 315 | 390 | 537 | 534 |
| 1500 | 312 | 393 | 594 | 576 |
| 2000 | 315 | 393 | 594 | 576 |
| 2500 | 315 | 393 | 594 | 567 |
| 3000 | 315 | 393 | 597 | 576 |
| 3500 | 315 | 393 | 789 | 567 |

When the simulation is carried out with different type of vehicle and the same type of vehicle on Link-1 Hospital Road, the following observation are made; buses or trucks can maintain free flow when the vehicle population is within 1 to 291 and reaches traffic congestion when the road contains 318 buses, or 393 trucks. Cars or Vehicle mix can maintain free flow when the vehicle population is within 1 to 468 and reaches traffic congestion when the road contains 393 cars or 789 vehicle mix.

On Link-2 New Jos Road, buses or trucks can maintain free flow when the vehicle population is within 1 to 330 and reaches traffic congestion when the road contains 522 buses, or 576 trucks. Cars or Vehicle mix can maintain free flow when the vehicle population is within 1 to 492 and reaches traffic congestion when the road contains 789 cars or 765 vehicle mix

The impact of Vehicle type(s) on Road Traffic Congestion are as follows;

a) On heterogeneous traffic stream, the more the number of trucks and buses on the road, the quicker the road get congested.

b) On homogeneous traffic stream, more cars can be on the road because of the size of the vehicle length.

## 4.3 Code Implementation of Route Information System

When Cloudsim simulator is run on Netbeans Integrated Development Environment (IDE), it reads the output of the vehicle information generated from the equipped vehicle during traffic simulation on VISSIM simulation tool and stored it in cloud storage. All the available routes are also compiled and stored in the cloud storage. The vehicle information and available route that are stored in the cloud storage are displayed below;

run:

Starting CloudSimExample1...

Initialising...

Starting CloudSim version 3.0

Datacenter_0 is starting...

Broker is starting...

Entities started.

0.0: Broker: Cloud Resource List received with 1 resource(s)

0.0: Broker: Trying to Create VM #0 in Datacenter_0

0.1: Broker: VM #0 has been created in Datacenter #2, Host #0

0.1: Broker: Sending cloudlet 0 to VM #0

400.1: Broker: Cloudlet 0 received

400.1: Broker: All Cloudlets executed. Finishing...

400.1: Broker: Destroying VM #0

Broker is shutting down...

Simulation: No more future events

Cloud Information Service: Notify all CloudSim entities for shutting down.

Datacenter_0 is shutting down...

Broker is shutting down...

Simulation completed.

Simulation completed.

========== OUTPUT ==========

| Cloudlet ID | STATUS | Data center ID | VM ID | Time | Start Time | Finish Time |
|---|---|---|---|---|---|---|
| 0 | SUCCESS | 2 | 0 | 400 | 0.1 | 400.1 |

Available Routes

| S/NO | ROUTE | SOURCE | DESTINATION | TRAFFIC FLOW | MAX FREE FLOW |
|---|---|---|---|---|---|
| 1 | Along PZ road | Kwangila | Gaskiya | 52 | 760 |
| 2 | Overhead bridge | Kwangila | Gaskiya | 20 | 543 |
| 3 | Dan Magaji road | Hospital Road | Kaduna | 22 | 349 |
| 4 | Zaria City road | Hospital Road | Kaduna | 399 | 400 |
| 5 | Zaria city road | Hospital Road | Zaria City | 400 | 600 |
| 6 | Along new Jos Rd | Zaria City | New Jos Road | 150 | 670 |
| 7 | Hospital road | New Jos Road | Gaskiya | 34 | 752 |
| 8 | Take DanMagaj Rd | New Jos Road | Gaskiya | 233 | 566 |
| 9 | Take Jos Road | New Jos Road | Kaduna Expr | 56 | 567 |
| 10 | Take Hospital Rd | New Jos Road | Kaduna Expr | 231 | 800 |

Vehicle Information

| S/No | Vehicle Id | Vehicle Type | Speed | Acceleration | Vehicle Length (M) | Entry Time | Exit Time |
|---|---|---|---|---|---|---|---|
| 1 | 10 | Bus | 44.1 | 0.27 | 11.54 | 08:06:34 | 08:07:28 |
| 2 | 11 | Bus | 41.6 | 0.00 | 11.54 | 08:05:28 | 08:06:28 |
| 3 | 15 | Bus | 38.3 | -0.88 | 11.54 | 08:07:50 | 08:09:03 |
| 4 | 19 | Bus | 44.4 | -0.88 | 11.54 | 08:13:18 | 08:14:15 |
| 5 | 22 | Car | 39.8 | -0.07 | 3.75 | 08:12:21 | 08:12:55 |
| 6 | 23 | Car | 28.9 | -0.99 | 4.21 | 08:15:01 | 08:15:56 |
| 7 | 25 | Car | 47.4 | -0.02 | 4.76 | 08:14:10 | 08:15:06 |
| 8 | 32 | Car | 43.3 | -0.08 | 3.75 | 08:17:20 | 08:17:52 |
| 9 | 33 | Bus | 39.0 | -0.43 | 11.54 | 08:19:09 | 08:20:22 |
| 10 | 4 | Bus | 40.2 | 0.00 | 11.54 | 08:04:07 | 08:05:10 |
| 11 | 6 | Truck | 55.7 | -0.86 | 10.22 | 08:04:56 | 08:05:23 |
| 12 | 7 | Bus | 40.3 | -0.14 | 11.54 | 08:11:36 | 08:12:40 |
| 13 | 8 | Truck | 49.6 | 0.07 | 10.22 | 08:04:50 | 08:05:24 |

Figure 4.3: Available Routes and Vehicle Information Output

CloudSim Information Successfully Displayed!

BUILD SUCCESSFUL (total time: 2 seconds)

When the flow information is received at the Traffic Control Center (TCC), the vehicles received updated information of the road provided by the cloudlet in each ad-hoc network area. It is assumed that all the licensed vehicles are registered and only the licensed vehicles are allowed on the road. It is also assumed that route information and guiding system has been installed on each vehicle at the point of registration. There are four possible outputs that could be generated from the system. The first scenario is when the driver enters the source location as shown in Figure 4.4 and the destination as shown in Figure 4.5 so that the driver would be able to know which route is more congested or least congested.

In this circumstance, if the driver enters wrong destination or the destination that is not having linkage with the source link, the information that would be displayed on the screen of the On Board Unit (OBU) of the vehicle is shown in Figure 4.6

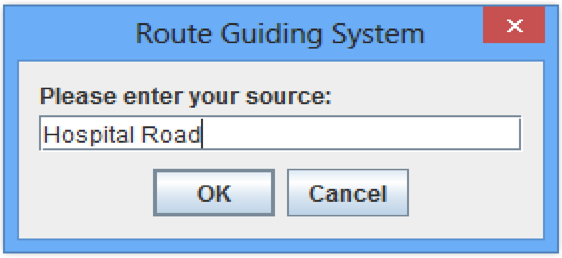



Figure 4.4: Route Guiding System Source Dialog Box (1st Scenario)

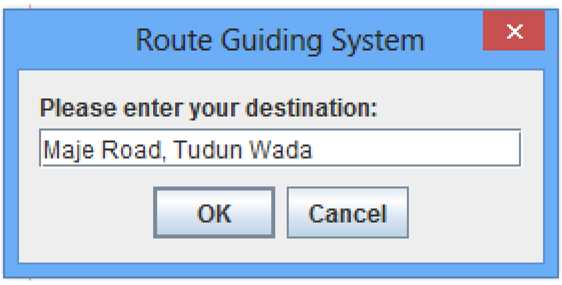



Figure 4.5: Route Guiding System Destination Dialog Box (1st Scenario)

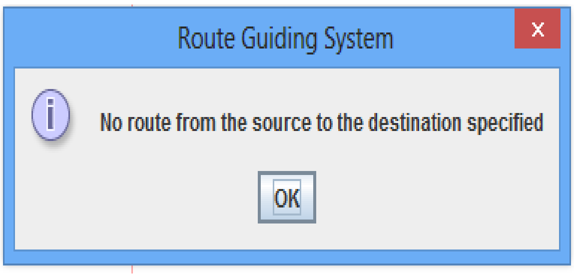



Figure 4.6: Route Guiding System Output Dialog Box (1st Scenario)

For the second scenario, if the driver enters the name of the road where he is taken off as shown in Figure 4.7 and the destination is as shown in Figure 4.8 and the destination is not having alternative road(s), the information system on the On Board Unit (OBU) will display information as shown in Figure 4.9

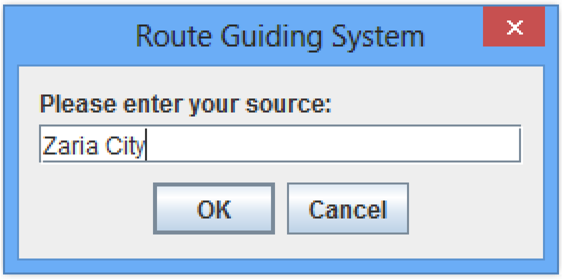



Figure 4.7: Route Guiding System Source Dialog Box (2nd Scenario)

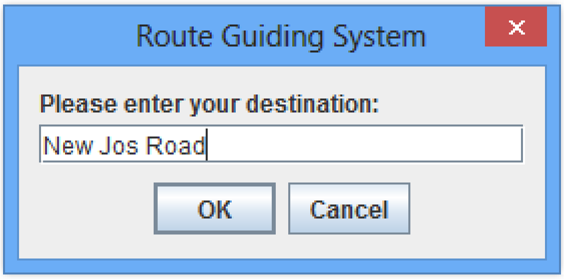



Figure 4.8: Route Guiding System Destination Dialog Box (2nd Scenario)

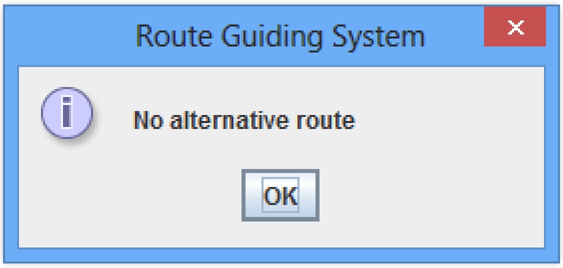
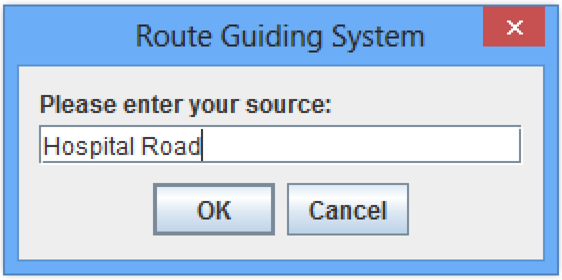



Figure 4.9: Route Guiding System Output Dialog Box (2nd Scenario)

For the third scenario, if driver enters the name of the road where he is taken off as shown in Figure 4.10 and the destination is as shown in Figure 4.11 and there is more than one alternative roads linking the source and all the flows in the alternative roads are less than the maximum capacity of the road, the information system on the On Board Unit (OBU) will display all the routes for the driver as shown in Figure 4.12 and it would be left for the driver to select any of the options and the database will be updated immediately. This is an indication that the system is flexible enough to consider the users' interest.



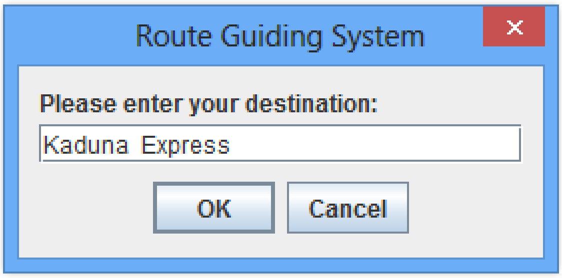




Figure 4.10: Route Guiding System Source Dialog Box (3rd Scenario)

Figure 4.11: Route Guiding System Destination Dialog Box (3rd Scenario)

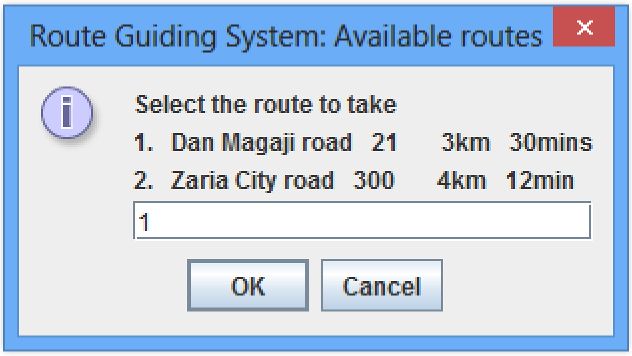



Figure 4.12: Route Guiding System Output Dialog Box (3rd Scenario)

The last Scenario is that, in another situation where the roads are congested, the system would display the least congested area and advice the driver to take the route.

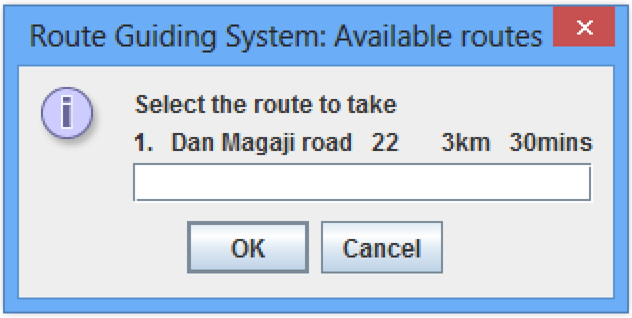



Figure 4.13: Route Guiding System Output Dialog Box (4th Scenario)

### 4.4 Effect of Road Capacity Expansion on Traffic Congestion Reduction

After simulation of the existing road, the capacity of the road was re-modeled and simulated to observe the differences. Effect of road capacity expansion on the current lane is investigated using traffic simulation model and the data collected is analyzed and evaluated with the percentage change. Percentage change is one means of demonstrating program impact or conveying the magnitude of a change. It shows the difference between the after versus before values. Percentage change can be positive or negative and it can be calculated as ((after value – before value) / before value) * 100 = % change (Pope, 2008). The Percentage of Improvement (PoI) as used to quantify the extent to which road capacity expansion can reduce traffic congestion.

Percentage of Improvement (PoI) is used to investigate the efficiency and proportional improvement of the road capacity expansion and it can be tested with any of the following parameters; the travel times, traffic flows and density of the vehicles. The PoI gives the absolute percentage increase of the relative change from the starting value.

$$PoI = \frac{100}{n}\sum_{i=1}^{n}\left(\frac{k_{expanded.lane}(i)-k_{original.lane}(i)}{k_{original.lane}(i)}\right) \tag{4.1}$$

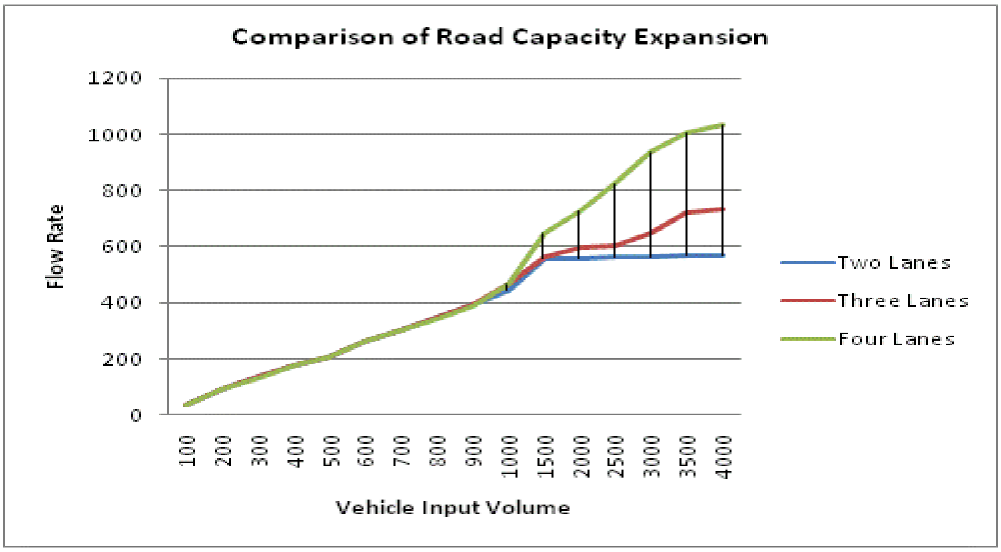



Figure 4.14: Comparison of road capacity expansion

Table 4.3: Data set to illustrate the comparison of road capacity expansion

| Volume | Flow on Two Lanes (L2) | Flow on Three Lanes(L3) | Flow on Four Lanes(L4) | diff3 =L3-L2 | diff4 =L4-L2 |
|---|---|---|---|---|---|
| 100 | 36 | 36 | 36 | 0 | 0 |
| 200 | 90 | 90 | 90 | 0 | 0 |
| 300 | 135 | 135 | 135 | 0 | 0 |
| 400 | 177 | 177 | 177 | 0 | 0 |
| 500 | 204 | 204 | 204 | 0 | 0 |
| 600 | 261 | 261 | 261 | 0 | 0 |
| 700 | 303 | 303 | 303 | 0 | 0 |
| 800 | 345 | 345 | 345 | 0 | 0 |
| 900 | 390 | 390 | 390 | 0 | 0 |
| **1000** | **444** | **468** | **468** | 0 | 0 |
| **1500** | **555** | **560** | **648** | 5 | 93 |
| **2000** | **558** | **597** | **730** | 39 | 172 |
| **2500** | **561** | **603** | **823** | 42 | 262 |
| **3000** | **564** | **645** | **940** | 81 | 376 |
| **3500** | **567** | **720** | **1007** | 153 | 440 |
| **4000** | **567** | **731** | **1034** | 164 | 467 |

In the first scenario, the volume of vehicle input is 100 and when simulated for the period of 30 minutes, the flow on the two lanes is 36 which is represented by $k_{original.lane}$ (1) and when the link is expanded by one lane, the flow is 36 which is also represented by $k_{expanded.lane}$ (1). This is an indication of free flow. In another scenario, when the volume of vehicle input is 4000, the flow on the original lane (two lanes), $k_{original.lane}$ (16) is 567 while the flow on the link when expanded by single lane, $k_{expanded.lane}$ (16) is 731. The link contains two lanes and when expanded by a single lane, it will be three lanes on the link.  When vehicle input volume increases to 1000, the improvement on the expansion started showing and the percentage of improvement was calculated at different scenario to realize an approximately 10.823% improvement on expansion by one lane.

where n= 7 for every scenario that shows traffic congestion.

$$PoI = \frac{100}{n}\sum_{i=1}^{n}(\frac{k_{expanded.lane}(i) - k_{original.lane}(i)}{k_{original.lane}(i)}) = 10.82\%$$

More so, when the link is expanded by two lanes and the volume of vehicle input used for each simulation in every 30 minutes is the same for uncongested traffics. Immediately the congestion started occurring, the original lane and the expanded lane started different values. Take for example, when the volume of vehicle input is 4000, the original lanes which is two lanes, $k_{original.lane}$ (16) has 567 number of vehicles and when the link is expanded by two lanes, $k_{expanded.lane}$ (16) the flow is 1034. The calculated percentage of improvement when the link is expanded by two lanes is approximately 46.617%

where n= 16.

$$PoI = \frac{100}{n}\sum_{i=1}^{n}(\frac{k_{expanded.lane}(i) - k_{original.lane}(i)}{k_{original.lane}(i)}) = 46.62\%$$

## 4.5 Calibration and Validation of the Simulation Model Using Simulated Data.

Calibration and Validation data is required only when a micro-simulation approach is used (FDOT, 2014). The importance of the accuracy of traffic counts and other field measured data for model calibration and validation emphasizes the need for careful planning and diligence of a data collection plan, in this research, flow rate is a parameter used for the calibration and validation of the simulation model. Validation of the models is carried out using simulated data. A traffic network similar to the field test bed is created in VISSIM and data collector is placed on each link of the route to collect the current flow, average flow and travel time. A route is the sequence of links and the connector. The vehicles are also generated based on the field values to mimic the field scenario. Traffic volumes from the field are used as input to VISSIM at every 10-minute interval which is an equivalent of 600 simulation time.

Data are generated for 12 hours, which included both peak and off-peak flows. These data are used for checking the validity of the proposed model. The flow of the vehicles is collected from the field manually and is compared to the flow rate given by the simulation. The results presented in Table 4.6 to 4.8 are the simulated data at every 30-minute interval which is an equivalent of the observed field data at every 1-hour interval during calibration process. Prior to analyzing the measure of effectiveness, the flow rate distributions and periodic time or interval of simulation data and observed data are graphically compared. When field observation and predicted (simulated) data closely match, the measures of effectiveness are employed to quantify the amount of error between the two data sets. In order to examine the accuracy of the proposed simulation model, Root Mean Square Error (RMSE) and Root Mean Square Normalized Error (RMSNE) are minimized during the calibration process to investigate the amount of error compared with the flow rate and periodic time at different routes. Running simulation model that has not been calibrated with real data may not give accurate result.

Typically the model will either give misleading results, or it will lock up and give no results at all. Even if non calibrated model is run, its results are highly dubious and should be regarded with utmost suspicion. Model validation is the process of testing the performance of the calibrated model. The Root Mean Squared Normalized Error (RMSNE) measures the percentage deviation of the simulation output from observed data. This statistic measures the percentage of the typical relative error and it can be used to determine the width of the confidence intervals for the predictions. Mathematically, it can be expressed as:

$$RMSNE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\frac{(k_{sim}(i)-k_{obs}(i))^2}{k_{obs}(i)}} \quad (4.2)$$

where $n$ is the total number of traffic measurement observations, $k_{sim}(i)$ and $k_{obs}(i)$ are simulated and observed data respectively. The Root Mean Square Error (RMSE) has been discussed in Chapter 2, Section 8,

Mathematically, RMSE is expressed as:

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(k_{sim}(i) - k_{obs}(i))^2} \qquad (4.3)$$

The model results are validated using field data by comparing them with simulation data obtained from VISSIM simulation tool. The results obtained for link 1 which is the Hospital road Tudun Wada in Zaria and is shown graphically in Figure 4.15 to Figure 4.21 (see Figure 3.4 in Chapter 3, Section 3.5 for the original background map of the study area and the road network of the simulation model in Figure 3.5 in Chapter 3, Section 3.6).

Data collection is a critical step in the analysis process. Knowing what to collect, when to collect, how long to collect, where to collect, and how to manage the data must be addressed before starting the collection. In each of the day, traffic count is taken between 07.00hrs-19.00hrs making 12hours.

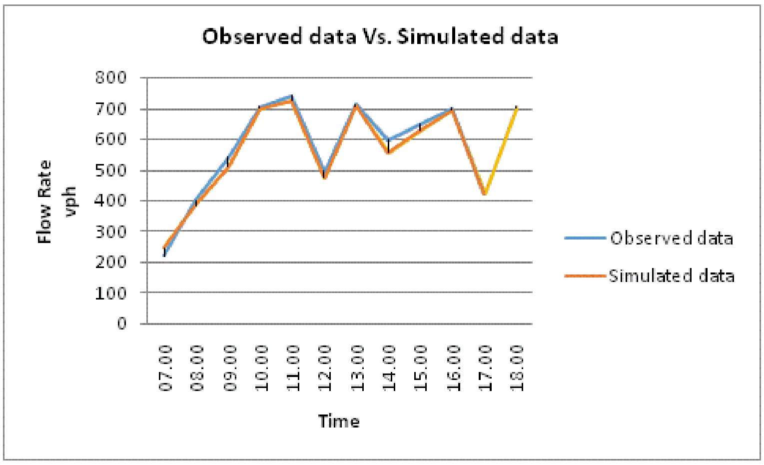



Figure 4.15 : Comparing Simulated data with Field Vehicular Traffic Flow for 12-hour on Saturday June 4th, 2016 on Link- 1

Table 4.4: Data set to illustrate the observed data on Saturday June 4th, 2016 and simulated data on Link-1

| Time interval | Observed, $k_{obs}(i)$ | Simulated, $k_{sim}(i)$ | $Q1$ | $Q1^2$ | $Q2$ | $Q2^2$ |
|---|---|---|---|---|---|---|
| 07.00 - 08.00 | 220 | 246 | 26 | 0676 | 0.1182 | 0.0140 |
| 08.00 - 09.00 | 400 | 384 | -16 | 0256 | -0.0400 | 0.0016 |
| 09.00 - 10.00 | 542 | 510 | -32 | 1024 | -0.0590 | 0.0035 |
| 10.00 - 11.00 | 705 | 702 | -03 | 0009 | -0.0043 | 2E-05 |
| 11.00 - 12.00 | 741 | 726 | -15 | 0225 | -0.0202 | 0.0004 |
| 12 .00 - 13.00 | 494 | 474 | -20 | 0400 | -0.0405 | 0.0016 |
| 13.00 - 14.00 | 713 | 708 | -05 | 0025 | -0.0070 | 5E-05 |
| 14.00 - 15.00 | 599 | 558 | -41 | 1681 | -0.0685 | 0.0047 |
| 15.00 - 16.00 | 648 | 630 | -18 | 0324 | -0.0278 | 0.0008 |
| 16.00 - 17.00 | 702 | 696 | -06 | 0036 | -0.0086 | 7E – 05 |
| 17.00 - 18.00 | 420 | 420 | 0 | 0000 | 0 | 0 |
| 18.00 - 19.00 | 706 | 702 | -04 | 0016 | -0.0057 | 3E-05 |

$$Q1 = k_{sim}(i) - k_{obs}(i)$$

$$Q2 = \frac{k_{sim}(i) - k_{obs}(i)}{k_{obs}(i)}$$

$$\sum_{i=1}^{n}\left(\frac{k_{sim}(i)-k_{obs}(i)}{k_{obs}(i)}\right)^2 = 0.0267$$

n= 12, where n is each hour

$$RMSNE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(\frac{k_{sim}(i) - k_{obs}(i)}{k_{obs}(i)}\right)^2} = 0.047$$

$$\sum_{i=1}^{n}(k_{sim}(i) - k_{obs}(i))^2 = 4672$$

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(k_{sim}(i) - k_{obs}(i))^2} = 19.732$$

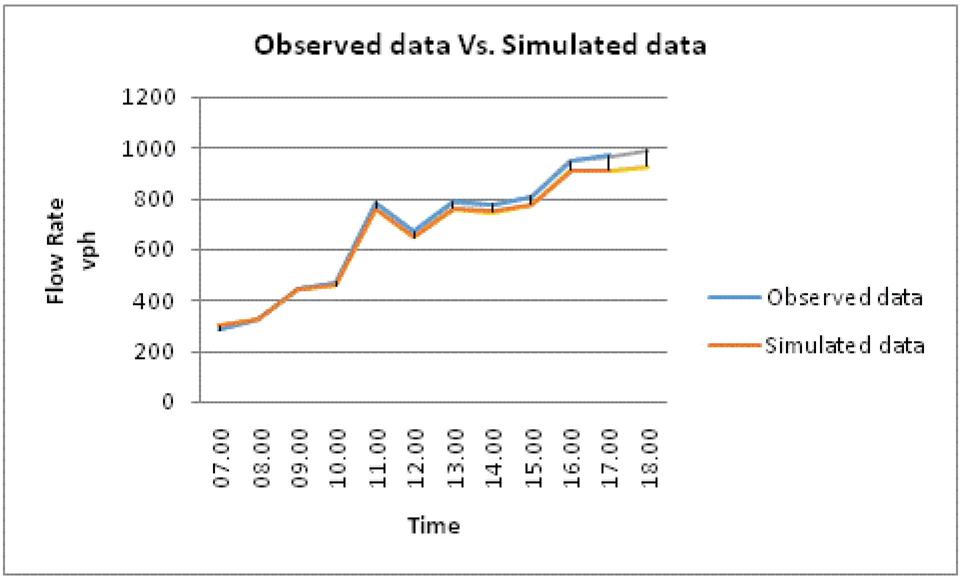



Figure 4.16: Comparing Simulated data with Field Vehicular Traffic Flow for 12-hour on Monday June 6th, 2016 on Link-1

Table 4.5: Data set to illustrate the observed data on Monday June 6th, 2016 and simulated data on Link-1

| Time interval | Observed, $k_{obs.}(i)$ | Simulated, $k_{sim}(i)$ | $Q1$ | $Q1^2$ | $Q2$ | $Q2^2$ |
|---|---|---|---|---|---|---|
| 07.00 - 08.00 | 286 | 300 | 14 | 0196 | 0.0031 | 0.0024 |
| 08.00 - 09.00 | 323 | 324 | 1 | 0001 | 0.0031 | 1E-05 |
| 09.00 - 10.00 | 444 | 444 | 0 | 0000 | 00000 | 00000 |
| 10.00 - 11.00 | 469 | 456 | -13 | 0169 | -0.0277 | 0.0008 |
| 11.00 - 12.00 | 785 | 762 | -23 | 0529 | -0.0293 | 0.0009 |
| 12 .00 - 13.00 | 668 | 648 | -20 | 0400 | -0.0299 | 0.0009 |
| 13.00 - 14.00 | 789 | 762 | -27 | 0729 | -0.0342 | 0.0012 |
| 14.00 - 15.00 | 777 | 750 | -27 | 0729 | -0.0348 | 0.0012 |
| 15.00 - 16.00 | 808 | 780 | -28 | 0784 | -0.0347 | 0.0012 |
| 16.00 - 17.00 | 949 | 912 | -37 | 1369 | -0.0390 | 0.0015 |
| 17.00 - 18.00 | 970 | 912 | -58 | 3364 | -0.0598 | 0.0036 |
| 18.00 - 19.00 | 991 | 930 | -61 | 3721 | -0.0616 | 0.0038 |

$$Q1 = k_{sim}(i) - k_{obs}(i)$$

$$Q2 = \frac{k_{sim}(i) - k_{obs}(i)}{k_{obs}(i)}$$

$$\sum_{i=1}^{n}(\frac{k_{sim}(i) - k_{obs}(i)}{k_{obs}(i)})^2 = 0.0174$$

$n = 12$, where n is each hour

$$RMSNE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(\frac{k_{sim}(i) - k_{obs}(i)}{k_{obs}(i)})^2} = 0.038$$

$$\sum_{i=1}^{n}(k_{sim}(i) - k_{obs}(i))^2 = 11991$$

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(k_{sim}(i) - k_{obs}(i))^2} = 31.611$$

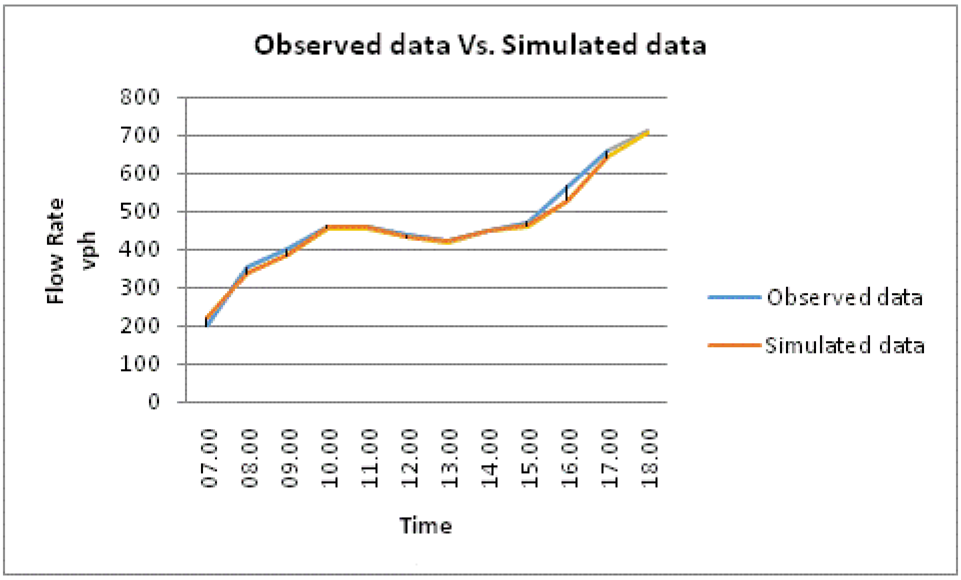



Figure 4.17 : Comparing Simulated data with Field Vehicular Traffic Flow for 12-hour on Wednessday June 8th, 2016 in Link- 1

Table 4.6: Data set to illustrate the observed data on Wednessday June 8th, 2016 and simulated data on Link-1

| Time | Observed, $k_{obs}(i)$ | Simulated, $k_{sim}(i)$ | $Q1$ | $Q1^2$ | $Q2$ | $Q2^2$ |
|---|---|---|---|---|---|---|
| 07.00 - 08.00 | 201 | 222 | 27 | 0729 | 0.1045 | 0.0109 |
| 08.00 - 09.00 | 353 | 336 | -17 | 0289 | -0.0482 | 0.0023 |
| 09.00 - 10.00 | 400 | 384 | -16 | 0256 | -0.0400 | 0.0016 |
| 10.00 - 11.00 | 460 | 456 | -04 | 0016 | -0.0087 | 8E-05 |
| 11.00 - 12.00 | 458 | 456 | -02 | 0004 | -0.0044 | 2E-05 |
| 12 .00 - 13.00 | 436 | 432 | -04 | 0016 | -0.0092 | 8E-05 |
| 13.00 - 14.00 | 421 | 420 | -01 | 0002 | -0.0024 | 6E-06 |
| 14.00 - 15.00 | 450 | 450 | 0 | 0000 | 0 | 0 |
| 15.00 - 16.00 | 471 | 462 | -09 | 0081 | -0.0191 | 0.0004 |
| 16.00 - 17.00 | 565 | 528 | -37 | 1369 | -0.0655 | 0.0043 |
| 17.00 - 18.00 | 659 | 642 | -17 | 0289 | -0.0258 | 0.0007 |
| 18.00 - 19.00 | 712 | 708 | -04 | 0016 | -0.0056 | 3E-05 |

$$Q1 = k_{sim}(i) - k_{obs}(i)$$

$$Q2 = \frac{k_{sim}(i) - k_{obs}(i)}{k_{obs}(i)}$$

$$\sum_{i=1}^{n}\left(\frac{k_{sim}(i)-k_{obs}(i)}{k_{obs}(i)}\right)^2 = 0.0204$$

$$\text{n} = 12, \text{where n is each hour}$$

$$RMSNE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(\frac{k_{sim}(i) - k_{obs}(i)}{k_{obs}(i)}\right)^2} = 0.041$$

$$\sum_{i=1}^{n}(k_{sim}(i) - k_{obs}(i))^2 = 3067$$

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(k_{sim}(i) - k_{obs}(i))^2} = 15.986$$

It can be seen that the flow rate obtained from manual collection and the simulated data are in good agreement for all days. Root Mean Squared Normalized Error (RMSNE) is computed to be 0.047, 0.038 and 0.041. A RMSNE of less than 0.15 is considered acceptable for traffic model calibration. Examination of the traffic flow rates and the RMSNE confirms that the model reasonably replicates existing flow rates which are shown in Figures 4.15 to 4.17. The RMSE between the simulation data and data collected manually from the field are 19.731, 31.611, and 15.986 for Saturday June 4$^{th}$, Monday June 6$^{th}$ and Wednesday June 8$^{th}$ 2016 respectively. The summary of the data validation result on the link-1 which is the Hospital road, Tudun Wada in Zaria as shown in Table 4.9 in three different days. According to Singh *et al.* (2004), if *RMSE* value is smaller than half of the standard deviation of the measured data, then it may be considered low and appropriate for model evaluation.

The Standard Deviation (S.D) of the observed data collected on Saturday June 4$^{th}$, 2016, Monday June 6$^{th}$ , 2016 and Wednessday June 8$^{th}$, 2016 is 155.73, 238.77 and 128.52 respectively. Hence, the model is acceptable because each of the RMSE is less than half of the standard deviation of the observed data. The researchers decided to choose one of the links on the road network of the study area because the movement of vehicles from one of the links can lead to any of the links.

Table 4.7 Summary of the Data Validation Result on Route 1, Hospital road- link

| Statistical Tool | Traffic Flow for 12-hour on Saturday June 4$^{th}$, 2016 | Traffic Flow for 12-hour on Monday June 6$^{th}$, 2016 | Traffic Flow for 12-hour on Wednessday June 8$^{th}$, 2016 |
|---|---|---|---|
| RMSNE | 0.047 | 0.038 | 0.041 |
| RMSE | 19.731 | 31.611 | 15.986 |
| S.D | 155.73 | 238.77 | 128.52 |

## 4.6 Simulation and Evaluation of the Proposed TCS Framework at Different Traffic Routing Scenarios

The data collected from four different links on the road network is shown in Table 4.8. The relative ratio of the maximum flow rate in each link is used to guide the vehicles on route request during the simulation process. The relative ratio 3:2:6:2 in link1 to link4 is used to simulate the vehicle on route request from the traffic control center. The traffic flows on the road network when the movement of vehicles at the roundabout is non-signalized traffic stream and when the vehicles are being control by the traffic signal is simulated and the data collected is graphically presented in Figure 4.18 to 4.21 and the data set are on the Table 4.9 to 4.12. The vehicles with route request based on the real time information from the traffic control center is compared with the vehicles using traffic signal control before passing at the roundabout which is the existing solution in most of Nigerian Cities and it is the implementation of VISSIM vehicular traffic control architecture (see Chapter 2, Section 2.7.3, Figure 2.13).

Many Cities in Nigeria are not having signal control system at the roundabout on their road network and the traffic stream on the road network is non-signalized traffic stream. There is always traffic congestion at the roundabout leading to congestion on the road linking the roundabout probably there is no device to control the traffic and occasionally the road traffic police officers, road safety officers and volunteers usually assist in controlling traffic when there is congestion (sometimes resulted in road block). The vehicles are simulated on different scenarios and the percentage of improvement is taken on each scenario over another. On the average of the simulation result, the traffic stream on signalized traffic control reduces the traffic congestion by approximately 15% over non-signalized traffic stream. The vehicles on route request guided with road real-time information reduces traffic congestion by approximately 54% when it is compared with non-signalized traffic stream and 34.5% when it is compared with signalized traffic control system.

Table 4.8: Data Set to Illustrate the Simulation of Vehicles in Non-Signalized Traffic Stream

| Volume | Route-1 | Route-2 | Route-3 | Route-4 |
|---|---|---|---|---|
| 100 | 57 | 48 | 36 | 15 |
| 200 | 126 | 102 | 90 | 27 |
| 300 | 177 | 144 | 135 | 54 |
| 400 | 216 | 207 | 177 | 84 |
| 500 | 261 | 183 | 204 | 99 |
| 600 | 255 | 171 | 261 | 108 |
| 700 | 297 | 189 | 303 | 120 |
| 800 | 294 | 180 | 345 | 144 |
| 900 | 303 | 279 | 390 | 159 |
| 1000 | 306 | 186 | 444 | 153 |
| 1500 | 309 | 150 | 555 | 186 |
| 2000 | **321** | 150 | 558 | 195 |
| 2500 | 318 | 99 | 561 | **198** |
| 3000 | 315 | **207** | 564 | 195 |
| 3500 | 303 | 135 | **567** | 186 |

The result of the simulation of vehicles in non-signalized traffic stream on the route-1 which is representing Hospital road to Zaria City on the road network modeled in this research (see chapter 3, section 3.6 and figure 3.5) has been compared with vehicles moving in the same route when traffic signal are stationed at the roundabout to control the traffics and when vehicles received road information of all the routes to his destination based on route request. The results are presented in Figure 4.18 graphically and the dataset are shown in Table 4.9 which is the average travel time for all the volume of vehicles on the route for the period of 1800 simulation period (which also equivalent to 30 minutes). Different volume of vehicles is used for the simulation starting with 100 vehicles to 3500 vehicles and the corresponding average travel time is recorded.

Table 4.9: Data Set of Vehicles in Non-Signalized Traffic Stream, Signal Control and Vehicles with Route Request on Route-1

| Volume | Ave.TT of Veh. in Non-signalized TC | Ave.TT of Veh with signal Control | Ave.TT of Veh with route request | $Q_i$ | $Q_j$ | $Q_k$ |
|---|---|---|---|---|---|---|
| 100 | 154.26 | 127.80 | 117.12 | -0.0912 | -0.2070 | -0.3171 |
| 200 | 176.94 | 131.28 | 122.34 | -0.0731 | -0.3478 | -0.4463 |
| 300 | 190.08 | 188.16 | 123.06 | -0.5290 | -0.0102 | -0.5446 |
| 400 | 202.80 | 149.52 | 122.46 | -0.2210 | -0.3563 | -0.6561 |
| 500 | 203.22 | 165.42 | 121.44 | -0.3622 | -0.2285 | -0.6734 |
| 600 | 203.76 | 198.72 | 122.10 | -0.6275 | -0.0254 | -0.6688 |
| 700 | 208.92 | 179.58 | 121.44 | -0.4788 | -0.1634 | -0.7204 |
| 800 | 212.64 | 171.12 | 121.14 | -0.4126 | -0.2426 | -0.7553 |
| 900 | 210.18 | 175.68 | 122.04 | -0.4395 | -0.1964 | -0.7222 |
| 1000 | 231.90 | 172.98 | 121.98 | -0.4181 | -0.3406 | -0.9011 |
| 1500 | 273.60 | 184.56 | 124.44 | -0.4831 | -0.4824 | -1.1986 |
| 2000 | 276.12 | 200.94 | 126.12 | -0.5932 | -0.3741 | -1.1893 |
| 2500 | 265.98 | 222.90 | 130.02 | -0.7144 | -0.1933 | -1.0457 |
| 3000 | 288.96 | 222.06 | 131.82 | -0.6846 | -0.3013 | -1.1921 |
| 3500 | 275.46 | 227.10 | 144.18 | -0.5751 | -0.2129 | -0.9105 |

where

Ave.TT of Veh = Average Travel Time of Vehicles

TC = Traffic Control

The Percentage of Improvement (PoI) of drivers traveling on non-signalized traffic route when compared with the drivers or vehicles that are controlled by the traffic signal and drivers that are guided with real time information on routes request are calculated.

n = is the total simulation runs (that is the number of time the simulation is carried out)

i = each simulation run

$\sum_{i=1}^{n} Q_i = -6.7033$ , $\sum_{i=1}^{n} Q_i - 3.6824$, $\sum_{i=1}^{n} Q_i = -11.9416$

n=15

$$Q_i = \frac{V_{route\ request}(i) - V_{signal\ control}(i)}{V_{route\ request}(i)}, \quad \text{for i=1, 2, 3, .......n}$$

$$Q_j = \frac{V_{signal\ control}(j) - V_{non-signalized}(j)}{V_{signal\ control}(j)} \quad \text{for j=1, 2, 3, .......n}$$

$$Q_k = \frac{V_{route\ request}(k) - V_{non-signalized}\ (k)}{V_{route\ request}(k)} \quad \text{for k=1, 2, 3, .......n}$$

$$PoI\ of\ \ V_{route\ request}\ over\ V_{signal\ control} = \frac{100}{n}\sum_{i=1}^{n} Q_i \ \approx 45\%$$

$$PoI\ of\ \ V_{signal\ control}\ over\ V_{non-signalized} = \frac{100}{n}\sum_{j=1}^{n} Q_j \ \approx 25\%$$

$$PoI\ of\ \ V_{route\ request}\ over\ V_{non-signalized} = \frac{100}{n}\sum_{k=1}^{n} Q_k \ \approx 80\%$$

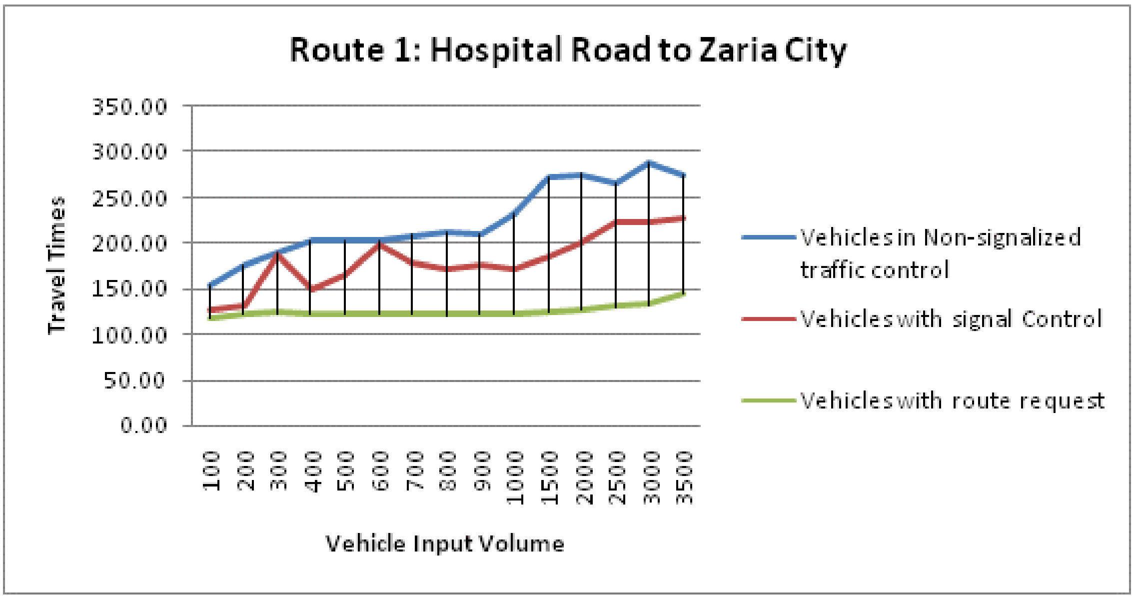



Figure 4.18: Comparison of Vehicles in Non-Signalized Traffic Stream, Signal Control and Vehicles with Route Request on Route-

The result of the simulation of vehicles in non-signalized traffic stream on the route-2 which is representing Zaria City to Hospital Road on the road network modeled in this research (see chapter 3, section 3.6 and figure 3.5) has been compared with vehicles moving in the same route when traffic signal are stationed at the roundabout to control the traffics and when vehicles received road information of all the routes to his destination based on route request. The results are presented in Figure 4.19 graphically and the dataset are shown in Table 4.10 which is the average travel time for all the volume of vehicles on the route for the period of 1800 simulation period (which also equivalent to 30 minutes). Different volume of vehicles is used for the simulation starting with 100 vehicles to 3500 vehicles and the corresponding average travel time is recorded.

Table 4.10: Data Set of Vehicles in Non-Signalized Traffic Stream, Signal Control and Vehicles with Route Request on Route-2

| Volume | Ave.TT of Veh in Non-signalized TC | Ave.TT of Veh with signal Control | Ave.TT of Veh with route request | $Q_i$ | $Q_j$ | $Q_k$ |
|---|---|---|---|---|---|---|
| 100 | 132.36 | 161.52 | 121.74 | -0.3268 | 0.1805 | -0.0872 |
| 200 | 148.32 | 171.78 | 125.10 | -0.3731 | 0.1366 | -0.1856 |
| 300 | 143.22 | 190.26 | 123.00 | -0.5468 | 0.2472 | -0.1644 |
| 400 | 149.94 | 207.96 | 122.46 | -0.6982 | 0.2790 | -0.2244 |
| 500 | 152.04 | 180.36 | 123.24 | -0.4635 | 0.1570 | -0.2337 |
| 600 | 160.50 | 181.92 | 124.92 | -0.4563 | 0.1177 | -0.2848 |
| 700 | 184.62 | 188.40 | 125.94 | -0.4960 | 0.0201 | -0.4659 |
| 800 | 223.68 | 200.58 | 124.20 | -0.6150 | -0.1152 | -0.8010 |
| 900 | 245.16 | 208.68 | 126.12 | -0.6546 | -0.1748 | -0.9439 |
| 1000 | 339.06 | 215.22 | 125.82 | -0.7105 | -0.5754 | -1.6948 |
| 1500 | 390.78 | 299.34 | 134.82 | -1.2203 | -0.3055 | -1.8985 |
| 2000 | 356.70 | 331.02 | 150.96 | -1.1928 | -0.0776 | -1.3629 |
| 2500 | 400.44 | 327.66 | 323.88 | -0.0117 | -0.2221 | -0.2364 |
| 3000 | 389.94 | 315.72 | 397.98 | 0.2067 | -0.2351 | 0.0202 |
| 3500 | 336.90 | 338.58 | 376.22 | 0.1000 | 0.0050 | 0.1045 |

Where

Ave.TT of Veh = Average Travel Time of Vehicles

TC= Traffic Control

The Percentage of Improvement (PoI) of drivers traveling on non-signalized traffic route when compared with the drivers or vehicles that are controlled by the traffic signal and drivers that are guided with real time information on routes request are calculated.

n = is the total simulation runs (that is the number of time the simulation is carried out)

I, j, k = each simulation run

$\sum_{i=1}^{n} Q_i = -7.4588$ , $\sum_{i=1}^{n} Q_i = -0.5625$, $\sum_{i=1}^{n} Q_i = -8.4588$

n=15

$$Q_i = \frac{V_{route\ request}(i) - V_{signal\ control}(i)}{V_{route\ request}(i)}, \quad \text{for i=1, 2, 3, …….n}$$

$$Q_j = \frac{V_{signal\ control}(j) - V_{non-signalized}(j)}{V_{signal\ control}(j)} \quad \text{for j=1, 2, 3, …….n}$$

$$Q_k = \frac{V_{route\ request}(k) - V_{non-signalized}\ (k)}{V_{route\ request}(k)} \quad \text{for k=1, 2, 3, …….n}$$

$$PoI\ of\ \ V_{route\ request}\ over\ V_{signal\ control} = \frac{100}{n}\sum_{i=1}^{n} Q_i \ \approx 50\%$$

$$PoI\ of\ \ V_{signal\ control}\ over\ V_{non-signalized} = \frac{100}{n}\sum_{j=1}^{n} Q_j \ \approx 4\ \%$$

$$PoI\ of\ \ V_{route\ request}\ over\ V_{non-signalized} = \frac{100}{n}\sum_{k=1}^{n} Q_k \ \approx 56\ \%$$

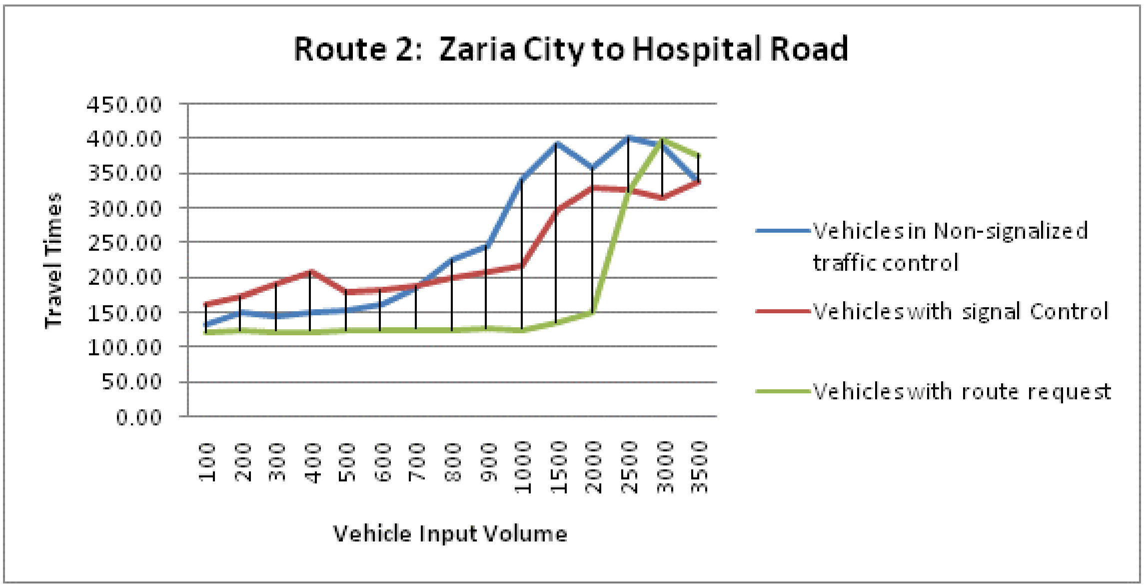



Figure 4.19: Comparison of Vehicles in Non-Signalized Traffic Stream, Signal Control and Vehicles with Route Request on Route-2

The result of the simulation of vehicles in non-signalized traffic stream on the route-3 which is representing New Jos Road to DanMagaji Road on the road network modeled in this research (see chapter 3, section 3.6 and figure 3.5) has been compared with vehicles moving in the same route when traffic signal are stationed at the roundabout to control the traffics and when vehicles received road information of all the routes to his destination based on route request. The results are presented in Figure 4.20 graphically and the dataset are shown in Table 4.11 which is the average travel time for all the volume of vehicles on the route for the period of 1800 simulation period (which also equivalent to 30 minutes). Different volume of vehicles is used for the simulation starting with 100 vehicles to 3500 vehicles and the corresponding average travel time is recorded.

Table 4.11: Data of Vehicles in Non-Signalized Traffic Stream, Signal Control and Vehicles with Route Request on Route-3

| Volume | Ave.TT of Veh in Non-signalized TC | Ave.TT of Veh with signal Control | Ave.TT of Veh with route request | $Q_i$ | $Q_j$ | $Q_k$ |
|---|---|---|---|---|---|---|
| 100 | 120.72 | 120.06 | 119.82 | -0.0020 | -0.0055 | -0.0075 |
| 200 | 118.86 | 118.68 | 118.68 | 0.0000 | -0.0015 | -0.0015 |
| 300 | 121.86 | 122.22 | 120.72 | -0.0124 | 0.0029 | -0.0094 |
| 400 | 122.88 | 123.12 | 121.14 | -0.0163 | 0.0019 | -0.0144 |
| 500 | 123.72 | 123.36 | 121.50 | -0.0153 | -0.0029 | -0.0183 |
| 600 | 124.38 | 123.78 | 121.32 | -0.0203 | -0.0048 | -0.0252 |
| 700 | 124.44 | 124.80 | 120.84 | -0.0328 | 0.0029 | -0.0298 |
| 800 | 127.80 | 124.50 | 121.08 | -0.0282 | -0.0265 | -0.0555 |
| 900 | 126.30 | 124.68 | 120.96 | -0.0308 | -0.0130 | -0.0441 |
| 1000 | 148.44 | 126.84 | 120.66 | -0.0512 | -0.1703 | -0.2302 |
| 1500 | 208.62 | 139.02 | 122.52 | -0.1347 | -0.5006 | -0.7027 |
| 2000 | 250.80 | 171.18 | 124.74 | -0.3723 | -0.4651 | -1.0106 |
| 2500 | 256.74 | 265.92 | 140.76 | -0.8892 | 0.0345 | -0.8240 |
| 3000 | 258.18 | 276.36 | 222.48 | -0.2422 | 0.0658 | -0.1605 |
| 3500 | 259.92 | 307.56 | 244.92 | -0.2558 | 0.1549 | -0.0612 |

where

Ave.TT of Veh = Average Travel Time of Vehicles; TC = Traffic Control

The Percentage of Improvement (PoI) of drivers traveling on non-signalized traffic route when compared with the drivers or vehicles that are controlled by the traffic signal and drivers that are guided with real time information on routes request are calculated.

n = is the total simulation runs (that is the number of time the simulation is carried out)

i = each simulation run

$\sum_{i=1}^{n} Q_i = -2.1034$, $\sum_{i=1}^{n} Q_i = -0.9274$, $\sum_{i=1}^{n} Q_i = -3.1950$

n=15

$$Q_i = \frac{V_{route\ request}(i) - V_{signal\ control}(i)}{V_{route\ request}(i)}, \quad \text{for i=1, 2, 3, …….n}$$

$$Q_j = \frac{V_{signal\ control}(j) - V_{non-signalized}(j)}{V_{signal\ control}(j)} \quad \text{for j=1, 2, 3, …….n}$$

$$Q_k = \frac{V_{route\ request}(k) - V_{non-signalized}(k)}{V_{route\ request}(k)} \quad \text{for k=1, 2, 3, …….n}$$

$$PoI\ of\ V_{route\ request}\ over\ V_{signal\ control} = \frac{100}{n}\sum_{i=1}^{n} Q_i \approx 14\%$$

$$PoI\ of\ V_{signal\ control}\ over\ V_{non-signalized} = \frac{100}{n}\sum_{j=1}^{n} Q_j \approx 6\ \%$$

$$PoI\ of\ V_{route\ request}\ over\ V_{non-signalized} = \frac{100}{n}\sum_{k=1}^{n} Q_k \approx 21\ \%$$

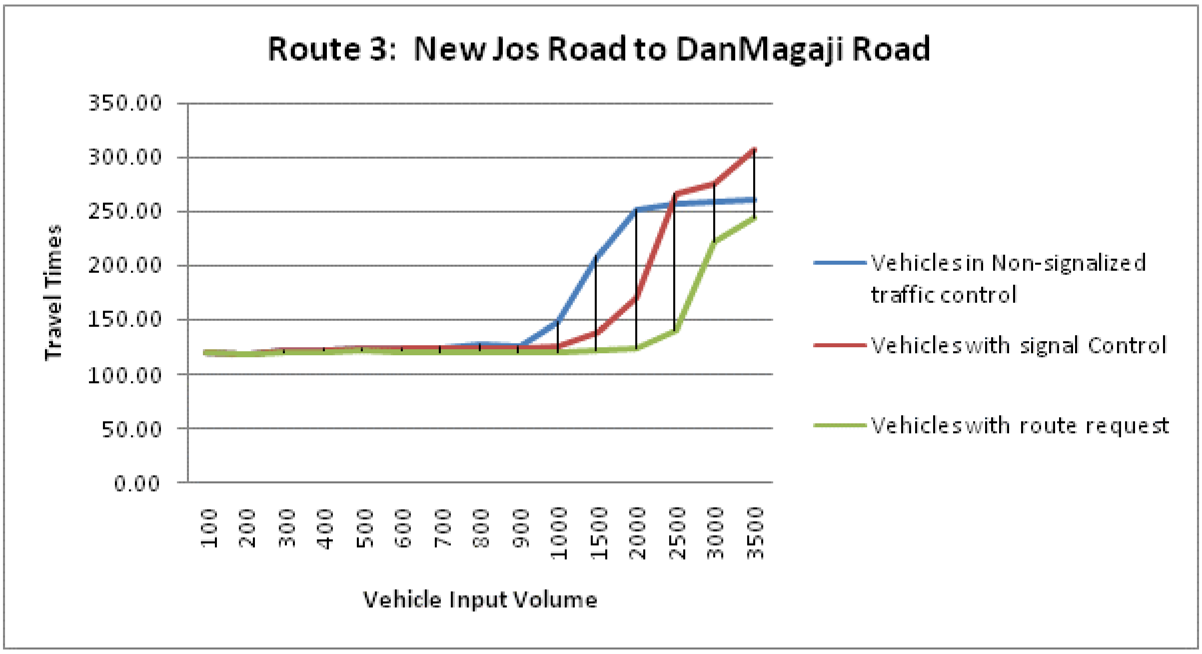



Figure 4.20: Comparison of Vehicles in Non-Signalized Traffic Stream, Signal Control and Vehicles with Route Request on Route-3

The result of the simulation of vehicles in non-signalized traffic stream on the route-4 which is representing DanMagaji road to New Jos road on the road network modeled in this research (see chapter 3, section 3.6 and figure 3.5) has been compared with vehicles moving in the same route when traffic signal are stationed at the roundabout to control the traffics and when vehicles received road information of all the routes to his destination based on route request. The results are presented in Figure 4.21 graphically and the dataset are shown in Table 4.12 which is the average travel time for all the volume of vehicles on the route for the period of 1800 simulation period (which also equivalent to 30 minutes). Different volume of vehicles is used for the simulation starting with 100 vehicles to 3500 vehicles and the corresponding average travel time is recorded.

Table 4.12: Data Set of Vehicles in Non-Signalized Traffic Stream, Signal Control and Vehicles with Route Request on Route-4

| Volume | Ave.TT of Veh in Non-signalized TC | Ave.TT of Veh with signal Control | Ave.TT of Veh with route request | $Q_i$ | $Q_j$ | $Q_k$ |
|---|---|---|---|---|---|---|
| 100 | 159.36 | 113.10 | 113.58 | 0.0042 | -0.4090 | -0.4031 |
| 200 | 154.56 | 157.26 | 115.50 | -0.3616 | 0.0172 | -0.3382 |
| 300 | 155.22 | 151.98 | 117.30 | -0.2957 | -0.0213 | -0.3233 |
| 400 | 154.20 | 147.54 | 119.04 | -0.2394 | -0.0451 | -0.2954 |
| 500 | 162.78 | 169.62 | 119.34 | -0.4213 | 0.0403 | -0.3640 |
| 600 | 166.44 | 151.86 | 119.76 | -0.2680 | -0.0960 | -0.3898 |
| 700 | 209.58 | 143.34 | 118.62 | -0.2084 | -0.4621 | -0.7668 |
| 800 | 186.24 | 140.88 | 121.62 | -0.1584 | -0.3220 | -0.5313 |
| 900 | 221.22 | 144.54 | 122.70 | -0.1780 | -0.5305 | -0.8029 |
| 1000 | 216.36 | 148.74 | 122.46 | -0.2146 | -0.4546 | -0.7668 |
| 1500 | 195.18 | 173.82 | 126.78 | -0.3710 | -0.1229 | -0.5395 |
| 2000 | 226.32 | 182.46 | 133.44 | -0.3674 | -0.2404 | -0.6960 |
| 2500 | 267.24 | 233.04 | 152.58 | -0.5273 | -0.1468 | -0.7515 |
| 3000 | 304.32 | 219.00 | 166.08 | -0.3186 | -0.3896 | -0.8324 |
| 3500 | 358.50 | 218.76 | 178.26 | -0.2272 | -0.6388 | -1.0111 |

where

Ave.TT of Veh = Average Travel Time of Vehicles

TC = Traffic Control

The Percentage of Improvement (PoI) of drivers traveling on non-signalized traffic route when compared with the drivers or vehicles that are controlled by the traffic signal and drivers that are guided with real time information on routes request are calculated.

n = is the total simulation runs (that is the number of time the simulation is carried out)

i = each simulation run

$\sum_{i=1}^{n} Q_i = -4.1527,\qquad \sum_{i=1}^{n} Q_i = -3.8216,\qquad \sum_{i=1}^{n} Q_i = -8.8120$

n=15, $Q_i = \frac{V_{route\ request}(i) - V_{signal\ control}(i)}{V_{route\ request}(i)}$, for i=1, 2, 3, …….n

$$Q_j = \frac{V_{signal\ control}(j) - V_{non-signalized}(j)}{V_{signal\ control}(j)} \quad \text{for } j=1, 2, 3, \ldots\ldots.n$$

$$Q_k = \frac{V_{route\ request}(k) - V_{non-signalized}(k)}{V_{route\ request}(k)} \quad \text{for } k=1, 2, 3, \ldots\ldots.n$$

$$PoI\ of\ V_{route\ request}\ over\ V_{signal\ control} = \frac{100}{n}\sum_{i=1}^{n} Q_i \approx 28\%$$

$$PoI\ of\ V_{signal\ control}\ over\ V_{non-signalized} = \frac{100}{n}\sum_{j=1}^{n} Q_j \approx 25\ \%$$

$$PoI\ of\ V_{route\ request}\ over\ V_{non-signalized} = \frac{100}{n}\sum_{k=1}^{n} Q_k \approx 59\ \%$$

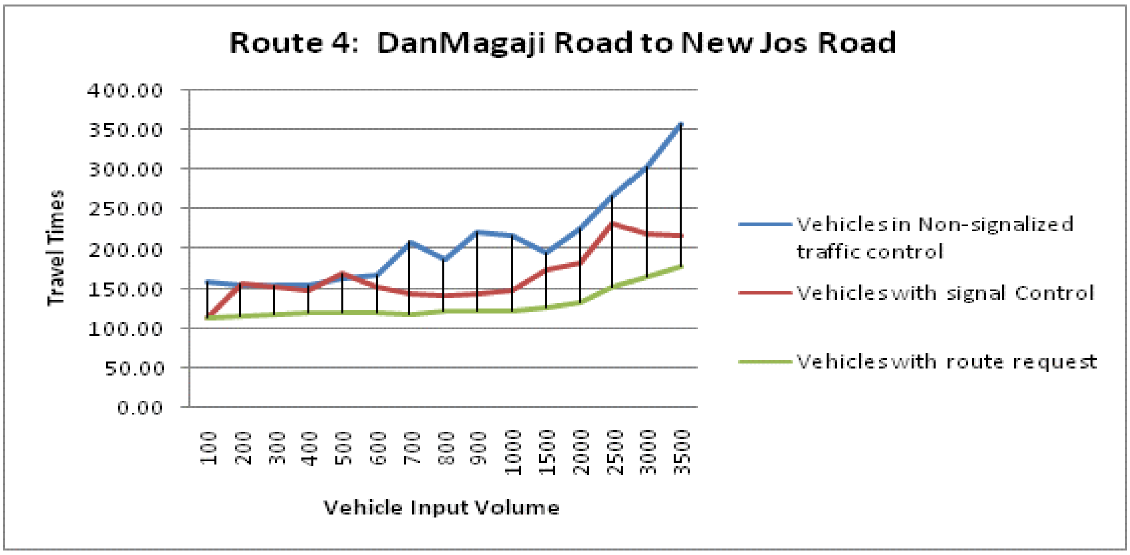



Figure 4.21: Comparison of Vehicles in Non-Signalized Traffic Stream, Signal Control and Vehicles with Route Request on Route-4

In summary, from the evaluation of the simulation framework, a free flow is achieved by approximately 54%, 34.5% and 15% when drivers are guided with route request information over traffic in non-signalized traffic stream, traffic control with traffic signal and traffic control stream over non-signalized traffic stream respectively.

# CHAPTER FIVE

# SUMMARY, CONCLUSION AND RECOMMENDATION

## 5.1 Summary

For traffic congestion to be reduced drastically, information gathering on traffic road such as congestion spots and volume of traffic on each road is essential. This thesis has proffered solutions on how to reduce traffic congestion on Nigerian roads by proposing road infrastructure that has internet connectivity to install cloudlet for local storage area in an ad-hoc network. Traffic control strategies framework has been developed which also provide management information system for delivery of information to the drivers to take decision on alternative route and traffic planners for traffic predictions. Cloudlet has been introduced in the framework to subsequently transmit the traffic information to the cloud controller for permanent storage and it can be used at any time. Storage provision of the periodic traffic information in the cloud will assist the future researchers in the field of transportation and the traffic authority in managing traffic information system.

In this research, Wiedemann model has been improved to provide heterogeneous traffic stream and classify the vehicles with different length on the road network. The vehicles and route information received in the cloud are used by the traffic control centers for the development and processing of route information and guiding system. Road network of the study area was developed for the simulation of the traffic flow which was calibrated to mimic the real road and validated the developed simulation model with the observed data from the field using a combination of Root Mean Squared Normalized Error (RMSNE) and Root Mean Square Error (RMSE) as statistical indicators. The evaluation results have shown how much is the expansion of road capacity can reduce traffic congestion and provision of route information for drivers' route request. In VISSIM, there are different types of traffic that can be modeled or simulated such as, Vehicles (cars, buses, and trucks), Public transport (trams, buses), Cycles (bicycles, motorcycles), Pedestrians and Rickshaws.

This research is limited to vehicular type of traffic using the cars, buses and trucks. The architecture of the communication between the traffic simulator and signal state generator that provide the existing solution to traffic congestion in most countries in the world (including Nigeria) developed by Planung Transport Verkehr (PTV), Transworld in the University of Karlsruhe, Karlsruhe, Germany (PTV, 2007) has been implemented and compared with the developed traffic control strategies for drivers guided with real time information. The result has shown that the vehicles/drivers that are guided with real time information move with considerably lesser traffic congestion than the vehicles that are controlled with traffic signals at the roundabout.

## 5.2 Conclusion

This thesis has demonstrated a combined simulation framework that can reduce traffic congestion from the path of both the government (expansion of road) and from the driver's side (route choice guiding scheme). The conceptual framework of traffic control strategy using cloud-based ad-hoc network has been developed as information system for the traffic authorities. Route alternation guiding scheme that can make routing decisions easy for drivers to reduce road traffic congestion has been proposed. Evaluation results showed that the proposed road expansion capacity can reduce traffic congestion by approximately 11 and 47% when expanded by one lane and two lanes respectively. Also, a free flow is achieved by approximately 54% and 34.5% when drivers are guided with route information over traffic in non-signalized traffic stream and traffic control with traffic signal which is the existing solution in Nigeria respectively.

## 5.3 Recommendation

The following recommendations are made;

a. Separate road should be constructed for Heavy Gross Vehicles or luxurious buses to reduce traffic congestion, accident rate and improve safety.

b. Route information system should be installed in every vehicle to guide the driver in chosen the alternative route to maintain free flow in the cities

c. Road capacity expansion is encouraged in the major road where there is no alternative route to reduce congestion

d. Federal Government policy should be introduced to have all vehicle users install the Route Information System.

## 5.4 Future Research

The following researches will assist the traffic agency in reducing traffic congestion;

a. Traffic flow has been used as measure of effectiveness for the evaluation of road capacity expansion and in the future, travel time, delay time and other traffic flow parameters should also be used as test parameters

b. Information variables on number of accident and traffic violations need to be kept in the cloud and use to assist decision makers in the formulation of traffic rules and policies.

c. Modeling of pedestrian crossing and waiting behavior for the safety of the pedestrians and to reduce traffic congestion.

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# APPENDICES

## APPENDIX 1: CloudSim Code that Display the Content in Cloud Storage

```
package vcloud;
/*
 * Title:          CloudSim Code for cloud storage
 * Description:  CloudSim (Cloud Simulation) Toolkit for Modeling and Simulation
 *             of Clouds. The sample program of the Cloudsim Toolkit was modified
 *             to read the Vehicle-Driver Route information released in
 *             The University of Melbourne, Australia by Hakeem Adewale Sulaimon
 */

import java.text.DecimalFormat;
import java.util.ArrayList;
import java.util.Calendar;
import java.util.LinkedList;
import java.util.List;
import org.cloudbus.cloudsim.Cloudlet;
import org.cloudbus.cloudsim.CloudletSchedulerTimeShared;
import org.cloudbus.cloudsim.Datacenter;
import org.cloudbus.cloudsim.DatacenterBroker;
import org.cloudbus.cloudsim.DatacenterCharacteristics;
import org.cloudbus.cloudsim.Host;
import org.cloudbus.cloudsim.Log;
import org.cloudbus.cloudsim.Pe;
import org.cloudbus.cloudsim.Storage;
import org.cloudbus.cloudsim.UtilizationModel;
import org.cloudbus.cloudsim.UtilizationModelFull;
import org.cloudbus.cloudsim.Vm;
import org.cloudbus.cloudsim.VmAllocationPolicySimple;
import org.cloudbus.cloudsim.VmSchedulerTimeShared;
import org.cloudbus.cloudsim.core.CloudSim;
import org.cloudbus.cloudsim.provisioners.BwProvisionerSimple;
import org.cloudbus.cloudsim.provisioners.PeProvisionerSimple;
```

```
import org.cloudbus.cloudsim.provisioners.RamProvisionerSimple;

/**
 * A simple example showing how to create a datacenter with one host and run one
 * cloudlet on it.
 */
public class VCloud {

	/** The cloudlet list. */
	private static List<Cloudlet> cloudletList;

	/** The vmlist. */
	private static List<Vm> vmlist;

	/**
	 * Creates main() to run this example.
	 *
	 * @param args the args
	 */
	@SuppressWarnings("unused")
	public static void main(String[] args) {

		Log.printLine("Starting CloudSimExample1...");

		try {
			// First step: Initialize the CloudSim package. It should be called
			// before creating any entities.
			int num_user = 1; // number of cloud users
			Calendar calendar = Calendar.getInstance();
			boolean trace_flag = false; // mean trace events

			// Initialize the CloudSim library
			CloudSim.init(num_user, calendar, trace_flag);

			// Second step: Create Datacenters
```

```
// Datacenters are the resource providers in CloudSim. We need at
// list one of them to run a CloudSim simulation
Datacenter datacenter0 = createDatacenter("Datacenter_0");

// Third step: Create Broker
DatacenterBroker broker = createBroker();
int brokerId = broker.getId();

// Fourth step: Create one virtual machine
vmlist = new ArrayList<Vm>();

// VM description
int vmid = 0;
int mips = 1000;
long size = 10000; // image size (MB)
int ram = 512; // vm memory (MB)
long bw = 1000;
int pesNumber = 1; // number of cpus
String vmm = "Xen"; // VMM name

// create VM
Vm vm = new Vm(vmid, brokerId, mips, pesNumber, ram, bw, size,
vmm, new CloudletSchedulerTimeShared());

// add the VM to the vmList
vmlist.add(vm);

// submit vm list to the broker
broker.submitVmList(vmlist);

// Fifth step: Create one Cloudlet
cloudletList = new ArrayList<Cloudlet>();

// Cloudlet properties
int id = 0;
```

```
                long length = 400000;
                long fileSize = 300;
                long outputSize = 300;
                UtilizationModel utilizationModel = new UtilizationModelFull();

                Cloudlet cloudlet = new Cloudlet(id, length, pesNumber, fileSize, outputSize, utilizationModel, utilizationModel, utilizationModel);
                cloudlet.setUserId(brokerId);
                cloudlet.setVmId(vmid);

                // add the cloudlet to the list
                cloudletList.add(cloudlet);

                // submit cloudlet list to the broker
                broker.submitCloudletList(cloudletList);

                // Sixth step: Starts the simulation
                CloudSim.startSimulation();

                CloudSim.stopSimulation();

                //Final step: Print results when simulation is over
                List<Cloudlet> newList = broker.getCloudletReceivedList();
                printCloudletList(newList);

                DBConnect connect = new DBConnect();
                connect.getRouteInformation();

            Log.printLine("VANET in Cloud Information Successfully Stored and Displayed!");
            } catch (Exception e) {
                e.printStackTrace();
                Log.printLine("Unwanted errors happen");
            }
```

```
	}

/**
 * Creates the datacenter.
 *
 * @param name the name
 *
 * @return the datacenter
 */
private static Datacenter createDatacenter(String name) {

	// Here are the steps needed to create a PowerDatacenter:
	// 1. We need to create a list to store
	// our machine
	List<Host> hostList = new ArrayList<>();

	// 2. A Machine contains one or more PEs or CPUs/Cores.
	// In this example, it will have only one core.
	List<Pe> peList = new ArrayList<>();

	int mips = 1000;

	// 3. Create PEs and add these into a list.
	peList.add(new Pe(0, new PeProvisionerSimple(mips))); // need to store Pe id
	and MIPS Rating

	// 4. Create Host with its id and list of PEs and add them to the list
	// of machines
	int hostId = 0;
	int ram = 2048; // host memory (MB)
	long storage = 1000000; // host storage
	int bw = 10000;

	hostList.add(
		new Host(
```

```
                        hostId,
                        new RamProvisionerSimple(ram),
                        new BwProvisionerSimple(bw),
                        storage,
                        peList,
                        new VmSchedulerTimeShared(peList)
                )
        ); // This is our machine

        // 5. Create a DatacenterCharacteristics object that stores the
        // properties of a data center: architecture, OS, list of
        // Machines, allocation policy: time- or space-shared, time zone
        // and its price (G$/Pe time unit).
        String arch = "x86"; // system architecture
        String os = "Linux"; // operating system
        String vmm = "Xen";
        double time_zone = 10.0; // time zone this resource located
        double cost = 3.0; // the cost of using processing in this resource
        double costPerMem = 0.05; // the cost of using memory in this resource
        double costPerStorage = 0.001; // the cost of using storage in this
                                                                // resource
        double costPerBw = 0.0; // the cost of using bw in this resource
        LinkedList<Storage> storageList = new LinkedList<>(); // we are not adding
        devices by now                  //
        DatacenterCharacteristics characteristics = new DatacenterCharacteristics(
                        arch, os, vmm, hostList, time_zone, cost, costPerMem,
                        costPerStorage, costPerBw);

        // 6. Finally, we need to create a PowerDatacenter object.
        Datacenter datacenter = null;
        try {
                datacenter = new Datacenter(name, characteristics, new
VmAllocationPolicySimple(hostList), storageList, 0);
        } catch (Exception e) {
        }
```

```
		return datacenter;
	}

	// We strongly encourage users to develop their own broker policies, to
	// submit vms and cloudlets according
	// to the specific rules of the simulated scenario
	/**
	 * Creates the broker.
	 *
	 * @return the datacenter broker
	 */
	private static DatacenterBroker createBroker() {
		DatacenterBroker broker = null;
		try {
			broker = new DatacenterBroker("Broker");
		} catch (Exception e) {
			return null;
		}
		return broker;
	}

	/**
	 * Prints the Cloudlet objects.
	 *
	 * @param list list of Cloudlets
	 */
	private static void printCloudletList(List<Cloudlet> list) {
		int size = list.size();
		Cloudlet cloudlet;

		String indent = "    ";
		Log.printLine();
		Log.printLine("==============OUTPUT ===================");
		Log.printLine("Cloudlet ID" + indent + "STATUS" + indent
			+ "Data center ID" + indent + "VM ID" + indent + "Time" + indent
```

```
                + "Start Time" + indent + "Finish Time");

        DecimalFormat dft = new DecimalFormat("###.##");
        for (int i = 0; i < size; i++) {
            cloudlet = list.get(i);
            Log.print(indent + cloudlet.getCloudletId() + indent + indent);

            if (cloudlet.getCloudletStatus() == Cloudlet.SUCCESS) {
                Log.print("SUCCESS");

                Log.printLine(indent + indent + cloudlet.getResourceId()
                        + indent + indent + indent + cloudlet.getVmId()
                        + indent + indent
                        + dft.format(cloudlet.getActualCPUTime()) + indent
                        + indent + dft.format(cloudlet.getExecStartTime())
                        + indent + indent
                        + dft.format(cloudlet.getFinishTime()));
            }
        }

    }

}
```

**APPENDIX 2: CloudSim Code that Connect to the Database and Read from it**

```
package vcloud;
import java.sql.*;
import java.util.ArrayList;
import java.util.List;
import java.util.Scanner;
import javax.swing.JOptionPane;

public class DBConnect {
   private static Connection dbh; //connects to the server
   private static ResultSet rs; //stores result record
   private static PreparedStatement ps;

   public DBConnect(){
      try{
         //load java jdbc driver class
         Class.forName("com.mysql.jdbc.Driver");

         //connect to the database
         dbh                                                                  =
DriverManager.getConnection("jdbc:mysql://localhost:3306/route_guiding_system","
root","");
         //st = con.createStatement();
      }catch(ClassNotFoundException | SQLException e){
         System.out.println("Error: "+e);
      }
   }

   public void getRouteInformation(){
      try {
         String query = "SELECT * FROM tbl_location AS l, "
               + "tbl_route AS r "
               + "WHERE l.location_id = r.loc_id";

         //prepare the query before executing it
```

```
ps = dbh.prepareStatement(query);
rs = ps.executeQuery();

//get the number of routes
int rowCount = rs.last() ? rs.getRow() : 0;
rs.beforeFirst();

if (rowCount < 1){
   //if no route exist
   System.out.println("No routes available");
}else{
   //if there are routes
   List<String> routeDescription = new ArrayList<>();
   List<String> source = new ArrayList<>();
   List<String> destination = new ArrayList<>();
   List<Integer> trafficFlowArray = new ArrayList<>();
   List<Integer> maxFreeFlowArray = new ArrayList<>();

   while(rs.next()){
      String route_desc = rs.getString("route_description");
      String route_source = rs.getString("source");
      String route_destination = rs.getString("destination");
      String traffic_flow = rs.getString("traffic_flow");
      String max_free_flow = rs.getString("max_free_flow");

      routeDescription.add(route_desc);
      source.add(route_source);
      destination.add(route_destination);
      trafficFlowArray.add(Integer.parseInt(traffic_flow));
      maxFreeFlowArray.add(Integer.parseInt(max_free_flow));

   }

   displayRouteInformation(routeDescription, source, destination,
trafficFlowArray, maxFreeFlowArray);
```

```
            dbh.close();
          }

        } catch (SQLException | NumberFormatException e) {
          System.out.println("Error: "+e);
        }
    }

    public static void displayRouteInformation(List<String> routeDescription, List<String> source, List<String> destination,
          List<Integer> trafficFlowArray, List<Integer> maxFreeFlowArray){
        try {
          System.out.println("\nAvailable routes");
          System.out.printf("%-7s%-17s%-17s%-17s%-17s%s\n", "S/NO", "ROUTE",
              "SOURCE", "DESTINATION", "TRAFFIC FLOW", "MAX FREE FLOW");
          int k = 1;
          for(int i = 0; i < trafficFlowArray.size(); i++){
            System.out.printf("%-7s%-17s%-17s%-17s%-17s%s\n", k, routeDescription.get(i),
                source.get(i), destination.get(i), trafficFlowArray.get(i), maxFreeFlowArray.get(i));
            k++;
          }
        } catch (Exception e) {
          System.out.println("Error: "+e);
        }
    }

}
```

**APPENDIX 3: Route Guiding Scheme code that Display Information to Driver**

```
package routeguidingsystem16;
import javax.swing.JOptionPane;
public class RouteGuidingSystem16 {
    public static void main(String[] args)    {
         DBConnect16 connect = new DBConnect16();
          //  connect.getData();

         String source = JOptionPane.showInputDialog(null, "Please enter your source: ",
                 "Route Guiding System", JOptionPane.PLAIN_MESSAGE);
        String dest = JOptionPane.showInputDialog(null, "Please enter your destination: ",
                "Route Guiding System", JOptionPane.PLAIN_MESSAGE);
        connect.getRoutes(source, dest);
    }

    public static String changeInput(String input) {
        String output = input.substring(0, 1).toUpperCase() + input.substring(1).toLowerCase();
        return output;
    }
}
```

**APPENDIX 4: Route Guiding Scheme code that Connect to the Database**

```
 *
 * @author Hakeem A. Sulaimon,
 */

import java.sql.*;
import java.util.ArrayList;
import java.util.List;
//import java.util.Scanner;
import java.sql.Connection;
import javax.swing.JOptionPane;
//import java.lang.*;
public class DBConnect16 {
    private static Connection dbh; //connects to the server
    private static ResultSet rs; //stores result record
    private static PreparedStatement ps;

    public DBConnect16(){
        try{
            //load java jdbc driver class
            Class.forName("com.mysql.jdbc.Driver");
            //connect to the database
            dbh                                                                                =
DriverManager.getConnection("jdbc:mysql://localhost:3306/route_guiding_system","root",""
);
            //st = con.createStatement();
        }catch(ClassNotFoundException | SQLException e){
            System.out.println("Error: "+e);
        }
    }

    public void getRoutes(String source, String dest){
        try {
            String query = "SELECT * FROM tbl_location AS l, "
                    + "tbl_route AS r "
```

```
        + "WHERE l.source = ? AND "
        + "l.destination = ? AND "
        + "l.location_id = r.loc_id";

//prepare the query before executing it
ps = dbh.prepareStatement(query);
ps.setString(1, source);
ps.setString(2, dest);
rs = ps.executeQuery();

//get the number of routes
int rowCount = rs.last() ? rs.getRow() : 0;
rs.beforeFirst();

if (rowCount < 1){
   //if no route exist
   //System.out.println("No route from the source to the
   //destination specified");
   JOptionPane.showMessageDialog(null, "No route from the "
           + "source to the destination specified",
           "Route Guiding System", JOptionPane.INFORMATION_MESSAGE);
}else if(rowCount == 1){
   //if only one route exist
   //System.out.println("No alternative route");
   JOptionPane.showMessageDialog(null, "No alternative route",
           "Route Guiding System", JOptionPane.INFORMATION_MESSAGE);
}else{

   //if there are more than one routes
   List<Integer> trafficFlowArray = new ArrayList<>();
   List<Integer> maxFreeFlowArray = new ArrayList<>();
   List<String> routeArray = new ArrayList<>();
   List<Integer> idArray = new ArrayList<>();
   List<String> routeDistance = new ArrayList<>();
   List<String> travelTime = new ArrayList<>();
```

```
            while(rs.next()){
                String route_ desc = rs.getString("route_description");
                String traffic_ flow = rs.getString("traffic_flow");
                String max_free_flow = rs.getString("max_free_flow");
                String route_ id  = rs.getString("route_id");
                String distance = rs.getString("route_distance");
                String time = rs.getString("travel_time");

                trafficFlowArray.add(Integer.parseInt(traffic_flow));
                maxFreeFlowArray.add(Integer.parseInt(max_free_flow));
                routeArray.add(route_desc);
                idArray.add(Integer.parseInt(route_id));
                routeDistance.add(distance);
                travelTime.add(time);
            }

            getLessCongestedRoute(trafficFlowArray, maxFreeFlowArray,
                    routeArray, idArray, routeDistance, travelTime);
            dbh.close();
        }

    } catch (SQLException | NumberFormatException e) {
        //System.out.println("Error: "+e);
        JOptionPane.showMessageDialog(null, "Error: Please contact your"
                + " admin", "Route Guiding System", JOptionPane.WARNING_MESSAGE);
    }
}

public static void getLessCongestedRoute( List<Integer> trafficFlowArray,
        List<Integer> maxFreeFlowArray,
        List<String> routeArray, List<Integer> idArray, List<String>
                routeDistance, List<String> travelTime){
    try {

        List<Integer> j = new ArrayList<>();
```

```
int k = 0;
String[] selectionValues = new String[trafficFlowArray.size() + 1];
selectionValues[k] = "Select the route to take";
k = k + 1;
for(int i = 0; i < trafficFlowArray.size(); i++){
   if(trafficFlowArray.get(i) < maxFreeFlowArray.get(i) - 1){
      //System.out.printf("%-10d%-17s%d\n", k+1, routeArray.get(i),
trafficFlowArray.get(i));
      selectionValues[k] = k +".        "+ routeArray.get(i) +"        "+
trafficFlowArray.get(i)+"  "
            + "    "+ routeDistance.get(i)+"   "+ travelTime.get(i);
      j.add(idArray.get(i));
      k++;
   }
}
// String res = (String) JOptionPane.showInputDialog(null, selectionValues, "Enter
route number");
String res = (String) JOptionPane.showInputDialog(null, selectionValues,
      "Route Guiding System: Available routes",
JOptionPane.INFORMATION_MESSAGE);

if(res == null){
   JOptionPane.showMessageDialog(null, "Please select a valid route",
         "Route Guiding System", JOptionPane.ERROR_MESSAGE);
}else{
   int response = Integer.parseInt(res);

   if(response < 1 || response > j.size()){
      //System.out.println("Invalid input");
      JOptionPane.showMessageDialog(null, "Invalid input", "Route Guiding
System",
            JOptionPane.ERROR_MESSAGE);
   }else{
      updateTrafficFlow(j.get(response-1));
   }
}
```

```
        } catch ( Exception e) {
            System.out.println("Error: "+e);

        }
    }

    public static void updateTrafficFlow(int id){
        try {

            String query = "UPDATE tbl_route SET traffic_flow = traffic_flow + 1"
                    + " WHERE route_id = ? ";
            //prepare the query before executing it
            ps = dbh.prepareStatement(query);
            ps.setInt(1, id);
            int rowCount;
            rowCount = ps.executeUpdate();
            if(rowCount == 1){
                //System.out.println("Success... safe trip");
                JOptionPane.showMessageDialog(null, "Success... safe trip", "Route Guiding
System",
                        JOptionPane.INFORMATION_MESSAGE);
            }else{
                JOptionPane.showMessageDialog(null, "Error", "Route Guiding System",
                        JOptionPane.WARNING_MESSAGE);
            }
        } catch (Exception e) {
            JOptionPane.showMessageDialog(null, "Error: Please contact your admin",
                    "Route Guiding System", JOptionPane.WARNING_MESSAGE);
            //System.out.println("Error: "+e);
        }
    }
}
```

**APPENDIX 5: Output of Data Collected from VISSIM Simulator**

Data Collection (Raw Data)

File: C:\Users\Public\Documents\PTV Vision\PTV Vissim 7\Zaria networkmixed2.inpx

Comment: Mixed vehicles traffic in the entire network

Date: Wednesday, June 29, 2016 8:58:52 PM

PTV Vissim 7.00-08 [53068]

Simulation Start Time: 2016-5-8 06:29:01

Data collection point 3: Link 1 lane 1 at 1.411 m.

Data collection point 4: Link 8 lane 1 at 74.685 m.

Data collection point 5: Link 4 lane 1 at 22.710 m.

Data collection point 6: Link 7 lane 2 at 257.995 m.

Data collection point 7: Link 6 lane 2 at 8.918 m.

Data collection point 8: Link 2 lane 1 at 89.463 m.

Data collection point 9: Link 3 lane 2 at 30.400 m.

Data collection point 10: Link 5 lane 2 at 55.473 m.

| Measurem.; | t(Entry); | t(Exit); | VehNo; | Vehicle type; | v[km/h]; | b[m/s2]; | VehLength[m]; |
|---|---|---|---|---|---|---|---|
| 9; | 4.07; | -1.00; | 4; | 301; | 40.2; | 0.00; | 11.54; |
| 7; | 4.50; | -1.00; | 8; | 200; | 49.6; | 0.07; | 10.22; |
| 5; | 4.56; | -1.00; | 6; | 200; | 55.7; | -0.86; | 10.22; |
| 9; | -1.00; | 5.10; | 4; | 301; | 40.2; | 0.00; | 11.54; |
| 3; | 5.28; | -1.00; | 11; | 301; | 41.6; | 0.00; | 11.54; |
| 5; | -1.00; | 5.23; | 6; | 200; | 53.3; | -1.09; | 10.22; |
| 7; | -1.00; | 5.24; | 8; | 200; | 49.8; | 0.07; | 10.22; |
| 3; | -1.00; | 6.28; | 11; | 301; | 41.5; | -0.20; | 11.54; |
| 7; | 6.34; | -1.00; | 10; | 301; | 44.1; | 0.27; | 11.54; |
| 7; | -1.00; | 7.28; | 10; | 301; | 45.0; | 0.27; | 11.54; |
| 3; | 7.50; | -1.00; | 15; | 301; | 38.3; | -0.88; | 11.54; |
| 3; | -1.00; | 8.63; | 15; | 301; | 36.2; | -0.20; | 11.54; |
| 8; | 11.36; | -1.00; | 7; | 301; | 40.3; | -0.14; | 11.54; |
| 3; | 12.21; | -1.00; | 22; | 100; | 39.9; | -0.07; | 3.75; |
| 8; | -1.00; | 12.40; | 7; | 301; | 39.7; | -0.14; | 11.54; |
| 3; | -1.00; | 12.55; | 22; | 100; | 39.8; | -0.07; | 3.75; |

10; 13.18; -1.00; 19; 301; 44.4; -0.88; 11.54;

**APPENDIX 6: A Snapshot of Route Information**

Show : 30 row(s) starting from record # 0
in horizontal mode and repeat headers after 100 cells
Sort by key: None

| route_id | route_description | max_free_flow | traffic_flow | route_distance | loc_id | travel_time |
|---|---|---|---|---|---|---|
| 1 | along PZ road | 760 | 52 | 7.0 km | 1 | 15 mins |
| 2 | overhead bridge | 543 | 20 | 5km | 1 | 35 mins |
| 3 | Dan Magaji road | 349 | 22 | 3km | 13 | 30 mins |
| 4 | Zaria City road | 400 | 399 | 4km | 13 | 12 mins |
| 6 | zaria city road | 600 | 400 | 2km | 14 | 45 mins |
| 7 | along new Jos Rd | 670 | 150 | 4km | 16 | 14 mins. |
| 8 | Hospital road | 752 | 34 | 7.0km | 2 | 11 mins |
| 9 | Take DanMagaj Rd | 566 | 233 | 9 km | 2 | 8 mins |
| 10 | take Jos Road | 567 | 56 | 10 km | 10 | 38 mins |
| 11 | Take Hospital Rd | 800 | 231 | 16 km | 10 | 34 mins. |

Check All / Uncheck All *With selected:*

**APPENDIX 7: A Snapshot of Location Table**

Show : 30 row(s) starting from record # 0
in horizontal mode and repeat headers after 100 cells
Sort by key: None

| location_id | source | destination |
|---|---|---|
| 1 | Kwangila | Gaskiya |
| 2 | New Jos Road | Gaskiya |
| 3 | ABU Zaria | FCE Zaria |
| 4 | FCE Zaria | ABU Zaria |
| 5 | Kwangila | Kofan Dokan |
| 6 | Agoro | Kofan Doka |
| 7 | Agoro | Kwangila |
| 8 | Tudun Wada | Kaduna Express |
| 9 | Kwangila | pz |
| 10 | New Jos Road | Kaduna Express |
| 11 | Dan Magaji | FCE Zaria |
| 12 | Tudun Wada | Gwarigoje |
| 13 | Hospital Road | Kaduna |
| 14 | Hospital Road | zaria City |
| 15 | Kofan Doka | FCE Zaria |
| 16 | Zaria City | New Jos Road |

Check All / Uncheck All *With selected:*

## APPENDIX 8: A Snapshot of Sample of Vehicle Information Database

Show : 30 row(s) starting from record # 0

in horizontal mode and repeat headers after 100 cells

Sort by key: None

| veh_id | veh_type | speed | acceleration | veh_length | entry_time | exit_time |
|---|---|---|---|---|---|---|
| 10 | Bus | 44.1 | 0.27 | 11.54 | 08:06:34 | 08:07:28 |
| 11 | Bus | 41.6 | 0.00 | 11.54 | 08:05:28 | 08:06:28 |
| 15 | Bus | 38.3 | -0.88 | 11.54 | 08:07:50 | 08:09:03 |
| 19 | Bus | 44.4 | -0.88 | 11.54 | 08:13:18 | 08:14:15 |
| 22 | Car | 39.8 | -0.07 | 3.75 | 08:12:21 | 08:12:55 |
| 23 | Car | 28.9 | -0.99 | 4.21 | 08:15:01 | 08:15:56 |
| 25 | Car | 47.4 | -0.02 | 4.76 | 08:14:10 | 08:15:06 |
| 32 | Car | 43.3 | -0.08 | 3.75 | 08:17:20 | 08:17:52 |
| 33 | Bus | 39.0 | -0.43 | 11.54 | 08:19:09 | 08:20:22 |
| 4 | Bus | 40.2 | 0.00 | 11.54 | 08:04:07 | 08:05:10 |
| 6 | Truck | 55.7 | -0.86 | 10.22 | 08:04:56 | 08:05:23 |
| 7 | Bus | 40.3 | -0.14 | 11.54 | 08:11:36 | 08:12:40 |
| 8 | Truck | 49.6 | 0.07 | 10.22 | 08:04:50 | 08:05:24 |

Check All / Uncheck All *With selected:*

**APPENDIX 9.a: Observed Field Data from Zaria – PZ Route Collected by Federal Road Safety Commission Zaria Command.**

TRAFFIC COUNT TEMPLATE (DATA SHEET)

COMMAND –RS1.13 ZARIA

DATE: 21/06/2015 WEATHER: OK

DIRECTION INDICATORS: Zaria - PZ, Afrik Bank

| TIME INTERVAL | car | LUX. BUS | LORRY/TRUCK | TOTAL |
|---|---|---|---|---|
| 07.00 – 0800HRS | 222 | 4 | 22 | 248 |
| 0801-0900HRS | 431 | 21 | 14 | 466 |
| 0901-1000HRS | 558 | 5 | 19 | 582 |
| 1001-1100HRS | 424 | 3 | 20 | 447 |
| 1101-1200HRS | 453 | 19 | 38 | 510 |
| 1201-1300HRS | 481 | 11 | 66 | 558 |
| 1301-1400HRS | 448 | 21 | 22 | 491 |
| 1401-1500HRS | 465 | 13 | 83 | 561 |
| 1501-1600HRS | 350 | 13 | 30 | 393 |
| 1601-1700HRS | 405 | 11 | 51 | 467 |
| 1701-1800HRS | 423 | 32 | 31 | 486 |
| 1801-1900HRS | 312 | 29 | 83 | 424 |
| TOTAL | 4591 | 182 | 479 | 5252 |

TRAFFIC COUNT TEMPLATE (DATA SHEET)

COMMAND –RS1.13 ZARIA

DATE: 22/06/2015 WEATHER: OK

DIRECTION INDICATORS: ZAR - TO PZ

| TIME INTERVAL | Car | LUX. BUS | LORRY/TRUCK | TOTAL |
|---|---|---|---|---|
| 07.00 – 0800HRS | 773 | 26 | 22 | 821 |
| 0801-0900HRS | 743 | 28 | 46 | 817 |
| 0901-1000HRS | 282 | 10 | 11 | 303 |
| 1001-1100HRS | 471 | 16 | 29 | 516 |
| 1101-1200HRS | 370 | 12 | 31 | 413 |
| 1201-1300HRS | 429 | 31 | 43 | 503 |
| 1301-1400HRS | 501 | 0 | 41 | 542 |
| 1401-1500HRS | 388 | 6 | 28 | 422 |
| 1501-1600HRS | 478 | 14 | 6 | 498 |
| 1601-1700HRS | 505 | 6 | 28 | 539 |
| 1701-1800HRS | 482 | 10 | 29 | 521 |
| 1801-1900HRS | 409 | 21 | 28 | 458 |
| TOTAL | 4682 | 127 | 311 | 5120 |

TRAFFIC COUNT TEMPLATE (DATA SHEET)

COMMAND –RS1.13 ZARIA

DATE: 23/06/2015 WEATHER: OK

DIRECTION INDICATORS: FORM: ZAR - TO PZ

| TIME INTERVAL | CAR | LUX. BUS | LORRY/TRUCK | TOTAL |
|---|---|---|---|---|
| 07.00 – 0800HRS | 152 | 0 | 6 | 158 |
| 0801-0900HRS | 405 | 0 | 3 | 408 |
| 0901-1000HRS | 301 | 5 | 7 | 313 |
| 1001-1100HRS | 275 | 2 | 5 | 282 |
| 1101-1200HRS | 436 | 6 | 0 | 442 |
| 1201-1300HRS | 327 | 11 | 4 | 342 |
| 1301-1400HRS | 420 | 2 | 21 | 443 |
| 1401-1500HRS | 310 | 6 | 21 | 337 |
| 1501-1600HRS | 279 | 10 | 41 | 330 |
| 1601-1700HRS | 403 | 16 | 31 | 450 |
| 1701-1800HRS | 344 | 10 | 21 | 375 |
| 1801-1900HRS | 338 | 8 | 2 | 348 |
| TOTAL | 3990 | 73 | | 4063 |

COMMAND –RS1.13 ZARIA

DATE: 24/06/2015 WEATHER: OK

DIRECTION INDICATORS: FORM: ZAR - TO PZ

| TIME INTERVAL | CAR | LUX. BUS | LORRY/TRUCK | TOTAL |
|---|---|---|---|---|
| 07.00 – 0800HRS | 163 | 0 | 19 | 182 |
| 0801-0900HRS | 339 | 0 | 14 | 353 |
| 0901-1000HRS | 358 | 1 | 41 | 400 |
| 1001-1100HRS | 320 | 23 | 14 | 357 |
| 1101-1200HRS | 405 | 0 | 41 | 446 |
| 1201-1300HRS | 386 | 1 | 21 | 408 |
| 1301-1400HRS | 338 | 8 | 21 | 367 |
| 1401-1500HRS | 412 | 31 | 42 | 485 |
| 1501-1600HRS | 297 | 24 | 56 | 377 |
| 1601-1700HRS | 347 | 0 | 76 | 423 |
| 1701-1800HRS | 471 | 4 | 24 | 499 |
| 1801-1900HRS | 327 | 12 | 8 | 347 |
| TOTAL | 4163 | 104 | 377 | 4644 |

**APPENDIX 9.b: Observed Field Data collected by Researchers at Hospital road, Zaria – PZ Route, Zaria**

TRAFFIC COUNT TEMPLATE (DATA SHEET)

OBSERVED DATA ON SATURDAY JUNE 4TH, 2016
FROM ZARIA ALONG HOSPITAL ROAD TO PZ

| TIME INTERVAL | CAR | LUX. BUS | LORRY/TRUCK | TOTAL |
|---|---|---|---|---|
| 07.00 – 0800HRS | 190 | 4 | 26 | 220 |
| 0801-0900HRS | 344 | 8 | 48 | 400 |
| 0901-1000HRS | 467 | 10 | 65 | 542 |
| 1001-1100HRS | 607 | 14 | 84 | 705 |
| 1101-1200HRS | 639 | 14 | 88 | 741 |
| 1201-1300HRS | 426 | 9 | 59 | 494 |
| 1301-1400HRS | 614 | 14 | 85 | 713 |
| 1401-1500HRS | 517 | 11 | 71 | 599 |
| 1501-1600HRS | 559 | 12 | 77 | 648 |
| 1601-1700HRS | 604 | 14 | 84 | 702 |
| 1701-1800HRS | 362 | 8 | 50 | 420 |
| 1801-1900HRS | 608 | 14 | 84 | 706 |
| TOTAL | 5937 | 132 | 821 | 6890 |

TRAFFIC COUNT

OBSERVED DATA ON MONDAY JUNE 6TH, 2016

FROM ZARIA ALONG HOSPITAL ROAD TO PZ

| TIME INTERVAL | CAR | LUX. BUS | LORRY/TRUCK | TOTAL |
|---|---|---|---|---|
| 07.00 – 0800HRS | 258 | 8 | 20 | 286 |
| 0801-0900HRS | 292 | 9 | 22 | 323 |
| 0901-1000HRS | 400 | 13 | 31 | 444 |
| 1001-1100HRS | 433 | 4 | 32 | 469 |
| 1101-1200HRS | 718 | 13 | 54 | 785 |
| 1201-1300HRS | 612 | 10 | 46 | 668 |
| 1301-1400HRS | 791 | 3 | 55 | 789 |
| 1401-1500HRS | 712 | 14 | 54 | 777 |
| 1501-1600HRS | 928 | 4 | 56 | 808 |
| 1601-1700HRS | 877 | 6 | 66 | 949 |
| 1701-1800HRS | 894 | 9 | 67 | 970 |
| 1801-1900HRS | 913 | 9 | 69 | 991 |
| TOTAL | 7828 | 102 | 572 | 8259 |

TRAFFIC COUNT

OBSERVED DATA ON WEDNESSDAY JUNE 8TH, 2016

FROM ZARIA ALONG HOSPITAL ROAD TO PZ

| TIME INTERVAL | CAR | LUX. BUS | LORRY/TRUCK | TOTAL |
|---|---|---|---|---|
| 07.00 – 0800HRS | 177 | 2 | 22 | 201 |
| 0801-0900HRS | 312 | 3 | 38 | 353 |
| 0901-1000HRS | 356 | 0 | 44 | 400 |
| 1001-1100HRS | 406 | 4 | 50 | 460 |
| 1101-1200HRS | 403 | 5 | 50 | 458 |
| 1201-1300HRS | 383 | 4 | 47 | 436 |
| 1301-1400HRS | 371 | 4 | 46 | 421 |
| 1401-1500HRS | 396 | 5 | 49 | 450 |
| 1501-1600HRS | 416 | 4 | 51 | 471 |
| 1601-1700HRS | 498 | 5 | 62 | 565 |

| | | | | |
|---|---|---|---|---|
| 1701-1800HRS | 581 | 6 | 72 | 659 |
| 1801-1900HRS | 627 | 7 | 78 | 712 |
| TOTAL | 4926 | 49 | 609 | 5586 |